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LUIS GUSTAVO TUDESCHINI

INCOME INEQUALITY AND ITS IMPACTS ON THE BRAZILIAN HOUSEHOLD CARBON FOOTPRINT

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LUIS GUSTAVO TUDESCHINI

INCOME INEQUALITY AND ITS IMPACTS ON THE BRAZILIAN HOUSEHOLD CARBON FOOTPRINT

Tese apresentada ao Programa de Pós-Graduação em Energia do Instituto de Energia e Ambiente da Universidade de São Paulo para obtenção do título de Doutor em Ciências

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To Vera and João, for always showing the power of education.

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EPIGRAPH

“**Everything is Going to be All Right**

How should I not be glad to contemplate
the clouds clearing beyond the dormer window
and a high tide reflected on the ceiling?
There will be dying, there will be dying,
but there is no need to go into that.
The poems flow from the hand unbidden
and the hidden source is the watchful heart.
The sun rises in spite of everything
and the far cities are beautiful and bright.
I lie here in a riot of sunlight
watching the day break and the clouds flying.
Everything is going to be all right.”

Derek Mahon, from *Selected Poems*

RESUMO

TUDESCHINI, Luis Gustavo. **Desigualdade de renda e seus impactos na pegada de carbono das famílias brasileiras**. 2018, 97 f. Tese (Doutorado em Ciências) – Programa de Pós-Graduação em Energia da Universidade de São Paulo, São Paulo, 2018**.**

A presente tese explora a relação entre dois importantes desafios da sociedade brasileira: desigualdade de renda e mudanças climáticas. Em um país em desenvolvimento como o Brasil, existe grande espaço para aumento e melhoria da distribuição de renda. O desenho de políticas que ataquem esses problemas necessitam considerar as relações entre níveis de renda, comportamento dos consumidores, e emissões de gases do efeito estufa (GEE). Para tanto, dois objetivos foram estabelecidos. O primeiro é analisar a desigual contribuição das famílias em diferentes classes de renda nas emissões de GEE no Brasil. A segunda é compreender os impactos das mudanças na distribuição de renda nas emissões de GEE no Brasil. O desenvolvimento desses objetivos trouxeram duas inovações principais: um método de ajustes de preços que corrige a alocação de emissiões entre as classes de renda, e uma análise detalhada da contribuição dos itens de consumo na pegada de carbono das famílias. Quatro questões derivam desses objetivos: i) como os padrões de consumo em diferentes classes de renda afetam a pegada de carbono das famílias?, ii) qual o impacto da variação de preços entre as classes de renda no cálculo da pegada de carbono das famílias, iii) qual o custo, em termos de emissões de GEE, de melhorar a distribuição de renda no Brasil?, e iv) como a melhoria da distribuição de renda afetaria a importância relativa de alguns bens e serviços na pegada de carbono das famílias? Para responder a primeira pergunta um modelo Insumo Produto Multiregional foi combinado com dados de consumo das famílias provienientes da pesquisa de orçamentos familiares. A segunda pergunta foi abordada com o cálculo da variação de preços de produtos similares em diferentes classes de renda. Para responder as terceira e quarta perguntas, cinco cenários foram criados para estimar o impacto das mudanças da desigualdade de renda no consumo das famílias e na pegada de carbono. Os cenários foram construídos com base nos Shared Socioeconomic Pathways (SSPs) and na identidade de Kaya. Os resultados principais mostram que tirar toda a população da linha da pobreza teria um impacto relativamente pequeno nas emissões de GEE. Porém a ascensão das famílias à classe de renda mais alta induz um acréscimo significativo nas emissões totais dado que as emissões per capita desse grupo (10tCO_2e) são quase cinco vezes maiores que a média nacional. Finalmente, as emissões de GEE no cenário mais igualitário seriam apenas 12% maiores que aquelas no cenário mais desigual. Outros estudos apontam que mudanças tecnológicas e de padrões de consumo possuem o potencial de mitigar esse incremento nas emissões. Portanto, dado os benefícios econômicos e sociais da melhoria da distribuição de renda esse potencial incremento nas emissões seria um preço justo a se pagar.

Palavras-chave: 1. Desigualdade de renda 2. Pegada de carbono 3. Cenários 4. Brasil.

ABSTRACT

TUDESCHINI, Luis Gustavo. **Income inequality and their impacts on the Brazilian household carbon footprint.** 2018, 97 p. Ph.D. Dissertation (Doctor of Science) – Graduate Program on Energy, University of Sao Paulo, Sao Paulo, 2018.

The dissertation explores the link between two crucial development challenges for the Brazilian society: income inequality and climate change. In a developing country like Brazil, there is still a large room for income growth and distributional improvements. The design of social and distributional policies need to understand the links between income level, consumer behavior, and greenhouse gases (GHG) emissions. Two main objectives are set to tackle these links. First, to analyze the unequal contribution of household consumption across income groups on the Brazilian GHG emissions, and second, to understand the impacts of changes in income distribution on the total Brazilian household GHG footprint. The development of these objectives brings two main innovative contributions: a price index method that corrects the distortion on emission allocation caused those price variation, and detailed analysis on the contribution of the consumption items to the household carbon footprint. Additionally, four questions derive from these objectives: i) how do the consumption patterns of households in different income groups affect their GHG footprints?, ii) what is the impact of prices variations across income classes on GHG footprint estimations?, iii) what is the emission cost of building a more egalitarian Brazilian society?, and iv) how the improvement or worsening of the income distribution would affect the relative importance of the consumption sectors on the household emissions?. To answer the first question, an Environmentally Extended Multiregional Input-Output model (EE-MRIO) was combined with the consumption data from the household budget survey. The second question was tackled by estimating the price variations across the income classes. To answer the third and fourth questions, five scenarios were developed to estimate the impact of inequality changes on the household consumption and carbon footprint. These scenarios were built based on the Shared Socioeconomic Pathways (SSPs) and the Kaya Identity. The primary results show that, on the one hand, increasing the families' income to a level just above the poverty threshold has a relatively low emission cost. On the other hand, the ascension of households to the upper-income group (G10) induces a significant impact on the total consumption and related emission, since the emission per capita of this group (10 tCO_2e)

is almost five times higher than the national average. Secondly, the most egalitarian scenario would emit about 12% more GHG than the least egalitarian one. Previous studies have shown that technological and consumption shifts have the potential to mitigate these increments on the emission. Thus, given the social and economic benefits of improving the distribution, this increment would be a “fair price” to pay.

Keywords: 1. Income inequality, 2. Carbon footprint, 3. Scenarios, 4. Brazil.

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1. INTRODUCTION

The IPCC's [1]Fifth Assessment Report (AR5) has shown the evidence of an unequivocal increase in the global temperature level by 0.85°C from the year 1880 to 2012, registering the warmest 30-year period of the last 1400 years (from 1983 to 2012). These changes in the climate systems have been mainly driven by anthropogenic greenhouse gases (GHG) emissions, and, since the pre-industrial period, the cumulative anthropogenic CO_2 emissions increased by 2040 $GtCO_2$. The impacts attributed to climate change have been more often and extreme. As a consequence, changes in precipitation and hydrological systems have negative impacts on both natural systems and economy (IPCC, 2014c). As a consequence, in Brazil, the low-risk production areas are expected to reduce for soybean (-34% to -30%), maize (-15%), and coffee (-17% to -18%) by the year 2050. Summing-up, the impacts of climate change on agriculture could cost around 0.5% to 2.3% of the Brazilian GDP by the year 2050 (MARGULIS; DUBEUX, 2011).

In 2014, the global GHG emissions were around 48.9[2]$GtCO_2e$, and Brazil was responsible for almost 3% of these emissions. Although the Brazilian total GHG emissions have reduced 6% from 1990 to 2014, the country still ranks as the 6th larger emitter in World and contributed with 1.36 $GtCO_2e$ (the year 2014). The other five countries with larger emissions are China (11.60 $GtCO_2e$), the United States (6.32 $GtCO_2e$), India (3.20 $GtCO_2e$), Indonesia (2.47 $GtCO_2e$), and the Russia Federation (2.03 $GtCO_2e$). The current Brazilian sectoral emissions from Brazil is distinctive when compared with the other top 5 emitters. In China, India, the U.S., and Russia the vast majority of emissions come from the energy sector (from 69% to 93%). The Indonesian emissions are also very concentrated, but instead of the Energy sector, the Land-Use Change and Forestry (LUCF) is responsible for 68% of the country`s emissions. In Brazil, the emissions are more equally distributed between the energy, the agriculture, and the LUCF sectors and each one accounts for about one-third of the country`s emissions[3] (MCTI, 2016; WRI, 2017).

[1] Intergovenmental Panel for Climate Change
[2] Total GHG Emissions Including Land-Use Change and Forestry in 2014
[3] Updated estimation from the System for Greenhouse Gas Emissions and Removals Estimates (SEEG) shows an increase in Brazilian GHG emissions for 2016. However, this database is not available for major emitter countries not allowing global comparisons.

However, as shown in Figure 1-1, from 2000 to 2008, LUCF were the primary contributor to the Brazilian GHG emissions, responsible for more than half of the total emissions. However, from 2005 to 2014, the total Brazilian net emissions dropped almost 30% mainly pushed by a 67% reduction in LUCF emissions. These reductions were mainly caused by a decline in deforestation rates in both the Brazilian Amazonia and the Cerrado (Brazilian savanna) biome. Conversely, in the same period, the emissions from Agriculture and Energy sectors emissions rose 8% and 53%, respectively. Brazil is the world`s second livestock producer, and more than 80% of this production is consumed nationally (FAS/USDA, 2017). In the agriculture sector, methane (CH_4) from enteric fermentation, and nitrous oxide (N_2O) from nitrogen fertilizer are the most important GHG. Therefore, the animal production alone was responsible for emitting 355 Mt CO_2e, more than total emissions in the transport sector. (AZEVEDO; RITTL; ANGELO, 2016). The beef and veal consumption in Brazil has been historically high, varying from 23.4 to 26.5 kg/capita/year, a level almost four times greater than the global average and 1.6 times higher than OECD average consumption (OECD, 2017).

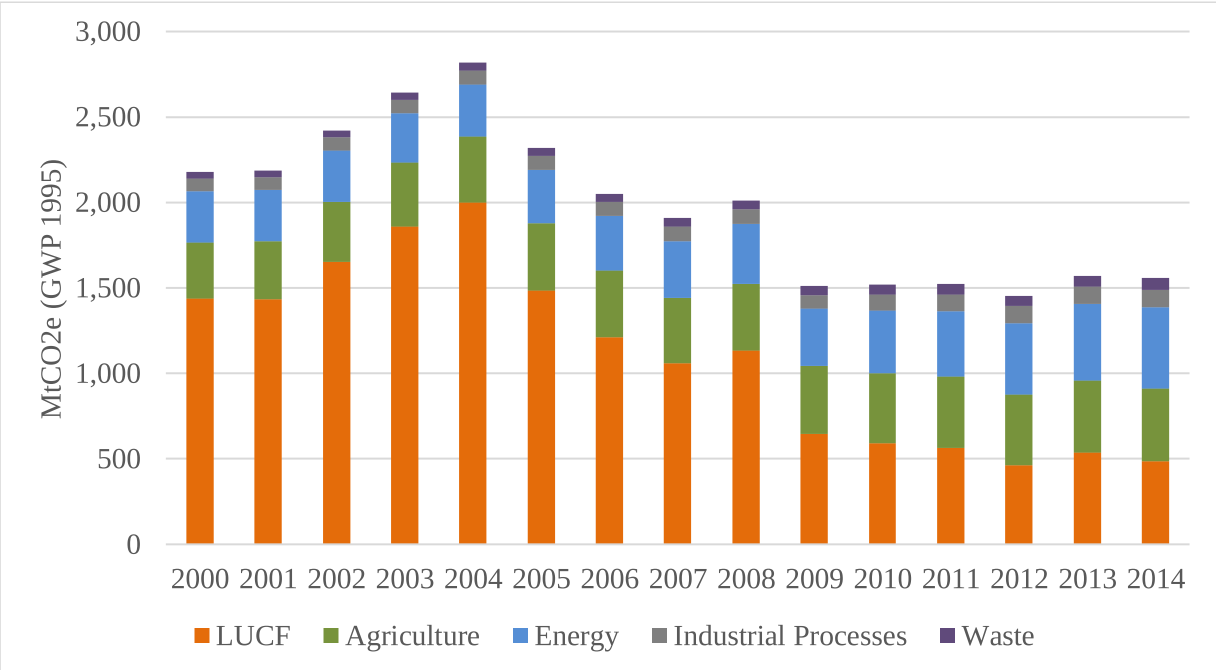


Figure 1-1- Evolution of Brazilian GHG emissions by sector from 2000 to 2014
Source: SEEG (2016)

The Energy sector represented about 30% of total emissions and was the second major emitter in 2014. Within this sector, the most critical drivers of GHG emissions are transports (46%), power generation (17%), industry (16%), and fuels production (12%). From 2000 to

2009, Energy emissions increased at a steady pace of about 1% per year, however, in the following year this rate increased six times. Two leading causes pushed these emissions up - first, the incremental use of thermal electric power plants during dry years, and consequently smaller hydropower generation. Second, high ethanol prices pushed flex-fuel-cars-owners to choose filling their tanks with gasoline, which increased the gasoline consumption by 75% (AZEVEDO; RITTL; ANGELO, 2016; SOUZA; POMPERMAYER, 2015).

The responses to climate change impacts have to be made collectively and globally. At the twenty-first session of the Conference of the Parties (COP21), representatives of the 196 parties approved the Paris Agreement, which has the objective to "strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty" (UNFCCC 2015b, Article 2, pg. 2). Facing the increased likelihood of future impacts on natural and human systems caused by climate change, the representatives agreed to hold the increase in the global average temperature to below 2ºC (UNFCCC, 2015b). Hence, substantial anthropogenic emissions reductions would be required in the next decades, presenting many mitigation challenges. The first step to deal with these challenges is to identify the primary drives of anthropogenic emissions, such as consumption, economic and population growth, and energy consumption, which are all interlinked (IPCC 2014a).

