Demographic Changes and its Impacts on Consumption and Greenhouse Gas Emissions in Brazil: a computable general equilibrium model approach[1]

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Abstract: In recent years, the debate on issues related to demographic changes and their impacts on the economy has increased. However, demographic changes affect not only variables such as economic growth and the labor market, but also aggregate consumption, and especially the composition of this consumption. These changes in population composition may occur in the coming decades in many parts of the globe, and their effects on the composition of consumption, notably on energy demand and emissions are not yet known. In this context, this article aims to estimate 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 a recursive dynamic computable general equilibrium model (CGE) considering 65 sectors and 7 age groups for the Brazilian economy. The results suggest that the change in age structure seem to lead to an emissions less intensive consumption pattern, around 0.25% (accumulated deviation relative to baseline) in 2050.

Keywords: general equilibrium model, demographic changes, CO_2 emissions, consumption.

Resumo: Nos últimos anos, aumentou o debate sobre questões relacionadas às mudanças demográficas e seus impactos na economia. No entanto, as mudanças demográficas afetam não apenas variáveis como o crescimento econômico e o mercado de trabalho, mas também o consumo agregado e, principalmente, a composição desse consumo. Essas mudanças na composição populacional podem ocorrer nas próximas décadas em muitas partes do globo, e seus efeitos sobre a composição do consumo, notadamente sobre a demanda de energia e as emissões ainda não são conhecidos. Nesse contexto, este artigo tem como objetivo estimar as mudanças no padrão de consumo no Brasil em função das mudanças projetadas na pirâmide etária em 2050 e as consequências dessas mudanças nas emissões de CO_2. Para isso, serão feitas projeções usando um modelo de equilíbrio geral computável dinâmico (CGE) considerando 65 setores e 7 grupos etários para a economia brasileira. Os resultados sugerem que a mudança na estrutura etária parece levar a um padrão de consumo menos intensivo de emissões, em torno de 0,25% (desvio acumulado em relação à linha de base) em 2050.

Palavras-chave: modelo de equilíbrio geral computável, mudanças demográficas, emissões de CO_2, consumo.

Código JEL: C68, Q54, J11

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1. Introduction

In the last few decades, researchers around the world have shown growing concern in studying issues related to demographic changes and their impacts on the economy. According to Park and Hewings (2007), the focus is on the impact of population size on economic growth, whose debate was centered on whether economic growth is limited, promoted or independent of population growth. Among the pessimistic current, like Ehrlich (1968), it is believed that rapid economic growth is a threat to limited resources since much of the investment needs to be used to serve the growing population. On the other hand, the more optimistic (Kuznets, 1967; Simon, 1981) believe that a larger population facilitates economies of scale and promotes technological innovation.

Another concern of this literature is the effect of population growth on the labor market and its consequences on social security systems, which may face difficulties if the ratio of pensioners per worker increases (Kronenberg, 2009; O'Neil et al. 2010; DeWhurst, 2006; Yoon and Hewings, 2006). However, demographic change affects not only variables such as economic growth and the labor market, but also aggregate consumption and especially the composition of this consumption. In general, according to O'Neil et al. (2010), population treatment in the literature has been limited to the direct effects of changes in population size and, according to Park and Hewings (2007), pay little attention to how population structure can influence economic growth and consumption.

On the other hand, studies by Park and Hewings (2007), Kronenberg (2009), Dalton et al. (2008) and Fougère et al. (2007) attempted to decompose population growth in terms of fertility and mortality components and more importantly, to examine the impacts of age distribution on economic growth. If individuals have different behaviors at various stages of life, changes in age structure in the economy can have an immediate effect. For example, a country with a high proportion of older people may experience lower economic growth because a large proportion of the resources will have to be allocated to serve a less productive population.

In the same direction, Dalton et al. (2008) stated that other demographic factors may be important, such as the indirect effects of scale that may arise through changes in population composition due to aging, urbanization or other determinants of economic growth. However, with many economies experiencing demographic changes, it is necessary to consider the impacts of these changes on the structure of production and consumption.

According to Kronenberg (2009), it is generally accepted by most economists that the current pattern of consumption is unsustainable, and the debate revolves around the instruments that can be used to change it. Often, they forget that in fact, patterns are already changing because of demographic changes. The process resulting from higher life expectancy rates coupled with lower fertility rates contributes to changes in consumption patterns.

These changes in population composition may occur in the coming decades in many parts of the globe, and their effects on the composition of consumption, notably on energy demand and emissions are not yet known. The composition of the population can affect consumption patterns which vary in their indirect energy requirements because of the energy incorporated in the different consumer goods (Bin and Dowlatabadi, 2005). While such changes may affect energy use and hence greenhouse gas (GHG) emissions, analyzes of emissions scenarios have left these issues aside (Yoon and Hewings, 2006).

Statistical analyzes of historical data suggest that population growth has contributed to emissions growth in recent years (Dietz and Rosa, 1997; Cole and Neumayer, 2004; Fan et al., 2006) and that urbanization, aging, and changes in household size can also affect energy use and emissions. Nevertheless, according to O'Neil et al. (2010), an explicit analysis of the effects of this demographic change on emissions in the future has been limited. Although much of the studies includes assumptions about future population growth, only a few studies have explicitly investigated the separate effects of demographic changes on emissions (O'Neil et al., 2010). Families can affect emissions directly through consumption or indirectly through the effects on the sectors of the economy via the production chain.

As observed by Dewhurst (2006), the consumption pattern of the younger and older is different. Thus, a general result of studies on patterns of consumption is the observation that people of different age groups have different consumption patterns. Retirees do not exhibit the same pattern of consumption as those currently employed and parents with younger children have different demands from those who have older children. Any aging population will shift demand patterns from younger people to older people, increasing demand for some goods and services, and decreasing demand for others. This change in consumption pattern and the consequent multiplier effect across the economy will show opportunities for expansion for some sectors and contraction in others (Dewhurst, 2006).

In the Brazilian case, Wong and Carvalho (2006) pointed out a differentiated growth predicted for the population of active age in the coming decades. Brazil is in an advanced stage of transition for both mortality and fertility, which makes it possible to predict that the population of the elderly over 65 will increase at an accelerated rate (2 to 4% per year), while the young population will decrease (Nasri, 2008). This transition began in the 1960s with the reduction of fertility that began in the most privileged population groups and in the more developed regions. In the future, the population will stabilize, but it will become older and with a low, perhaps even negative, growth rate.