In its Nationally Determined Contribution (NDC), the Brazilian Government has made a bold pledge to reduce GHG emissions by 37% by 2025 and 43% by 2030, below 2005 levels (UNFCCC, 2015a). The commitment highlights specific mitigation targets and measures for the Energy, LUCF, and Agriculture sectors. In the energy sector, the primary strategy is to expand the renewable power generation share achieving 45% of the energy mix by 2030, mainly by focusing on increasing the biofuels share (18% of the mix), wind, and solar power. A gain of 10% in efficiency is also planned in the electricity sector by the same year. For the LUCF sector, the most tangible goals are i) achieving zero illegal deforestation in the Brazilian Amazonia and compensating for GHG from legal forest suppression by 2030, and ii) restoring and reforesting 12 million hectares of forests by 2030. Additionally, for the agriculture sector, the NDC intends to strengthen the Low Carbon Emission Agriculture Program (ABC program) (UNFCCC, 2015a).

Even though the Brazilian NDC presents ambitious targets and measures, little is clear about mitigation plans in two critical areas: transportation and animal production. In the transport sector, the plan presents only broad goals of promoting energy efficiency and improving infrastructure for private and public transportation in urban areas. Within the Agriculture sector, there is the ABC program which aims to enhance sustainable agriculture practices. However, this program presents no specific targets or strategies to reduce emissions from enteric fermentation, responsible for 57% of agriculture sector emissions (AZEVEDO; RITTL; ANGELO, 2016; EMBRAPA, 2015). Together, transport and animal production represented almost 45% of total GHG emissions in 2014. The commitment also neglected demand-side policies that could induce changes in consumption patterns and emissions footprint, as presented in more detail in section 2.

In a developing country like Brazil, it is imperative that climate policies be designed and implemented considering other development challenges. Although in its 2016 Human Development Report, the United Nations Development Programme (UNDP) positioned Brazil at the “high development category” with a Human Development Index (HDI) of 0.754, this average index hides important development challenges “on the ground.” For instance, Brazil still among the 15th most unequal countries in the world, with almost 14.8 million people living on less than $1.90 a day, and more than 57% of adults are overweight (BÔAS, 2018; IHME, 2017; THE WORLD BANK, 2018b; UNDP, 2016).

1.1. Objectives and research questions

The two main objectives of this dissertation are: first, to analyze the unequal contribution of household consumption across income groups on the Brazilian GHG emissions, and second, to understand the impacts of changes in income distribution on the total Brazilian household GHG footprint. The first objective is tackled utilizing a Multi-Regional Input-Output model with an innovative price adjustment proposed here to correct the impact of price variations on the emissions footprint per income class. To meet the second objective the results from the first step are combined with the Share Socioeconomic Pathways (SSPs) framework to estimate GHG emissions under different income distribution scenarios.

The dissertation is divided into two main sections. The first section analyzes the consumption structures, and related GHG emissions, from different income classes. Also, it presents the new method to deal with the distortions on emissions per income group caused by price variations. The questions below guides this first section:

1. What is the impact of prices variations across income classes on GHG footprint estimations?

2. How do the consumption patterns of households in different income groups affect their GHG footprints?

The second section uses the lessons learned in the first part to understand the impact of different income distribution scenarios on the consumption structure, and resulting GHG emissions. Also, it identifies key production sectors that should receive attention when designing mitigation policies. The questions from this section are:

3. What is the emission cost of building a more egalitarian Brazilian society?
4. How the improvement or worsening of the income distribution would affect the relative importance of the consumption sectors on the household emissions?

The main original contributions of this dissertation are:

i) a price index method that corrects the distortion on emission allocation caused those price variation, and
ii) a detailed analysis of the contribution of the consumption items to the household carbon footprint.

# 2. HOUSEHOLD UNEQUAL CONTRIBUTION TO GHG EMISSIONS IN BRAZIL

2.1. Literature Review: Household emissions footprint

The scope of this dissertation is the contribution of households in different income classes to climate change. In the early stages of this research topic, the concern was to account for the energy embedded in the household expenditure (including non-energy services and goods) so that they could understand the relationship between the household expenditure and the resulting energy requirements (HERENDEEN, ROBERT; TANAKA, 1976). As Herendeen, Ford and Hannon (1981) present, energy is required across the whole life cycle of the products and services, including raw material extraction, use, and eventual disposal. Therefore, there is energy embedded in every good and service consumed by the households.

The total energy requirement (TER) is usually divided into *direct* and *indirect energy*. Yuan et al. (2015) define the *direct energy* requirements of households as "*the consumption of energy carriers (coal, petroleum, natural gas, and electricity) purchased directly by households for space heating, heating tap water, lighting, appliances, cooking and motor fuel, etc."* Also, Pachauri (2004) highlights the importance of accounting for non-commercial energy consumption, such as fuelwood and other biomass since these energy carries accounts for most of the energy required and carbon footprint in low-income households in developing countries. In contrast, in developed countries, *indirect energy* accounts for most of the energy consumed by the household, and it consists of all the upstream energy required to produce the goods and services consumed by the household (COELHO *et al.*, 2018; PACHAURI, 2004; PAPATHANASOPOULOU, 2010; SANCHES-PEREIRA; TUDESCHINI; COELHO, 2016; YUAN; REN; CHEN, 2015).

With the rising concern about climate change, many studies shifted attention to the household carbon emissions, also called household carbon footprint, and its impacts on climate change (CHANCEL, 2014; LIU *et al.*, 2011; MUNKSGAARD; PEDERSEN; WIEN, 2000; ROSAS; SHEINBAUM; MORILLON, 2010; WANG; YANG, 2014; WIEDENHOFER *et al.*, 2016a; ZHANG, JUNJIE *et al.*, 2017). This approach is also known as consumption-based method and is an alternative method to the territorial system boundary – or production-based - used by the United National Framework Convention of Climate Change (UNFCC), which only accounts for "*greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction*"(IPCC 2006, pp.5). The commitments made at COP21 are based on the territorial system boundary, but this system does not allocate carbon leakages from international trade and international transportation (PETERS, GLEN P, 2008).

Zhang et al. (2015) present a complete review of household carbon footprint research for the period from 1990 to 2014. They identify the use of three other common terms for household carbon footprint: household carbon dioxide emissions, the embedded carbon footprint of a household and household carbon emission. Also, they highlight two definitions. The first, by Fan et al. (2012), focuses on the value chain and define carbon footprint as "*the CO_2 emissions resulting from the whole life cycle of products and services for the household including those associated with their manufacturing and eventual breakdown*". Qu et al. (2013) present a more social-focused definition: "*the emissions of individuals or their families in order to meet the demands of their existence and development under certain socio-economic conditions, which includes both direct and indirect emissions*." Direct emissions come from direct energy consumed by households for cooking, lighting, heating, bathing, recreation, transportation and other activities (LI *et al.*, 2015).

In the same way as indirect energy requirements, *indirect emissions* are related to the production process of commodities and services. In this dissertation, this concept is expanded to include more GHGs[4] other than carbon dioxide. Thus the terms adopted here are GHG footprint, carbon footprint, or emissions footprint.

Most of the studies on household carbon footprint did not consider carbon embedded in imports until the broader availability of Environmental-Extended Multiregional Input-Output (EE-MRIO) databases, such as WIOD, EXIOBASE, and EORA (LENZEN, MANFRED *et al.*, 2013; MORAN; WOOD, 2014). In the early attempts, imports were treated as if they were produced with domestic technologies, neglecting essential countries particularities in the industrial structure and energy matrix (BÜCHS; SCHNEPF, 2013; LENZEN, M *et al.*, 2006; LENZEN, MANFRED; DEY; FORAN, 2004; LIU *et al.*, 2011; NÄSSÉN, 2014; SHAMMIN *et al.*, 2010; WEI *et al.*, 2007). Conversely, this dissertation aligns with the more recent research; and uses an EE-MRIO to represent the international trade better and reduce the uncertainties related with imports.

Also, a series of studies investigated the drivers of household energy and carbon footprint. The more significant drivers identified are the household income (LENZEN, M *et al.*, 2006; PACHAURI, 2004; YUAN; REN; CHEN, 2015), age (BÜCHS; SCHNEPF, 2013; NÄSSÉN, 2014), household size (JONES; KAMMEN, 2014), education level of the household

[4] Detailed in the methodology and data section.

members (BÜCHS; SCHNEPF, 2013), and spatial characteristics (ALA-MANTILA; HEINONEN; JUNNILA, 2014; FENG; ZOU; WEI, 2011; NÄSSÉN, 2014; WEI *et al.*, 2007; YUAN; REN; CHEN, 2015).

According to Zhang's et al. (2015) review on 69 papers, the household income is the most significant factor driving household carbon emissions. Some studies separate households into different income groups and analyze the CO_2 emissions from each group (CHANCEL; PIKETTY, 2015; PEROBELLI; FARIA; DE ALMEIDA VALE, 2015; WIEDENHOFER *et al.*, 2016a; ZHANG, JUNJIE *et al.*, 2017). The main findings from previous studies show that the carbon footprint increases with household income, given that affluent households consume and emit significantly more CO_2 than low-income households.

Also, Shammin et al. (2010) show that in the United States the contribution of direct energy to the total energy requirement decreases as income rises. Affluent households tend to expend a higher share of its income on non-energy[5] commodities and services. This trend is also confirmed for Australia, Denmark, India, and Japan where consumer baskets tend to become less energy intensive as income and expenditure rise (LENZEN, M *et al.*, 2006; PACHAURI, 2004). Moreover, Dai et al. (2012) suggest that affluent households consume more high-quality goods that are not necessarily more energy intensive. However, a different trend is presented by Cohen, Lenzen, and Schaeffer (2005), where Brazilian households in 1996 increased both direct and indirect energy requirements as income rises.

In the context of Brazil, there are few studies associated with energy requirement and emissions across income classes. The seminal work of Cohen, Lenzen, and Schaeffer (2005) investigates the distribution of energy requirement across households in different income classes. The results show that the most affluent group requires 18 times more energy than the lower income group. In a comparative study, Lenzen *et al.* (2006) show a high correlation between expenditure, education, and house type with energy requirement. Also, they find a household expenditure elasticity of energy requirement higher than 1, meaning that the energy requirement increases at a faster rate than expenditure. However, this finding is not aligned with the majority of the literature that shows the expenditure elasticity ranging from 0.6 to 1 (ALA-MANTILA; HEINONEN; JUNNILA, 2014; RAO, NARASIMHA D.; MIN, 2018). Also, both studies did not focus on carbon or GHG footprint and neglected the energy embedded in imports.

[5] Excludes energy products such as fuels and electricity.

In the recent literature, Perobelli, Faria, and De Almeida Vale (2015) analyze the impacts of change in the income on the carbon emissions from households in different income groups. The results show that the higher income group contribute with 63% of the carbon emission, while the lower-income class contributes only 0.37%. Although this study considers the importance of the emissions embedded in global trade, it only accounts for energy-related CO_2.

However, the literature does not cover the following issues:

i) the impact of price variations across income groups on the household carbon footprint;

ii) the discussion on carbon intensity across income classes, and contribution of different consumption behavior to the household carbon footprint using updated data from 2009.

2.2. Data and Method: Household GHG footprint

2.2.1. Household expenditure and GHG emissions data

In Brazil, the Brazilian Institute of Geography and Statistics (IBGE[6]) defines a household[7] as "*The structurally separated and independent housing composed of one or more rooms, where the conditions of separation and independence access must be met.*"(IBGE, 2010b). This institute conducts the Brazilian Consumer Expenditures Survey (POF[8]) that gather information on household size, consumption structure socioeconomic conditions, food consumption, among others. The most recent version of POF is from 2009 and collected socioeconomic information from 55,970 households in urban and rural areas in all 27 Brazilian Federative Units (IBGE, 2010b). This survey collected the household expenditure on over ten thousand consumption items that are mapped into 99 items using the classification system from POF documentation and the Classification of Individual Consumption According to Purpose (COICOP) described in IBGE (2010a) and Min & RAO (2017). Some of these items contain physical information from where the price per unit is inferred.

[6] In portuguese: Instituto Brasileiro de Geografia e Estatística

[7] Original definition in Portuguese: *"É a moradia estruturalmente separada e independente, constituída por um ou mais cômodos, sendo que as condições de separação e independência de acesso devem ser satisfeitas".*

[8] In portuguese: Pesquisa de Orçamentos Familiares

This dissertation uses the latest version of the Multi-regional Input-Output (MRIO) database named EXIOBASE2 (TUKKER *et al.*, 2013; WOOD *et al.*, 2015). The EXIOBASE2 has the as the base year 2007 and is the MRIO database with the highest level of sectoral disaggregation (INOMATA; OWEN, 2014; MIN; RAO, 2017). It presents monetary and material flows (including energy, water, land, and emissions) of 200 products, 163 sectors, for 48 regions[9]. The EXIOBASE2 also provides GHG emissions satellites that account for energy-related and agriculture-related emissions for the year 2007. The gases analyzed are Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbon (HFC), Perfluorocarbon (PFC), and Sulphur hexafluoride (SF_6) and their global warming potential (GWP) calculations were considering the Fifth Assessment Report (AR5) of the IPCC guidelines (MYHRE *et al.*, 2013).

2.2.2. Household Carbon Footprint: An Input-Output Approach

There are energy and therefore GHG embedded in every good and service consumed by the households. The GHG are emitted across the whole life cycle of the products and services, including raw material extraction, use, and eventual disposal, and must be linked to the household consumption. To measure the contribution of the household to climate change is essential to understand its two main components. First is the level and structure of the household consumption basket across income classes. Second is the embedded GHG in those bundle of goods and services. The approach taken in this dissertation is similar to previous studies that analyzed household energy requirement and emissions in developed and developing countries (COHEN; LENZEN; SCHAEFFER, 2005; LENZEN, M et al., 2006; MIN; RAO, 2017; WIEDENHOFER et al., 2016a). This approach combines household expenditure data and the Environmental-Extended Multiregional Input-Output (EE-MRIO) methods to calculate the resources embedded in final consumption. This accounting approach is called consumption-based and contrasts with the territorial system boundary adopted by the United Nations Framework Convention on Climate Change (UNFCCC) to measure countries GHG emissions. The territorial approach, also called production-based, account for all emissions and removal taking place within national territories (IPCC, 1996), but lacks the explicit connection with the consumption side.

The EE-MRIO model is a sophistication from the basic Leontief IO model (LEONTIEF, 1966) and has been used to account the environmental impacts associated with the production and consumption of goods and services (GUILHOTO, J. J. M., SESSO FILHO, 2005; MILLER; BLAIR, 2009). The Leontief model shows the interrelationships between sectors, and the total output of an economy $\boldsymbol{x}$ can be expressed as the sum of inter-industry requirements and final consumption $\boldsymbol{f}$.

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{f} \qquad 1.1.1$$

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\,\boldsymbol{f} \qquad 1.1.2$$

The **I** is the identity matrix, **A** is the direct input coefficients matrix, and $(\mathbf{I} - \mathbf{A})^{-1}$, (or **L**), is known as the Leontief inverse matrix and shows the total input required for a sector to produce one unit of output**.** **D** is a matrix with the direct GHG emissions coefficients associated with each unit of output of each industrial sector, also known as emission intensity matrix, and is the Environmental Extension (EE) to the model.

$$\boldsymbol{e} = [\boldsymbol{D}\boldsymbol{L}]\,\boldsymbol{f} \qquad 1.1.3$$

The total GHG emissions of each household are obtained by post-multiplying the total GHG emissions coefficients (**DL**) by the vector corresponding to the household demand by sector $\boldsymbol{f}$, as presented in equation **1.1.3**. The national consumer expenditure surveys (CES), in this case, POF, provides household expenditure data that represents the consumption structure of each household in a country. However, often CES have a higher resolution of consumption categories than IO`s sectors. The harmonization and aggregation process between the two uses international standard classification systems such the International Comparison Program (ICP) and the International Classification of Individual Consumption According to Purpose (COICOP), and it is described in detail by Min&Rao (2017).

The impact of distributional changes is calculated by aggregating the households by income decile. Income deciles are groupings that result from ranking all households in ascending order according to their income per capita and dividing them into ten equal groups. Each group comprises approximately 10 percent of the estimated households. The first decile contains the bottom ten percent, the second decile contains the next ten percent, and the tenth decile contains the top 10 percent.

The Multiregional model (MRIO) adds another layer of complexity by incorporating the trade flows between countries (or regions). This layer is especially important when analyzing household consumption because, in a globalized economy, household are increasingly consuming imported goods (PETERS, G. P. et al., 2011). As mentioned before, the level and structure of households consumption are based on the POF for the year 2009, while the GHG emissions are based on EXIOBASE for the year 2007. Given the lack of more up to date EE-MRIO databases, it is assumed that the Brazilian emissions from energy and agriculture are the same in 2007 and 2009[10].

2.2.3. Price adjustment

Although the Environmental-Extended Input-Output model (EE-IO) has been widely used in estimating household carbon footprint and energy requirement (COHEN; LENZEN; SCHAEFFER, 2005; DAS; PAUL, 2014; DRUCKMAN; JACKSON, 2009; LENZEN, M *et al.*, 2006; LENZEN, MANFRED, 1998; LIANG; FAN; WEI, 2007; PEROBELLI; FARIA; DE ALMEIDA VALE, 2015), it generates uncertainties and distortions due to the harmonization of different data sources, and to the assumption of price homogeneity across income classes. As explained before the construction of a household-linked EE-MRIO requires four main data components: a consumption expenditure survey (CES), an MRIO model, a bridge between CES and MRIO, and a GHG extension matrix. The uncertainties related to those components are well explored in many studies (LENZEN, MANFRED, 2000, 2011; LENZEN, MANFRED; PADE; MUNKSGAARD, 2004; LENZEN, MANFRED; WOOD; WIEDMANN, 2010; MIN; RAO, 2017; USUBIAGA; ACOSTA-FERNANDEZ, 2015; WEBER, 2008; WIEDMANN, 2009; WILTING, 2012) and are not the scope of this section. This section describes an approach to reduce the distortions in emission allocation due to price variation across income classes.

The household carbon footprint is the product of GHG emissions coefficients ($\boldsymbol{DL}$) and the household demand $\boldsymbol{f}$, as shown in equation **1.1.3**. For instance, the emission coefficient of the item “Beer” is one row of the vector $\boldsymbol{DL}$ and represents a proxy for the emissions of all kinds of “Beer.” Thus, every additional dollar spent in “Beer” will emit the same marginal amount of GHG. However, if a household pays more for each liter of the “Beer,” more emissions will be allocated for this household regardless that the demand in physical terms (liters of Beer) stills the same. As a result, households that systematic pay higher prices (generally more affluent households) get more emissions allocated to them, possibly neglecting

[10] As shown in figure 2-1 this is a plausible assumption.

the decoupling of income and GHG emissions, and overestimating the income rebound effect (GIROD; DE HAAN, 2010). In the context of this dissertation, significantly higher prices among affluent families would attribute unrealistically more emissions to high-income groups and distort the results of the income-inequality scenarios.

The price differences can come from three primary sources: i) an identical or mostly similar item having different prices in different markets, ii) a similar item with different qualities and brands, and iii) a range of similar items being aggregated to merge the CES and EE-MRIO data. While the first two are related to the market structure such as price discrimination, and business strategy, the last characteristic regards the construction of the model. As described in sections 2.2.1 and 2.2.2, the more than four thousand items from CES are mapped into the same aggregation level of the EE-MRIO model, in this case, 99 items. This means that a large number of different items, with different qualities and prices, are aggregated into the same category.

The price adjustment proposed and implemented in this dissertation corrects the household's expenditure, and consequently the GHG footprint, using the price paid by each household. In the best-case scenario, price information would be available for all 99 consumption items generated after the harmonization process (section 2.2.2). However, the Brazilian CES of 2008/2009 (POF 2008/2009) provides the price information for 43 consumption items. Thus, the price information for those 43 items is used to build a price-index that corrects the expenditures by income class on the other 56 items without price information.

Although price indexes are usually applied to make economic variables comparable across time and between regions (HOFFMANN, 2006), here, they are adapted to compare household expenditure across income classes. Therefore, instead of calculating the price variations using a base-year ($\boldsymbol{t_0}$), it uses a base-income-group $\boldsymbol{g_1}$. Using the best information available, this method involves two major steps: i) adjust the expenditure on those items with price information available using a relative price index, and ii) use the classical Fisher method (FISHER, 1922) to build a general index using the price information available from the 43 items.

The relative price index ($\boldsymbol{IR}$) considers the relationship between the average price paid for item $\boldsymbol{c}$ by the income group $\boldsymbol{G_n}$ and the average price paid for the same item $\boldsymbol{c}$ paid by the base-income-group $\boldsymbol{G_1}$ (equation 1.1.4). There are ten income groups represented by the capital letter G and followed by a number from 1 to 10. The G_1 is the bottom 10% of the families with lower income per capita, and the G_{10} is the top 10% of the families with the highest income per capita. Any income group can be used as based-income-group, but here the G_1 is arbitrarily chosen. To indicate the group of 44 items $\boldsymbol{c}$ with price information is added a subscribed Greek letter $\boldsymbol{\alpha}$.

$$IR_{c_\alpha,G_n} = \frac{P_{c_\alpha,G_n}}{P_{c_\alpha,G_0}}\,.\,100 \qquad \textbf{1.1.4}$$

The total expenditure by income group in item $\boldsymbol{c_\alpha}$ is adjusted using the resulting index (***IR***), as shown in equation 1.1.5.

$$AE_{c_\alpha,G_n} = \frac{E_{c_\alpha,G_n}}{IR_{c_\alpha,G_n}}\,.\,100 \qquad \textbf{1.1.5}$$

The Fisher price index is the geometric mean of two other indices, the Laspeyres, and the Paasche. As shown in equation **1.1.6**, the Laspeyres index (***IL)*** is the weighted mean of the relative prices paid by households in income group $\boldsymbol{g_1}$ (base-income-group) and $\boldsymbol{g_n}$ (nth-income-group) for items $\boldsymbol{c}$ and uses as weight the monetary quantity spent in item $\boldsymbol{c}$ by the households in income group $\boldsymbol{g_1}$. The Paasche index (***IP***) differs from Laspeyres only by using the expenditure in item $\boldsymbol{c}$ by the household in the income group $\boldsymbol{g_n}$ as weight. In other words, ***IL*** is a relationship between the cost of purchasing (the expenditure) the bundle of goods bought by base-income-group ($\boldsymbol{E_{g_0}}$) with price level paid by the *nth*-income-group ($\boldsymbol{E_{g_n}}$) and the cost of purchasing the same bundle with the average price level paid by the base-income-group ($\boldsymbol{p_{c,g_0}}$). Also, ***IP*** is the relationship between the cost of purchasing the bundle of goods bought by the *nth* income group ($\boldsymbol{E_{g_n}}$) with price levels paid by the *nth*-income-group ($\boldsymbol{p_{g_n}}$) and the cost of purchasing the same bundle with the average price level paid by the base-income-group ($\boldsymbol{p_{g_1}}$) (HOFFMANN, 2006). As a result of these characteristics, the Laspeyres index tends to overstate the prices variations, while the Paasche index tends to understate it. In order to correct theses tendencies, Irvine Fisher proposed to use the geometric mean of the two indices shown in equation **1.1.8**.

Laspeyres index:

$$IL_{c_\alpha,G_n} = \frac{\sum\left(p_{c_\alpha,G_n}\cdot q_{c_\alpha,G_0}\right)}{\sum\left(p_{c_\alpha,G_0}\cdot q_{c_\alpha,G_0}\right)}\,.\,100 \qquad \textbf{1.1.6}$$

Paasche index:

$$IP_{c_\alpha,G_n} = \frac{\sum(p_{c_\alpha,G_n} \cdot q_{c_\alpha,G_n})}{\sum(p_{c_\alpha,G_0} \cdot q_{c_\alpha,G_n})} \qquad \mathbf{1.1.7}$$

Fisher Price Index:

$$IF_{G_n} = \sqrt{IP_{G_n} . IL_{G_n}} \qquad \mathbf{1.1.8}$$

The items without price information are noted as c_β and they are adjusted according to the equation 1.1.9 and the Fisher Index presented in Table 2.2.1. The impacts of the proposed adjustment on the household GHG footprint are presented in section 2.3.1.

$$AE_{c_\beta,G_n} = \frac{E_{c_\beta,G_n}}{IF_{G_n}} . 100 \qquad \mathbf{1.1.9}$$

Table 2.2.1 – Price Adjustment Index results.

Income Group	*Price Index*
G1	100
G2	101.12
G3	105.37
G4	104.77
G5	108.36
G6	111.42
G7	112.81
G8	117.78
G9	124.77
G10	141.08

2.3. Results of Price Adjustment, Household Consumption, and Carbon Footprint

2.3.1. Price adjustment

As detailed in section 2.2.3, the EE-MRIO model assumes that all items within a category (e.g., Bread) have the same emission intensity (CO_2e/USD) which neglects the price variation within the category and across income groups. Thus, within the same category, products with higher prices are assumed to emit more GHG. This section presents an implementation of the proposed price adjustment method implemented using the

Brazilian data. It is important to highlight that the objective of this method is to represent the distribution of emissions across the income classes better, but without changing the total emissions by sectoral. This section answers the second research question of the dissertation: What is the impact of prices variations across income classes on GHG footprint estimations?

The first step is to understand the information available on prices, its variation, and categories. As shown in Figure **2.3-1** and 2.3.2, the POF 2008/2009 survey provides price information for 43 consumption categories (30 food, four beverages, and nine energy products).

In Brazil, most of the energy market is regulated which limit the price variation. The Brazilian Electricity Regulatory Agency (ANEEL[11]) regulates the power sector and determines the residential electricity tariffs. The small variation in the electricity prices can be explained by differences between states and the Social Electricity Tariff[12]. In the first, utilities charge different tariffs according to the different costs in the generation and transmission across states (ANEEL, 2017). Secondly, low-income families with per capita income of up to USD 46.00 per month have the right to subsidies on the electricity bill. Those eligible families receive the discount on the electricity bills that range from 10% to 65% depending on the monthly electricity consumption (ANEEL, 2016).

The prices of fossil fuels are mainly determined by the price strategy of The Brazilian Petroleum Corporation (PETROBRAS). PETROBRAS is a semi-public multinational and has 65 percent of its shares owned by the Brazilian government. It is the larger fossil fuel producer, importer, and refiner in Brazil, whose price strategy controls the national market for fuel and production costs for the whole market in the country. The more significant part of consumer price is the refiner price given by PETROBRAS, and variations depend on transportation costs, different state taxes and retailers' price strategy (ALMEIDA; OLIVEIRA; LOSEKANN, 2015; PETROBRAS, 2018). Ethanol and gasoline became perfect substitutes after the popularization of flex-fuel vehicles, and the consumer can choose based on the relative prices and fuel economies (PACINI; SILVEIRA, 2011).