According to data from the IBGE (2010), the 5- to 9-year age group declined from 14 to 12% between 1970 and 1990. In this period, the presence of children under 5 years of age was reduced from 15 to 11%. In the year 2000, each of these groups came to represent 9% of the total population. 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. 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 to the projection of 2050.

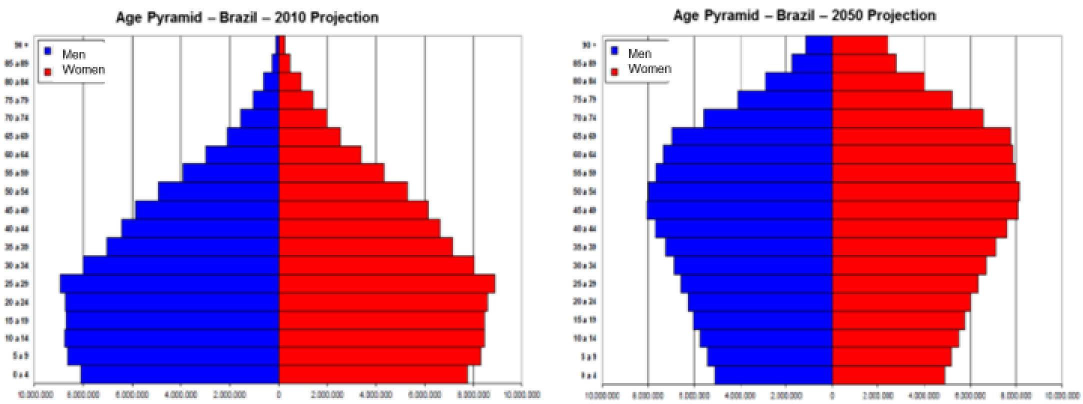


Figure 1 - Age pyramid in 2010 and projection of age pyramid in 2050 to Brazil
Source: IBGE (2010)

Figure 1 shows an increase in the participation of older people in the total population of Brazil. This projected demographic change affects final demand, which in turn generates repercussions on the production structure of the economy, that is, the participation of some sectors in total production. Kronenberg (2009) argues that there is reason to believe that changes in consumption induced by demographic changes will also affect energy use and GHG emissions. For example, 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. This and other changes are likely to affect GHG emissions in Brazil.

In this context, this article aims to estimate 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 a recursive dynamic computable general equilibrium model (CGE) considering 65 sectors and 7 age groups for the

Brazilian economy. As far as we know, this is an unprecedented study for Brazil, being the first to attempt to evaluate the impact of the population aging on consumption patterns and CO_2 emissions. The dynamic CGE model can capture both the direct effects of this change, the indirect effects via inter-sectoral linkages and the substitution effects over time. Another advance of the research is to make the analysis more appropriate estimating different elasticities by age groups and sectors.

2. Evidence from literature

Dietz and Rosa (1997) stated that the increasing GHG concentration threatens to produce significant changes in the global climate. There is a scientific consensus that increasing GHG concentrations are a consequence of human activity all over the globe. In this context, the authors developed a stochastic model called Impact (Population, Wealth, and Technology - IPAT) to estimate the effects of population, wealth and technology on CO_2 emissions. Their results showed that population growth, in this case, not considering their age distribution, tends to aggravate GHG emissions.

Cole and Neumayer (2004) used econometric panel data methods to estimate the relationship between two pollutants and demographic factors, as well as population size. For CO_2 emissions, the authors have found evidence that population growth causes a proportional increase in emissions, corroborating the findings by Dietz and Rosa (1997).

Fougère et al. (2007) evaluated the sectoral impacts of ageing population in Canada arising from the combination of two structural changes and the labor market but did not assess GHG emissions from these changes. The first is the negative shock of labor supply due to lower labor force growth. The second is the change in the composition of consumption due to the increase in the proportion of older consumers. The analysis is made using an occupational and sectoral computable general equilibrium model with overlapping generations. The main result of the study is that although the negative supply shock is dominant, there are also some important sectoral shifts due to changes in final demand. For example, sectoral participation of health services in total GDP is expected to increase by approximately 50% from 4.8% of GDP in 2000 to 7% in 2050.

Dewhurst (2006) assessed the effects of population ageing in Scotland without considering their impacts on GHG emissions. Considering that consumption patterns differ according to the average age of family members, he has disaggregated 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). The study also used projections of changes in household composition to predict changes that can be expected in consumption. Keeping the income fixed, an increase of older families and a decrease of younger families would reduce the final demand for some commodities and increase for other commodities.

Other studies have attempted to assess the effects of demographic changes, notably population ageing, on the economy and GHG emissions. According to Fan et al. (2006), all countries share the responsibility of limiting the rapid growth of GHG emissions to try to mitigate the effects of climate change around the world. To achieve this goal efficiently, researchers are concerned about the factors that impact on CO_2 emissions and the extent of those impacts.

There are two distinct perspectives on the impacts of population growth on the environment quality: the Malthusian tradition and the Boserupian approach. The first one states that environmental degradation happens because of the pressure that the population puts in the resources. In contrast, the Boserupian perspective (Boserup, 1981) states that population growth encourages the emergence of technological innovations which attenuate the negative impact on the environment. Consequently, Malthusians predict that the impact of the population on GHG emissions is more than proportional, while Boserupians claim that this relationship does not exist, or if does, has a negative elasticity (Fan et al., 2006).

In this sense, Fan et al. (2006) investigated the impact of population, wealth and technology on CO_2 emissions from countries with different income levels from 1975 to 2000, using the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) econometric model. Their results showed that globally, economic growth has the greatest impact on CO_2 emissions. The proportion of the population aged 15-64 has a negative impact on emissions in countries with higher income levels and a positive impact on emissions from countries with other income levels.

Dalton et al. (2008) analyzed how the age composition of US households may, in the coming decades, affect energy use and CO_2 emissions. For this, they incorporated the age structure of the population into a dynamic computable general equilibrium model with multiple heterogeneous families. The model is used to estimate and compare the effects of population ageing and technical changes on the trajectory of energy use and CO_2 emissions. The results showed that the population aging can contribute to the reduction of emissions in the long term by almost 40% in a scenario of low population growth. The effects of population ageing on emissions may be greater than the effects of technical changes in some cases.

Kronenberg (2009) estimated the impact of demographic change in Germany on energy use and GHG emissions. The author used microdata of household survey to identify age-specific consumption patterns and projected the impact of demographic change on the consumption structure by 2030 using an environmental input-output model. His results suggest that, by 2030, demographic change will increase the share of methane of total GHG emissions and will not contribute to reduce energy use and emissions in Germany. The author also evaluated two distinct policy scenarios: a redistribution of income from working-age families to older families, and a policy of replacing the use of private vehicles to public transportation. The first policy did not have a significant impact on emissions while the second policy helped to reduce both energy use and emissions.

3. Methodology

3.1 Theoretical Structure of the CGE model

The general equilibrium model used in this study was ORANIGBR-HOU. It is a model developed for the Brazilian economy that starts from the theoretical structure of the Australian model ORANI-G (Horridge, 2011) with a disaggregation of the household consumption vector by different age groups. The model was calibrated with 2010 data from the Brazilian national accounts and the input-output matrix. In addition, a recursive dynamics module was introduced that allows the implementation of simulations in which the stock of capital accumulates over time, just as the labor market presents a certain inertia in the adjustment of wages and employment.

The model has 65 sectors and 65 commodities, five components of final demand (household consumption, government expenditure, investment, exports and inventories), two elements of primary factors (capital and labor) and two margins (trade and transportation). The model also has a disaggregation of the consumption vector into seven age groups (better explanation in section 2.4).

ORANIGBR-HOU is composed of blocks of equations that determine demand and supply relationships according to optimization hypotheses and market equilibrium conditions. In addition, several national aggregates are defined in these blocks, such as aggregate employment, GDP, trade balance and price indices. Productive sectors minimize production costs subject to a technology of constant scale returns in which combinations of intermediate inputs and primary factor (aggregate) are determined by fixed coefficients (Leontief). There is substitution via prices between domestic and imported goods in the composition of the inputs via a constant substitution elasticity function (CES). There is also substitution between capital and labor in the composition of the primary factors through CES functions.

In the model, households consume domestic and imported goods. The choice between domestic and imported is carried out by a CES specification (Armington hypothesis). The treatment of household demand is based on a combined CES/Klein-Rubin preference system. Thus, utility derived from consumption is maximized by this utility function. This specification represents the linear spending system (LES), in which the share of expenditure above the subsistence level for each good represents a constant proportion of the total subsistence expenditure of each family.

Government expenditure is exogenous. The demand for exports is defined in the usual way, that is, as a decreasing function of the effective price of export goods given the export elasticity. In turn, the variation of inventories accompanies the production level of the sectors, and it is also possible to treat it as exogenous.

The model operates with market equilibrium for all goods, both domestic and imported, as well as in the factor market (capital and labor). The purchase prices for each of the use groups (producers, investors, households, exporters and government) are the sum of basic values and sales taxes (direct and indirect) and margins (trade and transportation). Sales taxes are treated as ad valorem rates on the basic flows. The demands for margins (transport and trade) are proportional to the flows of goods to which the margins are connected. The production structure considers that each industry can produce several products (secondary production), using the inputs (domestic and imported) and the productive factors (capital and labor).

The ORANIGBR-HOU model has a recursive dynamic specification, in which investment and capital stock follow mechanisms of accumulation and intersectoral displacement from pre-established rules, associated with depreciation and return rates. Thus, one of the modifications to make ORANIGBR-HOU dynamic is to link annual investment flows to capital stock. The labor market also presents an element of intertemporal adjustment which involves variables such as real wages, current employment and trend employment.

3.2 Disaggregation of consumption vector in age groups

This paper uses Consumer Expenditure Survey data set for the years of 2008/2009 to estimate the association between household expenditure composition and the presence of children and elderly individuals in households. This survey is carried out by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*). The main aim of this survey is to estimate household consumption expenditure in order to subsidize the build of the National Consumer Price Index (INPC).

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

In order to analyze aging effect on expenditure composition it is necessary to classify households according to the presence of elderly residents and children. The classification of households is done taking into account the number of adults (residents aged from 15 to 59 years stratified into two age groups), elderly persons (residents aged over than 59 stratified into three age groups) and children (residents aged from 0 to 14 years stratified into three age groups) in the household. The disaggregation of elderly individuals and children by age is important to allow the use demographic projections.

Seven types of households were defined: households with only two adults; households with two adults and one child (0-4 years old, 5-9 years old, 10-14 years old); households with two adults aged from 15 to 49 and one adult aged from 50 to 59; households with two adults aged from 15 to 49 years and one elderly aged from 60 to 69 and finally two adults aged from 15 to 49 years and one elderly over 70´s. Households including only two adults (15-49) were considered as the reference category for the comparison of expenditure composition. In order to allow the identification of aging effect, households with elderly and children living together were excluded from the sample. The seven groups of households defined in our typology represents 20% of the total sample (48.470 households) surveyed by POF in 2008/2009, that is, 12,144 households. Table 1 reports the distribution of households according to each group. The largest group corresponds to households with only two adults (4,335 observations).

Table 1: Distribution of households according to the household typology

Households typology	Number of observations	Frequency
Two adults (15-49) - reference category	4,335	35.70
Two adults (15-49) and one child (0-4)	2,904	23.91
Two adults (15-49) and one child (5-9)	1,870	15.40
Two adults (15-49) and one child (10-14)	1,280	10.54
Two adults (15-49) and one adult (50-59)	1,061	8.74
Two adults (15-49) and one elderly (60-69)	394	3.24
Two adults (15-49) and one elderly (70+)	300	2.47
Total	12,144	100.00

Source: Elaborated by the authors.