[11] In Portuguese: Agência Nacional de Energia Elétrica
[12] In Portuguese: Tarifa Social de Energia Elétrica - TSEE

The statistical bureau (IBGE) imputes the same price for all “Firewood and other fuels” observations. There is less than 50 observation of consumption of categories “Firewood and other fuels,” “Other biomass,” and “Charcoal/coal/briquette/coke" (0.09% of the sample). Therefore, they have no significant impact on the emissions, and price index estimation. Overall, the standard deviations (SD) of the prices of energy carriers range from 0 to 0.55 US$2010PPP/unit. Thus, these categories have little impact on the final price index (Figure **2.3-1**).

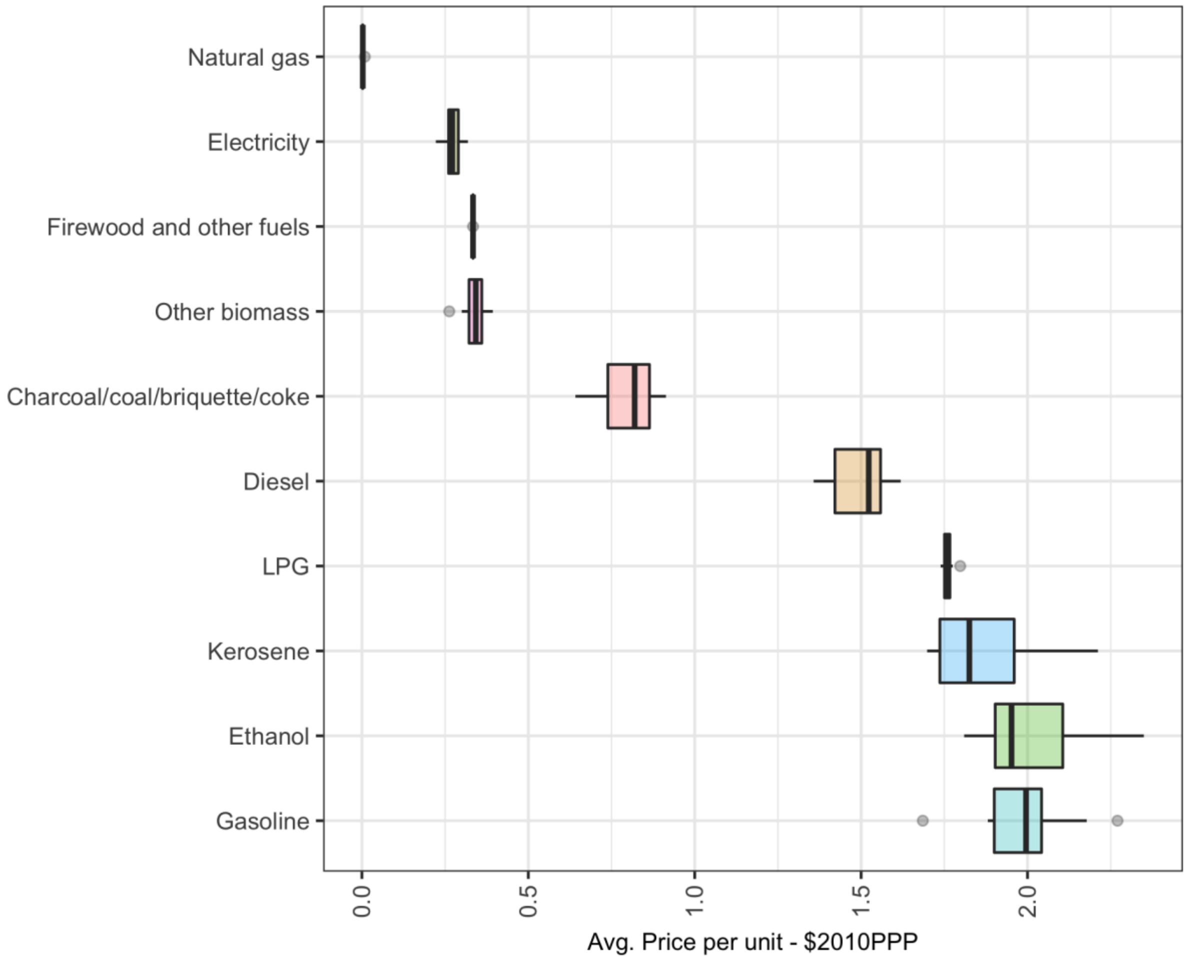


Figure 2.3-1 - Price variation for nine energy consumption items. Each boxplot presents five information on the item’s price: minimum, first quartile, median, third quartile, and maximum values (from left to right). The items are ordered from lower to higher median price (from top to bottom).
Source: Prepared by the author based on POF 2008/2009

Conversely, most food and beverages categories have SD higher than 2 US$2010PPP/unit and drive most of the index results (APPENDIX A). As shown in Figure **2.3-2**, some categories such as “Sugar,” “Confectionery, chocolate and ice cream,” and “Other cereals, flour and other products" present significant price variations. Two factors could explain that. First, affluent families buy from supermarkets that focus on this public and charge more for a similar product. Second, there are products with different characteristics within the same category. For instance, the granulated sugar costs about USD 0.40 while an organic brown sugar costs USD 4.00.

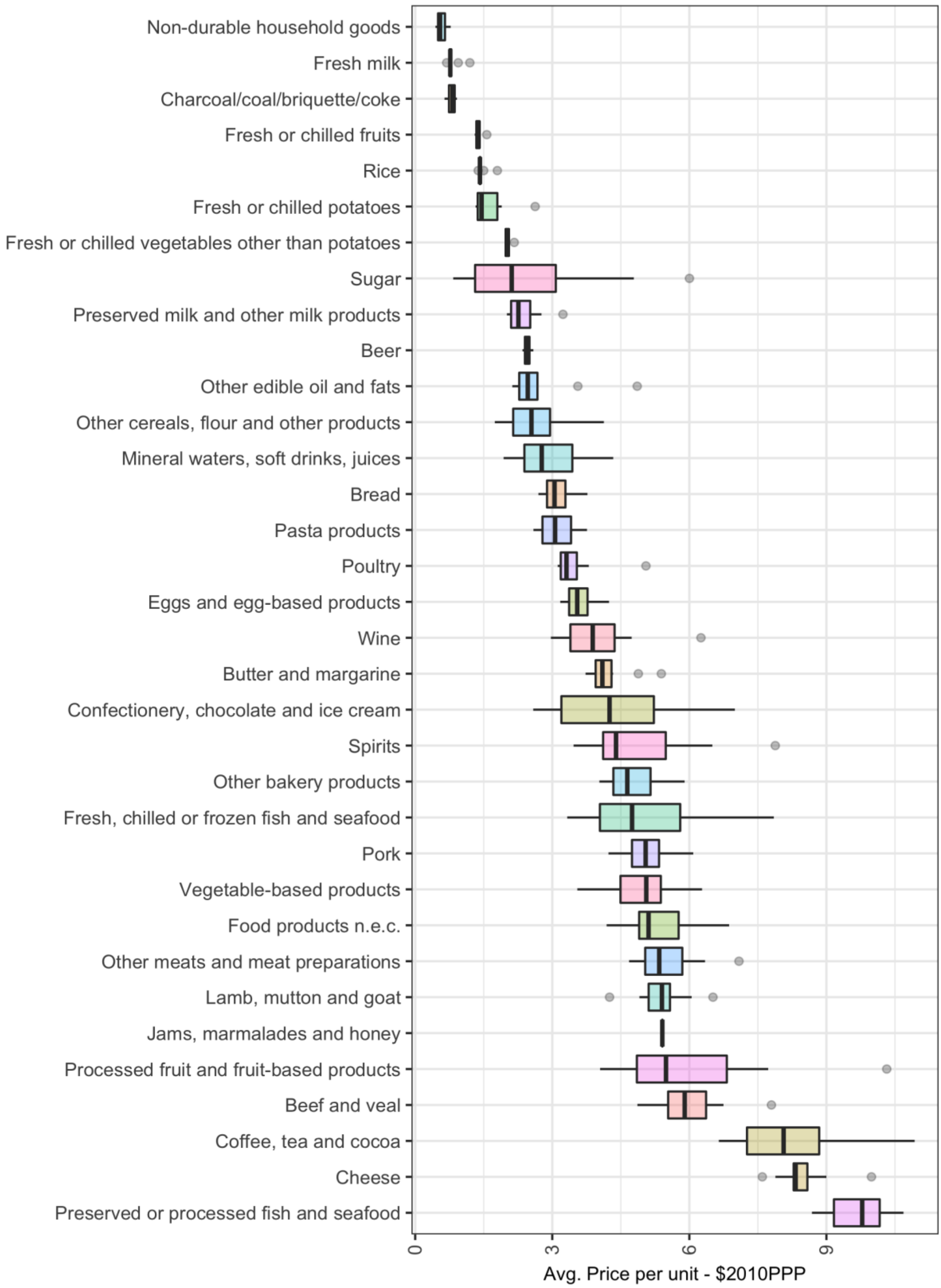


Figure 2.3-2 - Price variation for 34 non-energy consumption items. Each boxplot presents five information on the item’s price: minimum, first quartile, median, third quartile, and maximum values (from left to right). The items are ordered from lower to higher median price (from top to bottom).
Source: Prepared by the author based on POF 2008/2009

Figure 2.3-3 -Price adjustment impact on total GHG footprint by income group. In the first chart, the bars represent the total GHG footprint per income group: the blue bar is the footprint without price adjustment, and the orange bar is the footprint after implementing the price adjustment. In the second chart, bars show the percentaged impact of the price adjustment on the total footprint by income group.
Source: Prepared by the author based on POF 2008/2009 and EXIOBASE

As a result, the most affluent group (G10) pays on the average price of 57% higher than the lowest-income group (G1). The Top 10 income group pays higher prices for 33 categories. However, this is not uniform, and the price variation between the extreme income groups (G10 – G1) ranges from -72% to 621%. To highlight the extreme cases: seven categories have prices more than 100% higher for the G10, in ten the prices are more than 50% higher, and the Top 10 pays the lower price just in six categories.

The second step is the analysis of the impacts of the price index on the household GHG footprint across the income classes. In 2009, the more than 57 million Brazilian households emitted in total about 514 $MtCO_2e$, which is the equivalent of an average of 3.2 tCO_2e per capita per year. As mention before, this adjustment affects just the emission distribution between income groups, not changing the total, the average, and the sectoral emissions. As shown in Figure **2.3-3**, the impact of the index on emissions are higher on the extremes of the income distribution. In the Bottom 20% (G1 and G2), the emissions increase by about 17% while decrease 11% at the Top 10 (G10). This distributional change reflects the price variations discussed before and balance the price distortion. In conclusion, prices differ considerably within many categories, and the price adjustment affects more the extremes of the income classes in the distribution.

To conclude, the consumption prices varies substantially across the income groups with the higher income group (G10) paying on average 57% more for similar products and services than the lower income group (G1). When classical EE-MRIO negletcs these variations, its distorts the footprint allocation, allocating more resources (or emissions) to the higher income classes. The results from the Brazilian case show that these distortions are more significantly on the extreme of the income distribution. After implementing the adjustment, there is a reduction of 11% on the carbon footprint allocated to the G10, and an increase of 17% on the G1.

2.3.2. Consumption level and structure across income groups

As extensively discussed in the literature, income is the most crucial driver of households GHG emissions (ZHANG, XIAOLING; LUO; SKITMORE, 2015). From the household perspective, income allows access to goods and services, the material basis for welfare. From the policy-making side, the better understanding of the poverty level, and income distribution helps to design policies that improve the conditions for social cohesion and promote social wellbeing (COOPER; MCCAUSLAND; THEODOSSIOU, 2013). This section aims to understand how income is distributed amongst the Brazilian households in the analyzed year (2009), and how households in different groups allocate their income.

Using a novel approach, Morgan (2017) combined household survey data, income tax declarations, and the national accounts to more precisely estimate the income inequality in Brazil. His results show that over the past 15 years the income distribution in Brazil has remained stable and extremely unequal. The most recent data (the year 2015) indicates that the top 10% received more than 55% of the total Brazilian income, while the bottom 50% of the population received around 12%, and middle 40% received 30% of the total income. As a comparison, in France, these numbers are 33% for the top 10%, 45% for the middle 40%, and 22% for the bottom 50% (in 2014). As mentioned in section 2.2.1, this dissertation uses the household budget survey (POF) since it is the most appropriate and reliable dataset to link income and consumption at the household level. However, this kind of survey tends to underrepresent the income of higher income classes that more often under-declare their earnings, and more difficult to reach and participate in the survey.

As shown in Table **2.3**.**1**, although 58% of the Brazilian population lives at the bottom 50% of the households, they receive less than 20% of the total Brazilian income. Meanwhile, the top 10% of the household receive 38% of the total income and represents 7% of the population, the middle 40% receives 42% of the income and are home for 34% of the population. In 2009, the national average income per capita was about USD 8,420.00 (BRL 16,390.00), but for those families at the bottom 50% gained an average of USD 2519 (BRL 4,904.00). The average income of the middle 40% is USD 8,476.00, similar to the national average. In the same year, about 75% of the national population earned less than the national average which highlights the income skewness of the distribution and lack of a broad middle class. At the top 10%, households earned on average about USD 37,710.00 (BRL 73,429.00) which is four times the national average and more than 41 times the average income of the 10% lowest-income households.

From the years 2000 to 2015, the Brazilian population increased by 31 million inhabitants (18% increase), and it is projected to increase just 9% in the next 15 years (IBGE, 2013). In 2009, the total population was about 191 million people, and its distribution across the income groups are shown in Table **2.3**.**1**. Note that, although each income group represents 10% of the households, the population is not equally distributed across the income groups. This is explained by the differences in the number of people by household (household size). For instance, households in the lower-income group (G1) have on average 4.8 family members, while households in the most affluent group (G10) the half of this number. As a result, 40% of the lower-income households (G1 to G4) are home for 49% of the Brazilian population.

Table 2.3.1 – Income Groups Threshold, Median income, Income, and Population distribution across income deciles. *USD2007

Income Group	*Threshold* (Income/Cap/Day)*	*Annual Median* Income/Capita*	*Daily Median* Income/Capita*	*Shares In Total Income*	*Share In Total Population*
G1	0.0	912	2.5	1.8%	14%
G2	3.6	1,669	4.6	3.1%	13%
G3	5.7	2,380	6.5	4.0%	11%
G4	7.7	3,183	8.7	5.1%	11%
G5	10.0	4,062	11.1	5.7%	9%
G6	12.7	5,133	14.1	6.9%	9%
G7	16.0	6,581	18.0	8.6%	9%
G8	20.9	8,779	24.1	10.8%	8%
G9	28.7	12,852	35.2	16.0%	8%
G10	48.4	27,411	75.1	38.0%	7%
	1946.0				

The household can allocate its total income to expenditure or savings, depending on the income level and level of uncertainty. While savings are essential for future use, expenditures are related to short-term use crucial to enhance or maintain health, status, and well-being of the households. When households move upwards in the income ladder, a smaller portion of its income tends to be allocated to expenditure. This trend in the Brazilian economy is shown in Figure 2.3-4, the bottom 50% of the households spend from 71% (G5) to 109% (G1 spends more than its income[13]) of its income. In the middle 40%, this share falls to 65% (G9) and 69% (G6). The portion of savings deposited in banks contributes to investments. However, the emissions impact from capital investments are poorly understood (SUNG; SONG; PARK, 2018) and are not considered here. Thus, the shifts in the income allocation from expenditure to savings can contribute to the reduction of the emissions intensity (CO_2/$) of affluent households.

[13] According to Cohen (2005), households living beyond their earnings can mean that "part of their monthly expenses are either not covered in the same in which the consumption occurs or are covered by third parties, or are earnings that they do not know they have or can count on regularly."

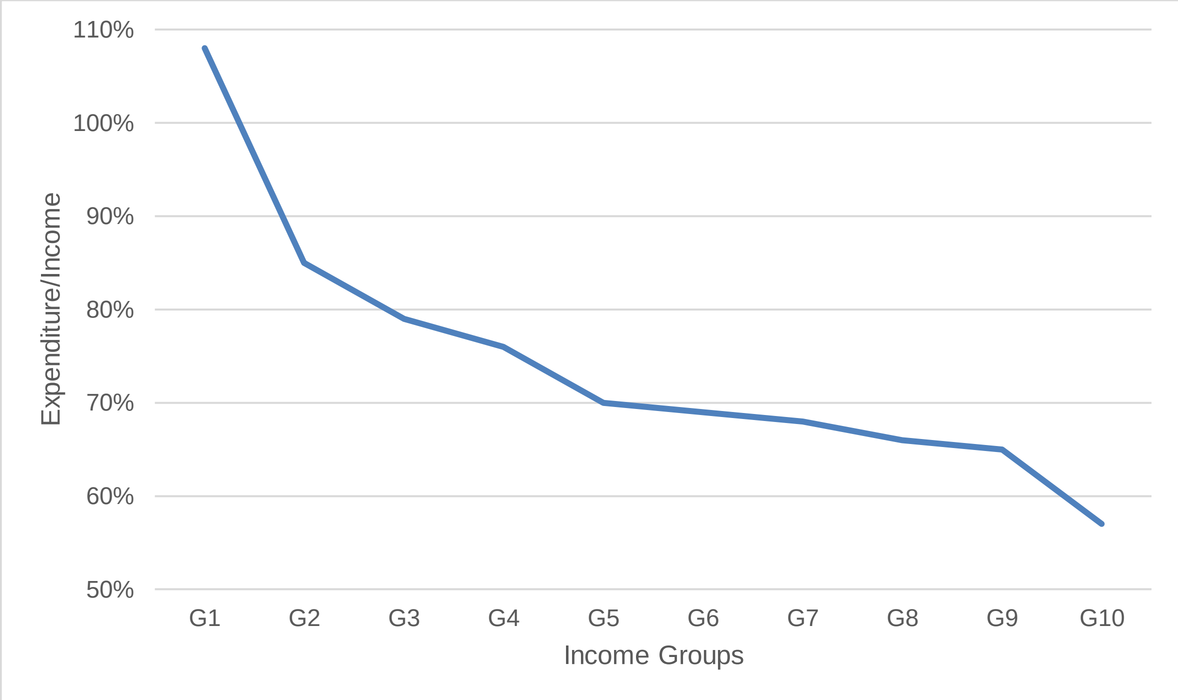


Figure 2.3-4 – Relationship between Expenditure and Income across income groups. More affluent groups tend to spend a lower share of its total earnings on goods and services.
Source: Prepared by the author based on POF 2008/2009

Both the volume of expenditure and the consumption structure change substantially as income increases. For instance, the bottom 50% of the households consume on average three times less than the middle 40% and 11 times less than the top 10%. Also, Figure **2.3-5** shows how each income group distributes their total expenditure into 11 consumption categories. On average, almost 90% of the expenditure correspond to five consumption categories: services (28%), goods (19%), food (13% on food, and 2% on beef), shelter (12% on direct energy in housing, and 3% on housing), and personal transport (13%).

Food is the main consumption category for half of the households with low income and loses its importance in higher income classes. On the opposite side of the income spectrum, food represents only 8% of the expenditure of the top 10%. Cohen et al. (2005) show very similar numbers regarding food in 11 Brazilian capital cities in 1996. Here, Beef is shown separated from food given its relevance in the household budget and to GHG emissions. In fact, within the food category, the share of expenses destined to beef is consistent across income classes, varying from 11% (G10) and 14% (G1).

Services is another consumption category with a wide variation across income groups, though in the opposite direction. While this category represents on average only 12% of the budget of households at the bottom 10% (G1), almost 40% of the top 10 % (G10) households are spent on services such private health, insurance, and education. Also, high-income groups employ significantly more money in mobility than low-income groups. Within this broad category, the shift from public to private transportation has a crucial impact on the household budget, direct energy consumption, and GHG emissions. The Top 20% of the households allocate more than 20% of its expenditure on private transport, including about 6% on fuels and 14% on automobile ownership.

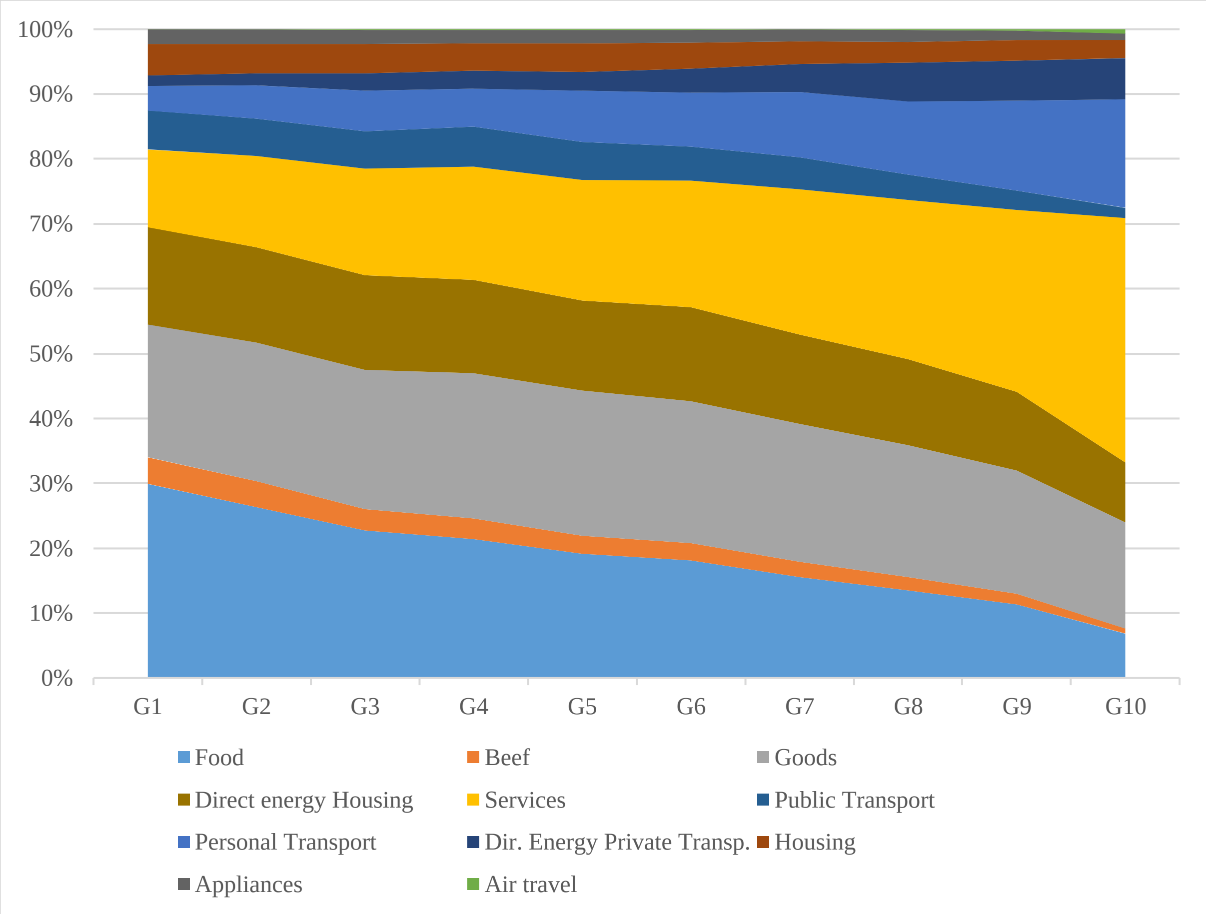


Figure 2.3-5 – Share of household expenditure employed in 11 consumption categories.
Source: Prepared by the author based on POF 2008/2009

To summarize, the severe Brazilian income inequality reflects on highly heterogeneous consumption patterns both regarding volume and composition. Regarding volume, the 10 % most affluent households consume, on average, 11 times more than the 50% poorest households. The allocation of these expenditures follows evident trends. Lower-income families tend to spend more than 30% of its income (and expenditure) on food-related items. However, as families get more affluent, this share on food decrease substantially and a higher portion of its expenditure is allocated to items in the services and private transportation categories.

2.3.3. Household GHG footprint across income groups

As mentioned in section 1, in 2007 Brazil was the seventh largest emitter regarding absolute emissions. However, the absolute GHG emission by country hides the number of people contributing to this number. Thus, this dissertation focuses on how individuals and families contribute to climate change. For instance, on a per capita basis, Brazil falls to the 88th position in the global emissions rank. While the average Brazilian resident emitted about 5.3[14]tCO_2e in 2007, the average Qatari emitted 68 tCO_2e, the Russian 15 tCO_2e, and the French 8 tCO_2e (JANSSENS-MAENHOUT *et al.*, 2017).

The results from this dissertation show that, in 2009, the total Brazilian household emissions was 514 $MtCO_2e$[15]. The Figure **2.3-6** shows that, in general, emissions increase as households climb the income ladder, yet the incremental jumps are more significant in the last four deciles especially from G9 to G10. While the difference in emissions between G1 and G2 are about 5 $MtCO_2e$, the total emissions from the top 10% (G10) are 66 $MtCO_2e$ higher than the previous income class (G9). In absolute terms, the top 10% households emit ten times more than the bottom 10%, and 5% more than all households in the bottom 50% (from G1 to G5). In other words, the consumption of the 10% most affluent households, 7% of the Brazilian population, induces 29% of the national household GHG footprint in 2009, which is 5% more than the emissions induced by bottom 50%, 59% of the population.

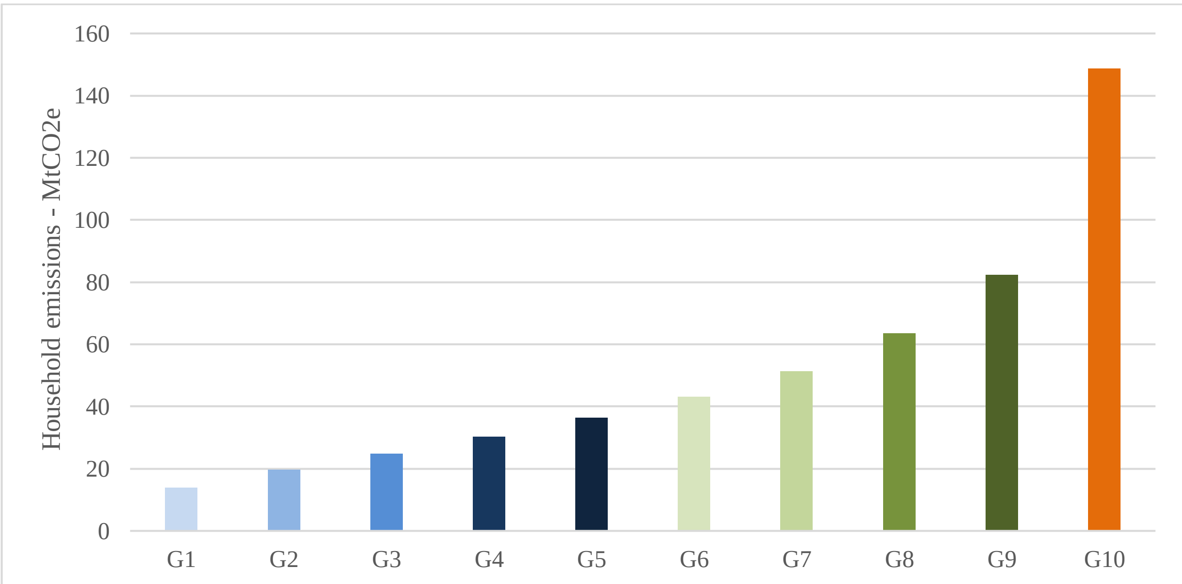


Figure 2.3-6 – Total household GHG emissions by income class in 2009
Source: Prepared by the author based on POF 2008/2009 and EXIOBAS

[14] This number does account to Land Use Change emissions.
[15] Accounts for agriculture and energy related emissions, as described in the methodology.