3.3 Households elasticities estimation

The association between household age structure and consumption composition was estimated through econometric models on Santiago (2014) for each household group and each type of product. It was run allowing the estimation of *household- type semi-elasticity*. All consumption items present in Expenditure Consumption Survey were aggregated into 15 groups of products. For groups of products which are considered as individual expenditure (15 products), initially it was calculated the average cost of each product, represented as:

$$gm_i = \frac{gt_i}{pop_{2010}} \tag{1}$$

Where: gm_i is the average spent on product i, gt_i corresponds to total spent on product i and pop_{2010} represents the Brazilian population in the year 2010.

Thus, the estimated cost with product i can be represented by the equation:

$$\begin{aligned} G_i^* = {} & (NA^{(15-49)} \times gm_i) + \left[NC^{(0-4)} \times gm_i(1+\alpha_i)\right] + \left[NC^{(5-9)} \times gm_i(1+\beta_i)\right] + \left[NC^{(10-14)} \times gm_i(1+\mu_i)\right] + \\ & + \left[NI^{(50-59)} \times gm_i(1+\delta_i)\right] + \left[NI^{(60-69)} \times gm_i(1+\lambda_i)\right] + \left[NI^{(70+)} \times gm_i(1+\eta_i)\right] \end{aligned} \tag{2}$$

Where: α_i is the marginal effect of spent for children of 0-4 years old on product i measured as a percentage. The other coefficients – β_i, μ_i, δ_i, λ_i, and η_i – correspond to the marginal effects of spent for the other group ages on product i. The coefficient that captures the marginal effect of adult spent among 15-59 years old is equal to zero, since this group is used as a reference, so the estimated spent will be equal to the average spent. The respective weights of the seven age groups are calculated as:

$$P_i^{A(15-49)} = \frac{(NA^{(15-49)} \times gm_i)}{G_i^*} \tag{3}$$

$$P_i^{C(0-4)} = \frac{(NC^{(0-4)} \times gm_i)(1+\alpha_i)}{G_i^*} \tag{4}$$

$$P_i^{C(5-9)} = \frac{(NC^{(5-9)} \times gm_i)(1+\beta_i)}{G_i^*} \tag{5}$$

$$P_i^{C(10-14)} = \frac{(ND^{(10-14)} \times gm_i)(1+\mu_i)}{G_i^*} \tag{6}$$

$$P_i^{A(50-59)} = \frac{(NA^{(50-59)} \times gm_i)(1+\delta_i)}{G_i^*} \tag{7}$$

$$P_i^{I(50-59)} = \frac{(NI^{(50-59)} \times gm_i)(1+\delta_i)}{G_i^*} \tag{8}$$

$$P_i^{I(60-69)} = \frac{(NA^{(60-69)} \times gm_i)(1+\lambda_i)}{G_i^*} \tag{9}$$

$$P_i^{I(70+)} = \frac{(NI^{(70+)} \times gm_i)(1+\eta_i)}{G_i^*} \tag{10}$$

$P_i^{A(15-49)}; P_i^{c(0-4)}$, $P_i^{c(5-9)}$, $P_i^{c(10-14)}$; $P_i^{I(50-59)}$, $P_i^{I(60-69)}$ and $P_i^{I(70+)}$ P_i^A, P_i^c and P_i^I are the weights of adults, children and elderlies, respectively, in the consumption of the good or service i. By construction, $P_i^{A(15-49)} + P_i^{c(0-4)} + P_i^{c(5-9)} + P_i^{c(10-14)} + P_i^{I(50-59)} + P_i^{I(60-69)} + P_i^{I(70+)} = 1$

Thus, the estimated spent distribution, weighted by each age group, is expressed as:

$$\begin{aligned} gt_i = \underbrace{gt_i.P_i^{A(15-49)}}_{G_i^{A(15-49)}} + \underbrace{gt_i.P_i^{c(0-4)}}_{G_i^{c(0-4)}} + \underbrace{gt_i.P_i^{c(5-9)}}_{G_i^{c(5-9)}} + \underbrace{gt_i.P_i^{c(10-14)}}_{G_i^{c(10-14)}} + \\ + \underbrace{gt_i.P_i^{I(50-59)}}_{G_i^{I(50-59)}} + \underbrace{gt_i.P_i^{I(60-69)}}_{G_i^{I(60-69)}} + \underbrace{gt_i.P_i^{I(70+)}}_{G_i^{I(70+)}} \end{aligned} \tag{11}$$

Where $G_i^{A(15-49)}, G_i^{c(0-4)}, G_i^{c(5-9)}, G_i^{c(10-14)}, G_i^{I(50-59)}, G_i^{I(60-69)}, G_i^{I(70+)}$ are the consumption of the referring age groups with product i.

In addition to data from input-output matrix, CGE models use estimates of elasticities and parameters, called behavioral parameters, in their calibration. Such values are usually extracted from the literature, which is justified by the scarcity of data for the estimation. One of the parameters related to the household structure is the elasticity of expenditure (EPS). In this work, econometric estimates were based on the model proposed by in Santiago (2014) to estimate these elasticities considering 15 product groups from the 2008/2009 POF microdata, by age groups. After this, the 15 aggregates were distributed in the 65 products of the model.

3.4 CO_2 Emissions

One of the goals of this article is to estimate the emissions resulting from the aging process of the Brazilian population. To meet this objective a vector of CO_2 emissions intensity was calculated. Then we are going to calculate what will be the change of the emissions in the production and consumption structure of the Brazilian economy caused by the change in the age pyramid. For this, we used data from Energy Balance for Brazil in 2010 (EPE, 2011). The first step was to disaggregate the sectors of BEN, 22 sectors[2] into the 65 sectors considered in the ORANIGBR-HOU model. The method to disaggregate the sectors is the one proposed by Montoya *et al.* (2014). Basically, the idea behind this method is to create a set of subsectors considering the 65 of the EGC model for each of the large sectors in BEN. Thus, it is considered that the energy consumption of the subsectors in toe (tonne oil equivalent) is proportionally related to their monetary flows contained in the IO (Montoya et al., 2014).

The second step of this stage was to convert the energy coefficients (in 1,000 toe) into CO_2 emissions (Gg) due to the use of fuels by the various sectors of the economy. For this, the conversion coefficients found in Economy & Energy (2002) were applied. Finally, to calculate the intensity vector, the total emissions of each of the 65 sectors were divided by their respective values of production. This vector will be used at the end of the simulations with the ORANIGBR-HOU model to design the changes in the emissions that can be caused by the change in the age pyramid that would be in the Brazilian economy. The hypothesis is that no technological innovation occurs, that is, the emissions vector does not change in 2050 and emissions are linear to production.