The average per capita emissions across income groups can help tell exciting stories of possible development challenges and pathways. One concerns the compatibility of reducing poverty and mitigate climate change. According to The World Bank (2018), the Brazilian headcount ratio of people living below the poverty line fell significantly from 9.7% in 2004 to 2.8% in 2014. However, since 2015 the Brazilian economic crisis has been deteriorating the macroeconomic conditions and shrinking the labor markets which drove more than 14.8 million people below the poverty line in 2017 (BÔAS, 2018; SKOUFIAS; NAKAMURA; GUKOVAS, 2017). As an exercise, if the average income of those 14.8 million people increases from the G1 to G2 level (USD 4.6 per capita/day), the annual total emissions would increase about 5 $MtCO_2e$ which represents less than 0.1% of the current total household. On the other extreme, the, also desirable, ascension of the same number of people from G9 to G10 would increase the total emissions by about 80 $MtCO_2e$.

As Figure **2.3-7** presents, when the population of each income class is considered the different contribution to emissions is even more evident. The results show that the average Brazilian household footprint is 2.7 tCO_2e/cap which, according to Wiedenhofer *et al.*, (2016) is almost three times smaller than the average carbon footprint from the countries in the European Union (6.7 tCO_2). However, while almost 70% of the population emit less this national average, the emissions level of the most affluent people is higher than the average Europeans and closer to the average Americans (10.4 tCO_2). The high income-inequality reflects on the emissions, once the average emission per capita is 1.1 tCO_2e for the bottom 50%, 3.7 tCO_2e for the middle 40%, and 10.8 tCO_2e for the 10% more affluent households. For instance, there is a gap of 10.3 tCO_2e between the average emission from a person in the bottom 10% and another at the top 10%.

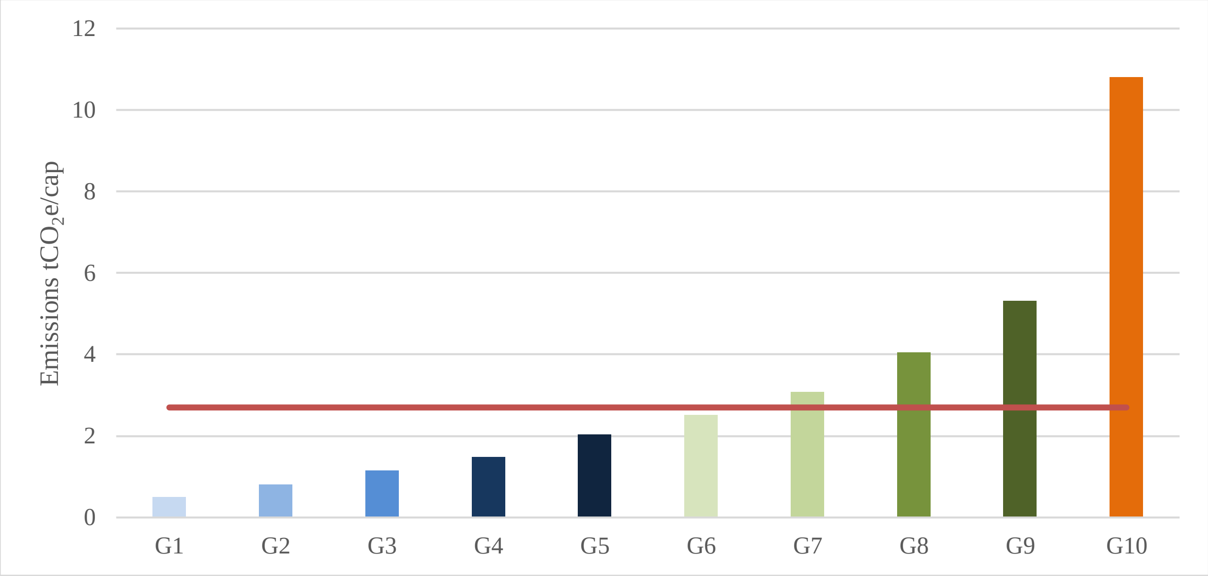


Figure 2.3-7 – Average GHG per capita footprints of Brazilian households in 2009. The red line is the average household GHG footprint (2.7 CO_2e/cap).
Source: Prepared by the author based on POF 2008/2009 and EXIOBASE

Breaking-down the emissions, the consumption from four major categories are drives about 90% of the total household carbon footprint: mobility (29%), shelter (26%), goods and appliances (22%), and food (14%). Private transportation plays a significant role in mobility emissions, being responsible for 79% of the emissions from this category. Inside the shelter category, the direct energy used in the household, used for lighting, cooking, heating, and cooling, accounts for 87% of the emissions of this category. As shown in Figure **2.3-8**, the relative importance of private transport, services, public transport, and food varies significantly across income groups. The shelter is the most relevant category for the households at bottom 50% contributing for 32% of their emissions, but its importance declines to 27% for middle 40%, and 19% at the top 10%. The food category follows a similar trend, representing 22% of the emissions of the households in the bottom 50% but just 8% for those at the top 10%. The emissions from private transportation and services have an opposite tendency. Brazil registers a very high elasticity of vehicle ownership, meaning that income gains have a substantial impact on the number of cars per households (DADUSH; ALI, 2012). For instance, the number of vehicles in the Brazilian streets more than doubled from 2000 to 2010, while the population increased by just 12.5%. The share of private transport on household emissions increases from 11% at the bottom 50%, to 23% in the middle 40% and 37% at the top 10%.

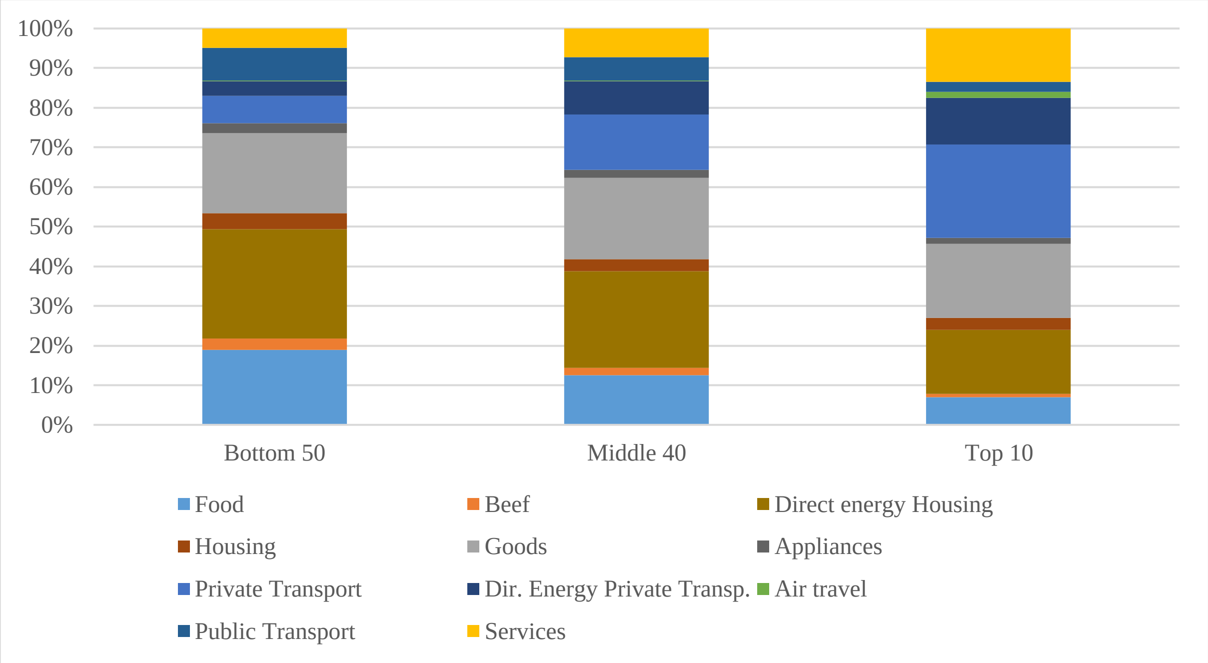


Figure 2.3-8 – Household emission structure in 2009
Source: Prepared by the author based on POF 2008/2009 and EXIOBASE

Due to its lower emission intensity, the services sector is responsible for only 8% of the average emissions even though it represents 28% of the expenditures. While each dollar spent on services emits on average 0.2 $kgCO_2e$, the impact of each dollar spent on food is on average almost three times higher (0.55 $kgCO_2e$/USD). The services category has a crucial role in reducing the overall emission intensity of higher income groups. Albeit affluent households allocate a higher share of is income on high-emission-intensity items such as private transport and air travel, the portion of money spend in services shrinks the overall emissions intensity of the bundles consumed by higher-income households. As shown in Figure **2.3-9**, the households at G10 consume a basket of goods and services that are on average 20% less emission intense than the one consumed by G1. The emission intensity per income group maintains similar the groups G1 to G6, but declines faster from G7 to G10 as a significant share of the expenditure shifts from food to services.

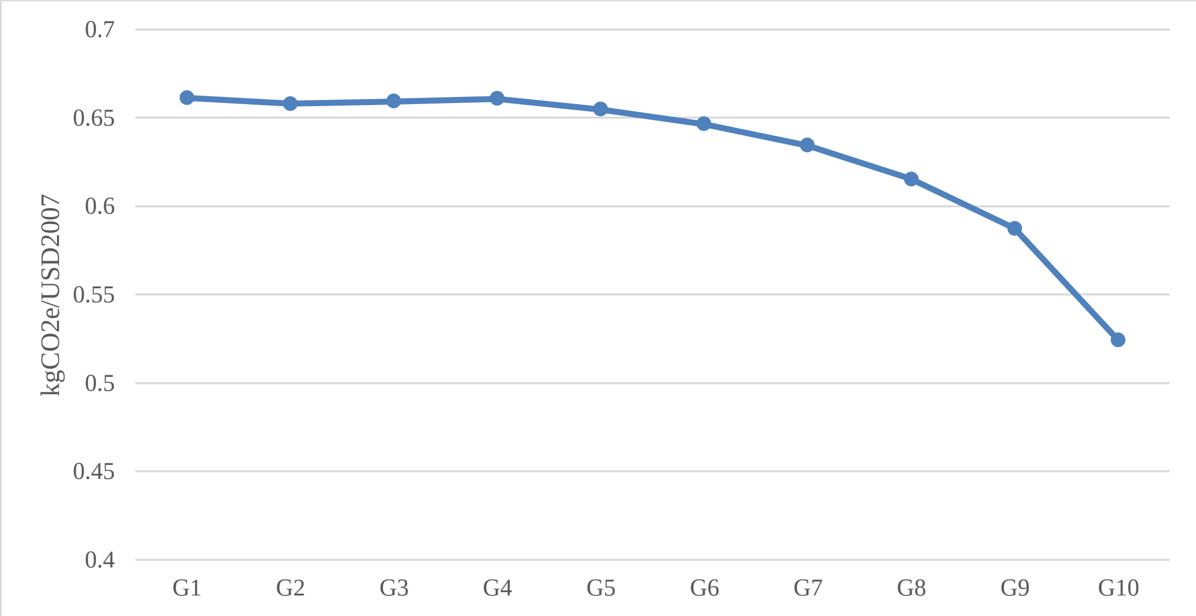


Figure 2.3-9– GHG emission intensity of household groups.
Source: Prepared by the author based on POF 2008/2009 and EXIOBASE

The demand for each consumption category and indirect emissions depends on the consumption behavior of each income group. Figure 2.3-10 presents the how each income group induces the emissions from each of the 11 consumption categories, and it becomes evident that the middle- and top-income classes are driving most of the emissions from air travel, private mobility, services, and goods. For instance, 95% of the total emissions from air travel, 89% for private mobility, 86% for services, 75% for goods are induced by the middle- and top-income groups, although they account for only 41% of the Brazilian population. The contribution of each income group to the emissions from food and beef category are more equal distribution than the other categories. This information is particularly relevant to design mitigation policies aiming to minimize the negative impacts on the low-income groups.