4. Simulations

In this section, we present the simulation strategies used to estimate the economic effects of 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.

Firstly, a baseline scenario for the Brazilian economy is built from 2010 to 2050. It is a trend scenario for the Brazilian economy in which deviations from it can be measured, estimating the effects of specific policies. The baseline represents a growth trajectory of the Brazilian economy between 2011 and 2050 in which no demographic change occurs.

Before the simulation of the baseline scenario, we need to define the model closure[3]. It is assumed that household consumption follows national income and that government expenditure follows household income. In addition, the share of the nominal trade balance over nominal GDP is exogenous. We also have the population growth and the imported price index as exogenous variables. The model works with relative prices and the price variable chosen as numeraire was the Consumer Price Index.

After determining the closure, the baseline was divided into two periods. In the first period, from 2011 to 2015, the main macroeconomic aggregates, real GDP, investment, household consumption, government expenditure and export volume are considered exogenous. The objective is to update the main macroeconomic variables according to observed data in the period. Table 2 shows those indicators:

Table 2 - Variables of the Macroeconomic Scenario for the period 2011 to 2015 – in % change

Macro variables	Years				
	2011	2012	2013	2014	2015
Real GDP	3.97	1.92	3.00	0.50	-3.77
Investment	6.83	0.78	5.83	-4.22	-13.91
Household Consumption	4.82	3.50	3.47	2.25	-3.94
Government Expenditure	2.20	2.28	1.51	0.81	-1.06
Exports	4.79	0.27	2.39	-1.13	6.28

Source: Elaborated by the authors based on data from the National Accounts, FUNCEX and IBGE.

[2] It includes the residential sector.

[3] The closure of the model is the determination of the endogenous and exogenous variables of the simulations performed. Then represents the assumptions about the functioning of the economy and its adjustments and shocks (policies). ORANIGBR-HOU is a dynamic model and allows the accumulation of capital over time and adjustments in the labor market.

In the second period of the baseline scenario, from 2016 to 2050, only real GDP is kept exogenous. This part of the baseline presents a path of economic growth of 2.5% per year for the period from 2016 to 2050 and represents the projection that is compared to the policy scenario (population ageing).

The second step was to perform the policy simulation. To do this, in the policy scenario, we considered all main macroeconomic indicators as endogenous variables. The scenario aims to evaluate the impact on the Brazilian economy of the change in the age pyramid according to IBGE projections. Table 3 presents the scenario projected for the seven age groups considered in the ORANIGBR-HOU model.

Table 3 – Demographic Scenario – accumulated rate of population growth for five years in Brazil, 2015-2050 (in % change)

	2015	2020	2025	2030	2035	2040	2045	2050
0-4	-1.92	-2.87	-5.16	-4.92	-4.58	-4.18	-3.80	-3.14
5-9	-7.61	-1.75	-3.07	-4.93	-5.03	-4.58	-4.16	-3.76
10-14	-6.33	-6.46	-2.70	-3.39	-4.83	-5.02	-4.56	-4.16
15-49	3.65	1.66	0.52	-1.10	-2.90	-3.50	-3.80	-4.60
50-59	16.66	9.35	6.72	8.65	11.38	5.34	-0.97	-0.36
60-69	24.76	16.12	18.47	13.27	7.49	9.49	12.15	5.95
70+	22.32	19.06	25.74	24.14	23.20	18.72	14.81	14.34
Total	4.66	3.12	3.20	2.45	1.78	1.16	0.59	0.08

Source: Elaborated by the authors based on ONU projections.

5. Analysis of the results

5.1 Sectoral results

The policy results presented here are reported as the cumulative percentage deviation (2020 to 2050) relative to the baseline scenario. Table 4 presents the projected results of activity level when the change of the age pyramid occurs. As the consumption pattern changes the sectors output of the economy will change indirectly via production chain. As we can see, the most benefited sectors are Other Food Industry, Domestic Services, Personal Services, Associative Organizations, Meat, Real State Activities and Livestock.

The most negative impact occurred in sectors as Financial Intermediate and Insurance, Private Education, Biodiesel, Clothing, Furniture and Other, Food and Textile.

It is worth to note that with the ageing of population, the sector Electricity (1.68%) is growing around two times as the Oil Refining (0.83%)

Regarding the results of sectoral emissions, Table 5 shows that the change of the Brazilian pyramid would cause an increase of 7,101.82 Gg of CO_2, which would represent an additional of a little more than 1% in relation to the baseline scenario. Although many sectors traditionally emitting CO_2 have shown an increase in their levels of activity, it is observed that they have shown a reduction in the share of total emissions. This is the case of the Cellulose and paper, Oil refining, and Metallurgy. Although the share of total emissions has not changed much, as they are very polluting sectors, the small reduction of their activity in the total Brazilian economy contributes to a small increase in emissions. On the other hand, sectors that are not very emitting and which are highly important in the Brazilian economy, such as Trade and Construction, increased relative participation, which possibly contributed to the low increase of emissions in the Brazilian economy.

Table 4 – Percent change in production by sector resulting from the changes in the age pyramid in 2050 (accumulated deviation from 2016 to 2050 relative to baseline)