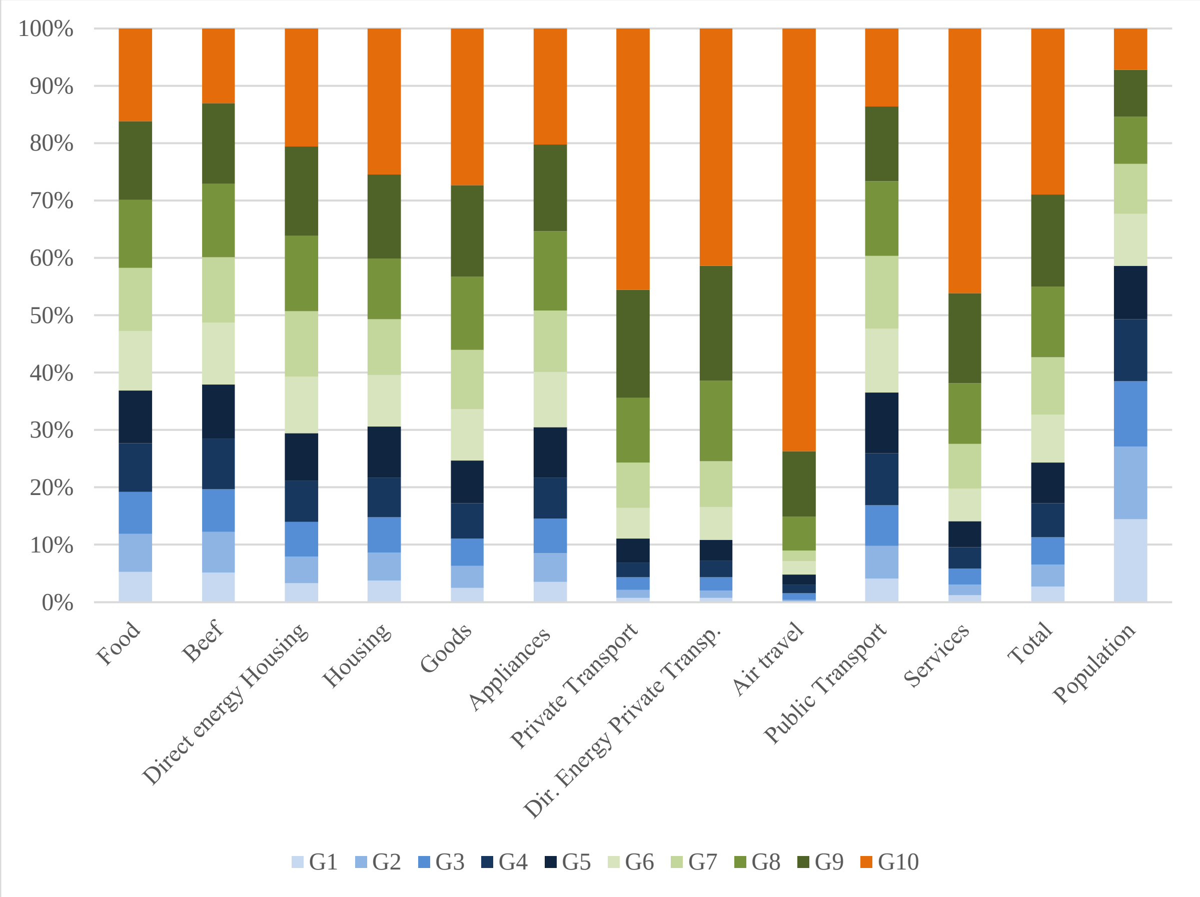


Figure 2.3-10 – The relative contribution of the income classes to the sectoral GHG emissions.
Source: Prepared by the author based on POF 2008/2009 and EXIOBASE

The Lorenz curve and Gini index are used to quantify the unequal contribution of the household groups to the total Brazilian household footprint. The Lorenz curve shows which proportion of the resource (in this case expenditure and emissions) is allocated to a particular share of the population (LORENZ, 1905). In the *x*-axis, the cumulative proportion of the population is ranked by income, and in the *y*-axis, the cumulative proportion is allocated for a given share of the population. In Figure **2.3-11**, the light blue line represents a situation where the resource is perfectly distributed also known as equidistribution line. As close to the equidistribution line the resource lines are less unequal distributed they are (BELLU; LIBERATI, 2005). The Gini index the ratio of the area that lies between the equidistribution line and the Lorenz curve, the value varies from 0 (perfect equality) to 1 (complete inequality). The results show that the total emission footprint is better distribution than the expenditure, with Gini indices of 0.47 and 0.50 respectively. Aligned the results from Figure 2.3-10, the emissions from food and shelter have the lowest Gini indices, 0.28 and 0.39. There is high inequality for the GHG footprint for services (0.63), mobility (0.59), and goods (0.45).

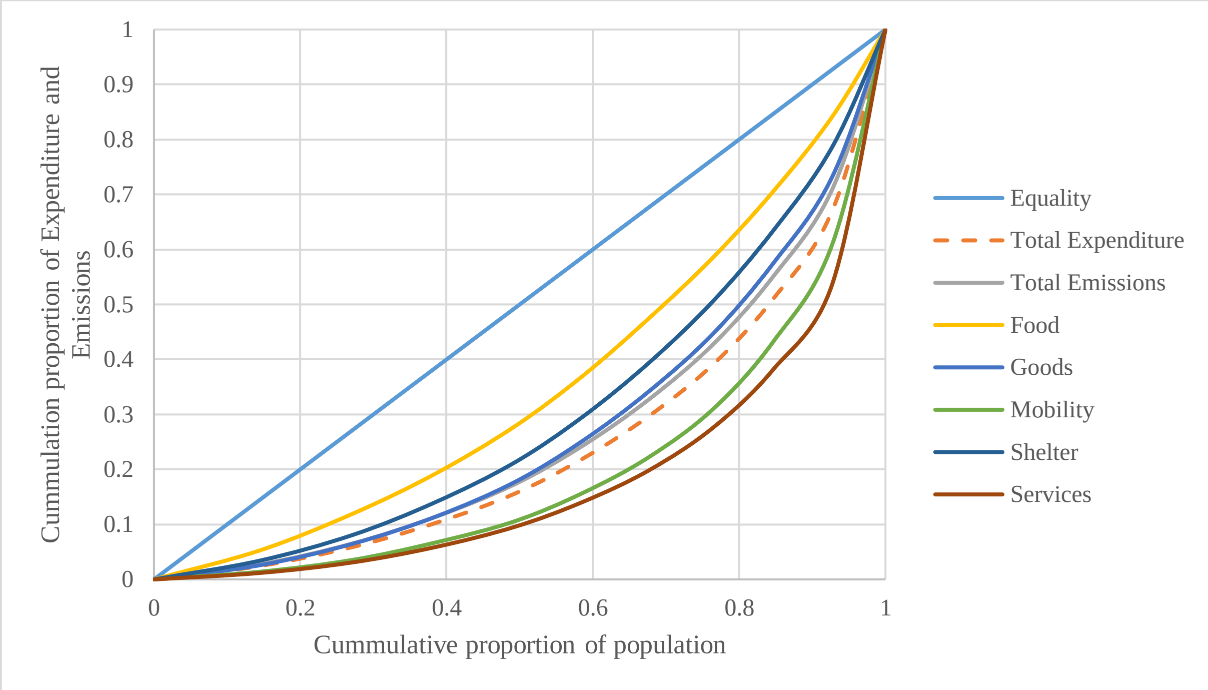


Figure 2.3-11 – Lorenz curve of the total expenditure, total emissions, and emissions per consumption category
Source: Prepared by the author based on POF 2008/2009 and EXIOBASE

In conclusion, although the total household carbon footprint (HCF) is better distributed than the total expenditure, the top 10 income group are responsible for more than 29% of the total HCF, which is 5% more emissions than the volume emitted by the bottom 50% of the families. On the one hand, the low emission per capita from the group G1 (0.5 CO_2e/cap) reinforces the argument that taking people from the poverty level will have a relatively small impact on the total HCF. On the other hand, transitioning from middle to affluent classes can double the emission per capita signalizing that mitigation policies should focus on these groups.

3. DISTRIBUTION AND EMISSION SCENARIOS

3.1. Literature Review: Inequality and Climate Change

In the context of climate change, inequality can be analyzed in four main perspectives: inequality regarding the risk to climate-related impacts, uneven influence in the policy-making process, policies that affect inequalities, and unequal contribution to climate change (CHANCEL; PIKETTY, 2015). Risks of climate-related impacts are unevenly distributed between and within countries. Worldwide, Honduras, Myanmar, and Haiti were the most affected countries by extreme events from 1995 to 2014, according to the long-term risk index (SÖNKE et al., 2015). In the United States, an increase of 1.5 °C in the global temperature is very likely to reduce its GDP by between –0.1% and 1.7%. However, the state of Florida is ten times more likely than Texas to have direct property damages from tropical cyclones and extratropical cyclones (HSIANG et al., 2017). The hazards, vulnerabilities, and exposure of human and nature systems depend on geographic, climate, culture, and socioeconomic characteristics such as population density, coastal areas, and hydrological systems (IPCC, 2014b).

Like other decision-making processes in society, climate policy-making can present critical participatory problems. Top-down policy-designing and governance have problems to include marginalized groups distorting the process by over-representing the interests of some socio groups with stronger lobby power and denying a voice to marginalized ones (FORSYTH, 2009). A more democratic policy-making process should allow the general public to participate in the early stages of the discussion, including a broad range of actors, and provide them sufficient information and evidence (WAN; SHEN; CHOI, 2017). For instance, in Brazil, hydropower represents about 70% of the electricity generation, which contributes to the overall low carbon intensity in the electricity matrix of 70 tCO_2e/GWh (CLIMATE OBSERVATORY, 2016). However, the riverside communities, directly affected by the construction of large hydroelectric power plants, are often excluded or underrepresented in the decision-making process (BERMAN, 2007).

Although the primary objective of a mitigation policy is the reduction of GHG emissions, its policy-design process must avoid undesirable adverse distributional effects. Policies that change prices (direct and indirectly) have proportionally different impacts across income groups. For instance, carbon taxes and other policies that increase energy prices can have a regressive effect, with the poor paying proportionally more. Additionally, the impacts of a carbon tax would be disproportionally higher for low-income families that rely on traditional and less efficient fuels like firewood, charcoal, and coal (CAMERON et al., 2016; GOLDEMBERG; JOHANSSON, 1995). Conversely, the tax revenues can be recycled through money transfers to low-income families to balance the policy's impacts. These revenues can also be used through energy efficiency policies which would balance the prices impacts by reducing the energy consumption. As an example, Magalhães and Domingues (2014) show that the implementation of energy efficiency policies in the Brazilian economy decreases the energy prices which bring proportionally more benefits to low-income families.

This dissertation focuses on the fourth type of inequalities, namely the unequal contribution to GHG emissions. On the global level, the current significant numbers can give the false impression that the emissions are reasonably distributed since the countries[16] that are home to almost 70% of the global population are also responsible for about 70% of the emissions. However, the territories of the United States and the European Union that only account for 10% of global population are responsible for more than 20% of the global emissions (GE; FRIEDRICH; DAMASSA, 2014). On the other extreme is India with the 1.2 billion inhabitants (17% of the global population) but are responsible for less than 5% of the global emissions (Figure **3.1-1**). The recent data from the Climate Watch (2018) shows that in 2014, China was larger emitter responsible for the emission of 12 $GtCO_2e$, followed by the United States (6.3 $GtCO_2e$), the European Union (3.6 $GtCO_2e$), India (3.2 $GtCO_2e$), Indonesia (2.5 $GtCO_2e$), Russia (2.0 $GtCO_2e$), and Brazil (1.4 $GtCO_2e$).

[16] In this rank, the European Union is considered as single territory.

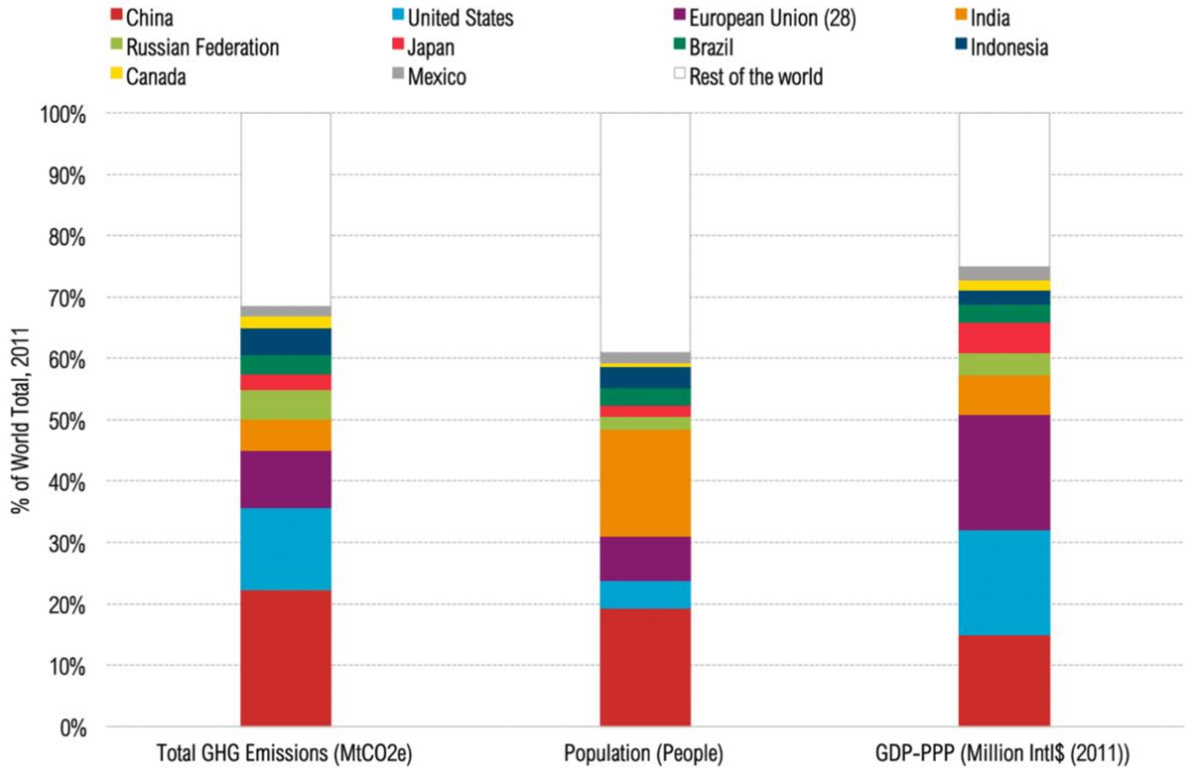


Figure 3.1-1 - Total GHG emissions, Population, and GDP from the Top 10 emitters in 2011.
Source: Ge; Friedrich; Damassa (2014)

Many authors are concerned about the compatibility of building a more egalitarian society and mitigate climate change (BAEK; GWEISAH, 2013; BERTHE; ELIE, 2015; CHANG; CHANG, 2016; GOLLEY; MENG, 2012; GRUNEWALD *et al.*, 2017; ISAKSEN; NARBEL, 2017; WIEDENHOFER *et al.*, 2016a; WOLDE-RUFAEL; IDOWU, 2017). Inequality could influence the total emissions in two main ways: by affecting economic growth, and affecting emissions intensity (emission per dollar spent). Firstly, whether inequality is good or bad for economic growth still an open question, with the empirical results pointing to ambiguous directions (BANERJEE; DUFLO, 2000). Additionally, the causal relationship between economic growth, energy consumption and carbon emissions is unclear (ACHEAMPONG, 2018; LENZEN, M *et al.*, 2006)

The second issue is whether the emissions intensity increases with income (elasticity greater than one) or decreases (elasticity less than one). Most of the literature presents that the household expenditure elasticity of emissions range from 0.6 to 1, indicating that the emission intensity of consumption decreases with growth in income (ALA-MANTILA; HEINONEN; JUNNILA, 2014; LENZEN, M *et al.*, 2006; MIKAYILOV; GALEOTTI; HASANOV, 2018; RAO, NARASIMHA D.; MIN, 2018). However, Cohen et al. (2005) observed an expenditure elasticity of energy larger than 1 for the Brazilian economy in 1996. These results indicate that, in most of the cases, the “income growth that occurs more in lower income households (or countries) would cause higher emissions than if that same growth occurred among higher income groups” (RAO, NARASIMHA D.; MIN, 2018). Furthermore, Rao&Min (2018) show that the scientific community should not be distracted by this problem given “enormous” social benefits of reducing inequality and the potential small increase in total emissions associated with it.