Sectors	% change	Sectors	% change
Agriculture	5,84	Parts and accessories for motor vehicles	-0,31
Livestock	8,14	Transport equipment	-1,10
Forestry, fishing and silviculture	5,39	Furniture and other	-4,79
Coal	1,87	Maintanance and repair	1,31
Oil and Gas	1,16	Electricity	1,68
Iron ore	0,71	Water	1,92
Non-ferrous metal minerals	0,39	Construction	1,83
Meat	9,80	Trade	2,11
Sugar Refining	3,58	Transport	1,73
Other Food Industry	12,67	Storage, auxiliary transport and mail	0,90
Beverage	6,95	Accomodation	2,11
Tobacco	-0,41	Food	-3,34
Textile	-3,02	Print-integrated editing	4,50
Clothing	-3,62	TV, radio and cinema	1,62
Footwear and leather	-2,83	Telecommunications	5,84
Wood	-0,19	Information services	0,30
Cellulose and paper	0,71	Financial intermediation and insurance	-15,42
Printing and Recording	0,16	Real state activities	9,75
Oil refining	0,83	Accounting and consulting activities	1,23
Biodiesel	-6,10	Architectural and engineering services	1,66
Chemistry	1,78	Other scientific and technical activities	0,99
Pesticides and various chemicals	2,44	Rents	1,63
Cleaning and cosmetics products	0,28	Other administrative activities	1,15
Pharmaceutical Industry	-0,61	Security activities	-2,16
Rubber and plastic	1,37	Public Administration	-0,64
Non-metallic minerals	1,96	Public Education	-0,63
Iron and Steel	0,91	Private Education	-8,70
Metallurgy	-0,01	Public Health	-0,59
Metal products	1,33	Private Health	-2,17
Computing, electronic and optical products	-0,69	Associative organizations	10,19
Electrical machinery and equipment	-0,97	Personal services	12,05
Machinery and mechanical equipment	2,06	Domestic services	12,23
Vehicles	-1,05		

Source: Elaborated by the authors based on CGE results.

Table 5 – Total change in CO_2 emissions by sector resulting from the changes in the age pyramid in 2050 (accumulated deviation from 2016 to 2050 relative to baseline)

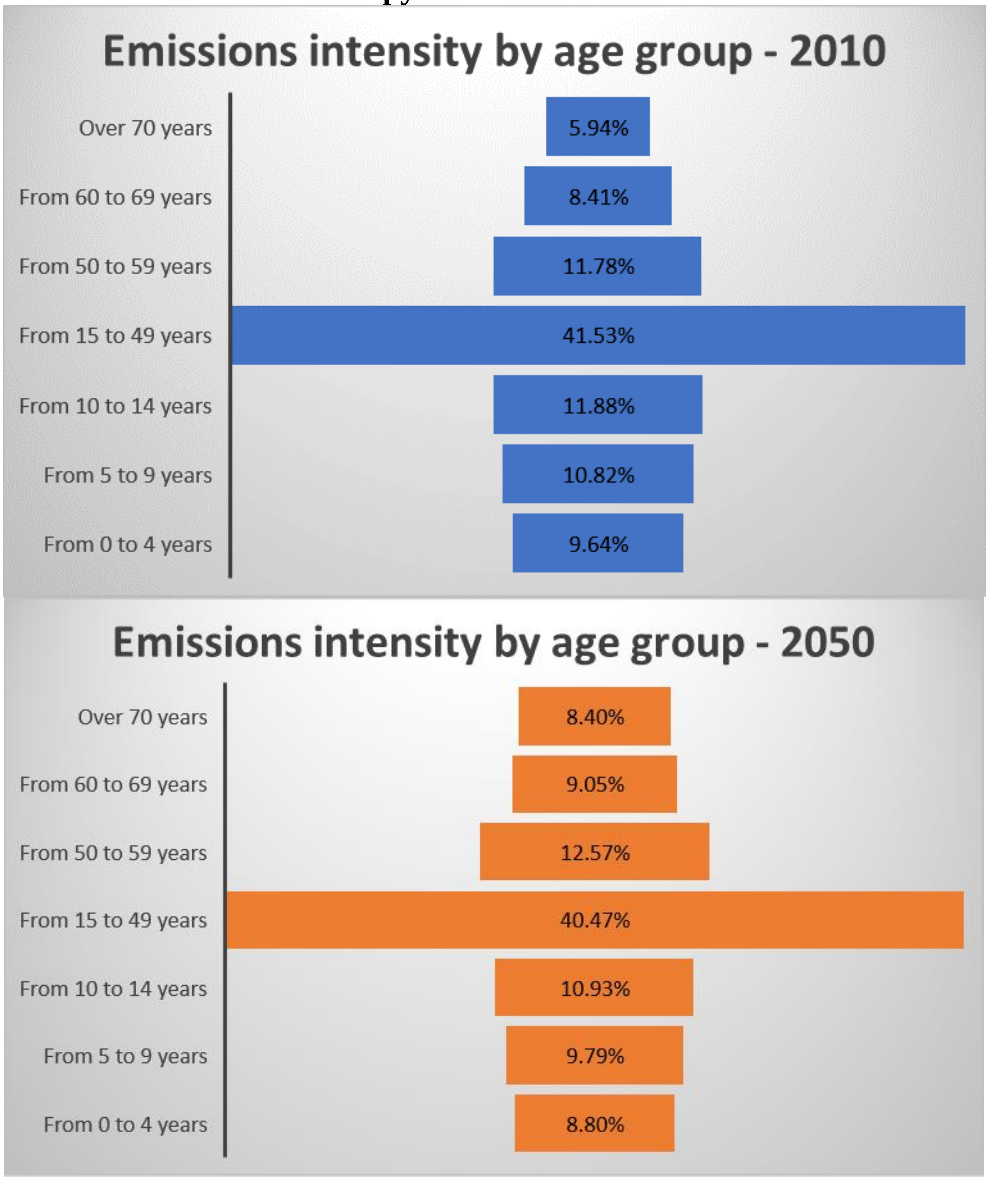
	Total emissions		Accumulated Deviation			Total emissions		Accumulated Deviation	
Sectors	Emissions	Emissions Share	Emissions	Emissions Share	**Sectors**	Emissions	Emissions Share	Emissions	Emissions Share
Agriculture	7401,31	1,06%	364,92	1,10%	Parts and accessories for motor vehicles	755,49	0,11%	-3,09	0,11%
Livestock	5732,15	0,82%	388,64	0,87%	Transport equipment	327,42	0,05%	-3,97	0,05%
Forestry, fishing and silviculture	906,59	0,13%	39,02	0,13%	Furniture and other	287,72	0,04%	-12,86	0,04%
Coal	16054,57	2,30%	289,78	2,32%	Maintanance and repair	550,59	0,08%	7,68	0,08%
Oil and Gas	5564,45	0,80%	48,08	0,80%	Electricity	31178,31	4,47%	264,20	4,47%
Iron ore	1165,08	0,17%	3,53	0,17%	Water	2518,17	0,36%	32,90	0,36%
Non-ferrous metal minerals	8858,02	1,27%	14,68	1,26%	Construction	48451,78	6,95%	1115,49	7,04%
Meat	8531,83	1,22%	670,10	1,31%	Trade	31393,38	4,50%	536,23	4,53%
Sugar Refining	714,66	0,10%	20,04	0,10%	Transport	85959,77	12,33%	1366,18	12,40%
Other Food Industry	5275,83	0,76%	527,38	0,82%	Storage, auxiliary transport and mail	11734,62	1,68%	92,83	1,68%
Beverage	2851,54	0,41%	181,66	0,43%	Accomodation	778,12	0,11%	13,88	0,11%
Tobacco	16,82	0,00%	-0,11	0,00%	Food	2026,77	0,29%	-93,61	0,27%
Textile	1299,18	0,19%	-49,25	0,18%	Print-integrated editing	474,23	0,07%	17,96	0,07%
Clothing	22,21	0,00%	-1,07	0,00%	TV, radio and cinema	703,49	0,10%	9,79	0,10%
Footwear and leather	113,16	0,02%	-4,09	0,02%	Telecommunications	891,56	0,13%	41,44	0,13%
Wood	1720,26	0,25%	-4,96	0,24%	Information services	1253,52	0,18%	5,42	0,18%
Cellulose and paper	18183,92	2,61%	82,81	2,59%	Financial intermediation and insurance	4982,93	0,71%	-1126,08	0,55%
Printing and Recording	10,83	0,00%	0,04	0,00%	Real state activities	497,86	0,07%	48,36	0,08%
Oil refining	210070,44	30,14%	876,81	29,96%	Accounting and consulting activities	5618,87	0,81%	59,62	0,81%
Biodiesel	694,98	0,10%	-43,65	0,09%	Architectural and engineering services	6998,02	1,00%	120,35	1,01%
Chemistry	23095,83	3,31%	314,07	3,32%	Other scientific and technical activities	1272,48	0,18%	11,43	0,18%
Pesticides and various chemicals	6601,39	0,95%	143,91	0,96%	Rents	6355,25	0,91%	78,51	0,91%
Cleaning and cosmetics products	2666,28	0,38%	-1,11	0,38%	Other administrative activities	4895,90	0,70%	49,13	0,70%
Pharmaceutical Industry	1338,51	0,19%	-9,90	0,19%	Security activities	777,42	0,11%	-18,49	0,11%
Rubber and plastic	3468,69	0,50%	42,05	0,50%	Public Administration	7509,79	1,08%	-161,26	1,04%
Non-metallic minerals	22127,65	3,17%	465,91	3,21%	Public Education	918,78	0,13%	-13,62	0,13%
Iron and Steel	16640,32	2,39%	146,88	2,38%	Private Education	179,04	0,03%	-24,32	0,02%
Metallurgy	54142,01	7,77%	-36,81	7,68%	Public Health	398,40	0,06%	-5,59	0,06%
Metal products	1181,33	0,17%	16,58	0,17%	Private Health	1186,20	0,17%	-40,43	0,16%
Computing, electronic and optical products	62,35	0,01%	-0,16	0,01%	Associative organizations	666,22	0,10%	53,40	0,10%
Electrical machinery and equipment	1489,65	0,21%	-16,69	0,21%	Personal services	1235,28	0,18%	123,57	0,19%
Machinery and mechanical equipment	4808,84	0,69%	104,71	0,70%	Domestic services	0,00	0,00%	0,00	0,00%
Vehicles	1470,38	0,21%	-17,00	0,21%	**Total**	697058,46	100,00%	7101,82	100,00%

Source: Elaborated by the authors based on CGE results.

3.2 Household Consumption Results

Figure 2 shows the change in emissions by age group. It is noted that there is an increase in the composition of emissions for the older age groups and a reduction of the base of the pyramid, caused by the projected reduction of the younger groups.

Figure 2 – Total change in CO_2 emissions by age group resulting from the changes in the age pyramid in 2050



Source: Elaborated by the authors based on CGE results.

Table 6 presents the sectoral results regarding to the household consumption which is directly affected by the population ageing.

Table 6 – Percent change in household consumption by sector resulting from the changes in the age pyramid in 2050 (accumulated deviation from 2016 to 2050 relative to baseline)

Sectors	% change	Sectors	% change
Agriculture	18,31	Vehicles	-9,00
Livestock	16,76	Transport equipment	-9,26
Forestry, fishing and silviculture	17,71	Furniture and other	-9,66
Meat	17,56	Maintanance and repair	16,12
Sugar Refining	17,90	Electricity	1,73
Other Food Industry	18,28	Water	4,21
Beverage	18,88	Trade	14,95
Tobacco	-0,79	Transport	-0,66
Textile	-4,13	Storage, auxiliary transport and mail	-1,54
Clothing	-4,25	Accomodation	-4,12
Footwear and leather	-4,21	Food	-4,93
Wood	-1,26	Print-integrated editing	16,05
Cellulose and paper	-0,91	TV, radio and cinema	15,23
Printing and Recording	-1,09	Telecommunications	15,58
Oil refining	-3,76	Information services	15,13
Biodiesel	-4,46	Financial intermediation and insurance	-39,05
Chemistry	-0,43	Real state activities	1,34
Pesticides and various chemicals	-0,35	Accounting and consulting activities	12,93
Cleaning and cosmetics products	-0,36	Architectural and engineering services	14,55
Pharmaceutical Industry	-0,78	Other scientific and technical activities	14,90
Rubber and plastic	-0,57	Rents	-1,54
Non-metallic minerals	-0,48	Other administrative activities	14,80
Iron and Steel	-0,75	Security activities	13,39
Metallurgy	-0,93	Private Education	-9,76
Metal products	-0,95	Private Health	-2,53
Computing, electronic and optical products	-10,07	Associative organizations	16,07
Electrical machinery and equipment	-9,32	Personal services	15,08
Machinery and mechanical equipment	-9,13	Domestic services	12,23

Source: Elaborated by the authors based on CGE results.

It is noted that the change in the composition of age groups makes the agricultural, food and beverage sectors as the activities that households most increase consumption. Financial intermediation and insurance services, as well as the sectors related to vehicles and transportation equipment, are the ones that reduce the most in household consumption. Note that households reduce Oil Refining consumption and increase electricity consumption. An expected result as older household tend to consume more electricity and less fuel**.**

Regarding the emission results, Table 7 shows a reduction in CO_2 emissions in the consumption vector of about 0.25%. That is, the change in the pattern of consumption due to the aging process of the Brazilian population leads to a reduction of emissions. From the results, it can be observed that the reduction of consumption in the Oil Refining sector is the one that most contributes to this result, since there is a decrease in the share of this sector in the total emissions.

Table 7 – Total change in CO_2 emissions in household consumption by sector resulting from the changes in the age pyramid in 2050 (accumulated deviation from 2016 to 2050 relative to baseline)

Sectors	Total emissions: Emissions	Total emissions: Emissions Share	Accumulated Deviation: Emissions	Accumulated Deviation: Emissions Share	Sectors	Total emissions: Emissions	Total emissions: Emissions Share	Accumulated Deviation: Emissions	Accumulated Deviation: Emissions Share
Agriculture	1651,17	1,41%	259,54	1,64%	Vehicles	590,29	0,50%	-66,36	0,45%
Livestock	597,66	0,51%	86,06	0,59%	Transport equipment	114,60	0,10%	-12,72	0,09%
Forestry, fishing and silviculture	272,83	0,23%	40,89	0,27%	Furniture and other	255,97	0,22%	-28,01	0,20%
Meat	6183,59	5,28%	932,76	6,09%	Maintanance and repair	0,73	0,00%	0,11	0,00%
Sugar Refining	81,18	0,07%	12,76	0,08%	Electricity	8551,21	7,30%	72,09	7,38%
Other Food Industry	4174,25	3,57%	660,31	4,14%	Water	780,39	0,67%	30,35	0,69%
Beverage	2005,21	1,71%	348,00	2,01%	Trade	943,50	0,81%	132,55	0,92%
Tobacco	18,55	0,02%	-0,21	0,02%	Transport	11990,77	10,24%	-132,87	10,15%
Textile	566,69	0,48%	-28,45	0,46%	Storage, auxiliary transport and mail	1188,13	1,01%	-25,19	1,00%
Clothing	37,45	0,03%	-1,99	0,03%	Accomodation	105,78	0,09%	-7,04	0,08%
Footwear and leather	138,83	0,12%	-7,20	0,11%	Food	1816,66	1,55%	-117,56	1,45%
Wood	81,75	0,07%	-1,42	0,07%	Print-integrated editing	227,86	0,19%	32,76	0,22%
Cellulose and paper	2061,89	1,76%	-28,05	1,74%	TV, radio and cinema	13,63	0,01%	1,84	0,01%
Printing and Recording	0,15	0,00%	0,00	0,00%	Telecommunications	396,96	0,34%	54,91	0,39%
Oil refining	52208,84	44,59%	-2431,13	42,61%	Information services	2,60	0,00%	0,35	0,00%
Biodiesel	657,17	0,56%	-39,30	0,53%	Financial intermediation and insurance	2497,60	2,13%	-938,20	1,33%
Chemistry	2,13	0,00%	-0,02	0,00%	Real state activities	77,38	0,07%	-3,53	0,06%
Pesticides and various chemicals	71,60	0,06%	-0,51	0,06%	Accounting and consulting activities	4425,58	3,78%	911,34	4,57%
Cleaning and cosmetics products	4855,74	4,15%	-35,26	4,13%	Architectural and engineering services	326,76	0,28%	43,03	0,32%
Pharmaceutical Industry	2013,10	1,72%	-22,37	1,70%	Other scientific and technical activities	9,92	0,01%	1,32	0,01%
Rubber and plastic	271,90	0,23%	-2,58	0,23%	Rents	229,03	0,20%	-5,78	0,19%
Non-metallic minerals	324,39	0,28%	-3,46	0,27%	Other administrative activities	449,31	0,38%	60,65	0,44%
Iron and Steel	16,98	0,01%	-0,24	0,01%	Security activities	5,35	0,00%	0,65	0,01%
Metallurgy	240,93	0,21%	-3,17	0,20%	Private Education	179,48	0,15%	-24,15	0,13%
Metal products	85,92	0,07%	-1,36	0,07%	Private Health	868,79	0,74%	-31,99	0,72%
Computing, electronic and optical products	10,71	0,01%	-1,19	0,01%	Associative organizations	400,51	0,34%	54,19	0,39%
Electrical machinery and equipment	1015,61	0,87%	-113,11	0,77%	Personal services	907,49	0,78%	124,12	0,88%
Machinery and mechanical equipment	79,71	0,07%	-8,98	0,06%	Domestic services	0,00	0,00%	0,00	0,00%
Total	-	-	-	-	-	117082,25	100,00%	-262,83	100,00%

Source: Elaborated by the authors based on CGE results.

4. Final considerations

In recent years, the debate on issues related to demographic change and its impacts on the economy has increased. The literature has mainly emphasized the effect of population growth on the labor market and its possible consequences on social security systems. However, demographic change has no effect only on variables such as economic growth, labor market and social security, but also on aggregate consumption, and especially on the distribution of this consumption. The process of population aging thus contributes to changes in consumption patterns. And consequently, the change in consumption pattern also causes effects on energy use and GHG emissions.

In this context, this article sought to estimate and analyze the changes in consumption pattern for Brazil due to the projected changes in the age pyramid from 2010 to 2050 and the possible consequences of these changes on CO_2 emissions. For this, projections were made using a dynamic computable general equilibrium model for the Brazilian economy considering 65 productive sectors and 7 age groups.

The results indicate that demographic change has a significant impact on the structure of household consumption expenditure considering different age groups. The most important impacts are observed in the areas of health and education. Household energy use is also significantly affected. In addition, the change in age structure seems to lead to a less emission-intensive consumption pattern. This result is mainly due to the decrease in participation in the consumption vector for 2050 of sectors such as Oil Refining. It is observed, therefore, that the aging population and the changes in the habits of consumption generate a reduction of the CO_2 emissions in 0.25%.

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