Despite still being among the most unequal countries in the world, most estimations show that Brazil has made progress in the past three decades due to improvement in the labor market, increases in the minimum wage, and growing coverage in the social assistance programs (FACUNDO *et al.*, 2017). The World Bank (2016) estimates that the Gini index for Brazil decreased from 0.605 in 1990 to 0.513 in 2015.

During the first fitting years of 21st century, the Brazilian household income increased on average 18%. However, this increment was more noticeable for the bottom 50% which witnessed a 21% increase in the average income, followed by 10% for the Top 10%, and 8% for the Middle 40% (MORGAN, 2017). This had a significant impact on both consumption levels, and consumption structure since more affluent individuals tend to prefer baskets with more goods and services, and more diversified baskets (PINDYCK; RUBINFELD, 2013). Since there are energy and carbon embedded in every good and service consumed by the households, the changes in consumer patterns alter not only the total carbon footprint but also the carbon intensity of the economy (HERENDEEN, ROBERT A.; FORD; HANNON, 1981; KERKHOF; BENDERS; MOLL, 2009).

From 2001 to 2015, the policies of revalorization of the minimum wage and money transfer policies had a substantial impact of 18% on the average income from the Bottom 50% (in real terms). During this period, the minimum wage increased more than 60% in real terms benefiting the surging formal labor, and the portion of the population relying on pensions and specific social programs (BRITO; FOGUEL; KERSTENETZKY, 2017). In the same period, the income inequality within the top 10% also grew, the average income of the top 1% increased 31%, the income of the top 0.001% richer families grew 121% (MORGAN, 2017). As shown in Figure **3.1-2**, the shape of income distribution is very similar among the emerging countries, while the differences in distribution between Western Europe and the US offers realities for a developed country.

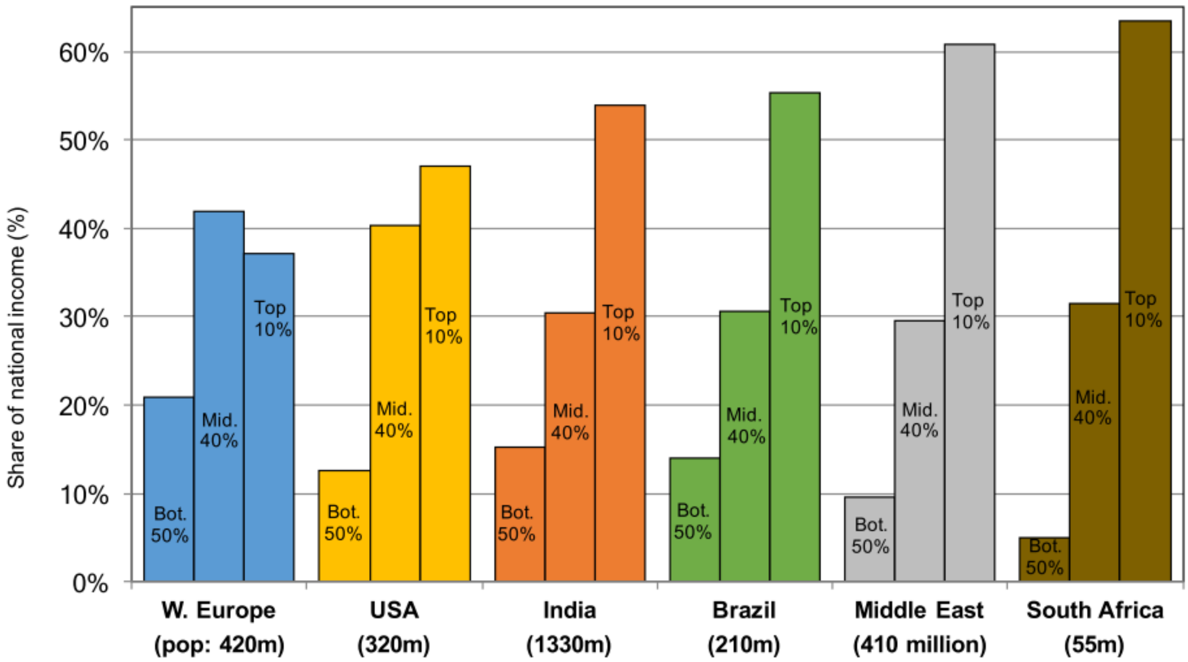


Figure 3.1-2 – Income share across the world: Bottom 50%, Middle 40%, and Top 10%.
Source: Assouad; Chancel; Morgan (2018)

At the twenty-first session of the Conference of the Parties (COP21), representatives of the 196 parties approved the Paris Agreement, which has the objective to "strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty." Facing the increased likelihood of future impacts on natural and human systems caused by climate change, the representatives agreed to hold the increase in the global average temperature to below 2°C. Hence, substantial anthropogenic emissions reductions would be required in the next decades, presenting many mitigation challenges (UNFCCC, 2015b).

The focus of climate change mitigation studies has been on supply-side solutions such as transitioning from fossil fuels to renewable and nuclear power, and most of them rely on negative emission technologies. However, negative emission technologies remain uncertain and could be insufficient to limit global temperatures below 2°C (CREUTZIG *et al.*, 2016). Thus, demand-side mitigation solutions could offer another range of possibilities to help to achieve the Paris goal.

In a developing country like Brazil, there is still a large room for income growth and distributional improvements. The design of social and distributional policies needs to understand the links between income level, individual consumer behavior, and GHG emissions (GROTTERA, CAROLINA *et al.*, 2018; WIEDENHOFER *et al.*, 2016a).

This dissertation aims to contribute to the literature by investigating how changes in the income distribution in the Brazilian society can impact the GHG emissions, and identifying the impact of different the consumption behavior on the household GHG emissions.

3.2. Methods for Building Scenarios of Income Inequality and Household Carbon Footprint

3.2.1. Scenario building

The scenarios of the household carbon footprint were built combining the economic and demographic projections from the Shared Socioeconomic Pathways (SSPs), the consumption and emissions structure from the Survey-EE-MRIO results, and the Kaya Identity. Proposed by the economist Yoichi Kaya, the Kaya identity has been used to understand the most critical drives of global anthropogenic emissions, and, in the IPCC reports, it plays a vital role in developing future emissions scenarios (IPCC, 2007). As shown below, this identity expresses the total global human-related emissions as a product of human population, economic activity, energy intensity, and carbon intensity.

Total emissions = population × affluence per capita (GDP/population) × energy used per unit affluence (energy/GDP) × emissions per unit energy used (emissions/energy)

This classic formulation of Kaya identity presents some key limitations. By definition, it assumes unit elasticity, meaning that a percentage change in one of the elements of the right side of the equation produces an equal impact on the emissions (ROSA; DIETZ, 2012). However, most of the studies have shown that the household expenditure elasticity of energy requirements and emissions ranges from 0.6 to 1.0 (ALA-MANTILA; HEINONEN; JUNNILA, 2014; RAO, NARASIMHA D.; MIN, 2018). On the other hand, the impacts of population growth are usually more than proportional (ROSA; DIETZ, 2012). To tackle these issues this dissertation increases de resolution of the model by discriminating the consumption structure in ten income classes, and the emission intensities of 11 consumption items (equation 2.7).

To attribute emissions for each income class, the concept can be modified as follows:

$$\boldsymbol{E_i = P_i * \sum_{j=1}^{11} X_{ij} * D_j} \qquad (2.7)$$

Where $\boldsymbol{E_i}$ is the total GHG emissions of the income group $\boldsymbol{i}$, $\boldsymbol{P}$ is the portion of the population at the income group $\boldsymbol{i}$. $\boldsymbol{X}$ is the average expenditure per capita of a person in income group ***i,*** which is composed of the expenditure in each of 11 consumption items $\boldsymbol{j}$. $\boldsymbol{D}$ is a vector of emission intensity (CO_2e per dollar spent) for each consumption item $\boldsymbol{j}$. There are ten income groups $\boldsymbol{i}$ ranging from G1 (lowest) to G10 (highest), and their income threshold are constant across the scenarios (Table **2.3.1**). Therefore, the number of households within each income group changes according to the income distributions. The total Brazilian population and GDP are calculated for each scenario based on SSPs results (IIASA, 2016), while the future income distributions are imputed using the Gini values from France in 2015 (THE WORLD BANK, 2018b).

Since the objective of this work is to measure the impact of changes income distribution on the household GHG emissions, the following scenarios assume constant: the production structure, the average consumption level per income group, and the consumption structure of each income group estimated in the previous chapter. The emission intensity **D** of each consumption item depends on the emissions occurred through the production process (indirect emissions), and the emissions related to the use of this item by the consumer (direct emissions) and are explained in section 2.2.2.

The Share Socioeconomic Pathways (SSPs) is a "new set of alternative pathways of future societal development" that drives global climate change challenges, such as mitigation and adaptation (O'NEILL *et al.*, 2017). The SSPs provides five primary qualitative narratives named: SSP 1- Sustainability – Taking the green road, SSP2 – Middle of the road, SSP3 – Regional rivalry – A rocky road, SSP4 – Inequality – A road divided, and SSP5 – Fossil-fueled development – Taking the highway. The SSPs were chosen in for this dissertation due to its broad use, flexibility and extensive documentation (BAUER *et al.*, 2016; MOSS *et al.*, 2010; O'NEILL *et al.*, 2014, 2017; RIAHI *et al.*, 2017).

These scenarios are plausible alternative future trends, which consider changes in crucial socioeconomic development and sustainability elements, such as demographics, human development, economy and lifestyle, policies and institutions (excluding climate policies), technology, and environment and natural resources (O'NEILL *et al.*, 2017). The tablesTable 3.2.1 Table **3.2.2** summarize the qualitative description of the critical elements across the five scenarios. Given the scope of this dissertation, the scenario selection process focuses on the SSPs that presents narratives with extremes within countries inequalities. Considering this criterion, the SSP1 and SSP4 were selected, given that the first portrays a reduced within income distribution, while the last presents a high cross- and within-country inequality.

Table 3.2.1 – Assumptions regarding demographic and human development elements of SSPs. Country groupings referred to in table entries for human development are based on the World Bank definition of low-income (LIC), medium-income (MIC) and high-income (HIC) countries.
Source:(O'NEILL et al., 2017)

SSP element	SSP1			SSP2			SSP3			SSP4			SSP5		
	Country fertility groupings for demographic elements														
	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD
Demographics															
Population															
Growth	Relatively low			Medium			High		Low	Relatively high		Low	Relatively low		
Fertility	Low	Low	Med	Medium			High	High	Low	High	Low	Low	Low	Low	High
Mortality	Low			Medium			High			High	Med	Med	Low		
Migration	Medium			Medium						Medium			High		
Urbanization															
Level	High			Medium			Low			High	High	Med	High		
Type	Well managed			Continuation of historical patterns			Poorly managed			Mixed across and within cities			Better mgmt. over time, some sprawl		
Human development															
Education	High			Medium			Low			V.low/uneq.	Low/uneq.	Med/uneq.	High		
Health investments	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High		
Access to health facilities, water, sanitation	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High		
Gender equality	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High		
Equity	High			Medium			Low			Medium			High		
Social cohesion	High			Medium			Low			Low, stratified			High		
Societal participation	High			Medium			Low			Low			High		

Table 3.2.2 - Assumptions regarding Economy & Lifestyle and Policies & Institutions elements of SSPs. Country groupings referred to in table entries are based on the World Bank.
Source:(O'NEILL et al., 2017)

SSP element	SSP1	SSP2	SSP3	SSP4	SSP5
Economy & lifestyle					
Growth (per capita)	High in LICs, MICs; medium in HICs	Medium, uneven	Slow	Low in LICs, medium in other countries	High
Inequality	Reduced across and within countries	Uneven moderate reductions across and within countries	High, especially across countries	High, especially within countries	Strongly reduced, especially across countries
International trade	Moderate	Moderate	Strongly constrained	Moderate	High, with regional specialization in production
Globalization	Connected markets, regional production	Semi-open globalized economy	De-globalizing, regional security	Globally connected elites	Strongly globalized, increasingly connected
Consumption & Diet	Low growth in material consumption, low-meat diets, first in HICs	Material-intensive consumption, medium meat consumption	Material-intensive consumption	Elites: high consumption lifestyles; Rest: low consumption, low mobility	Materialism, status consumption, tourism, mobility, meat-rich diets
Policies & institutions					
International Cooperation	Effective	Relatively weak	Weak, uneven	Effective for globally connected economy, not for vulnerable populations	Effective in pursuit of development goals, more limited for envt. goals
Environmental Policy	Improved management of local and global issues; tighter regulation of pollutants	Concern for local pollutants but only moderate success in implementation	Low priority for environmental issues	Focus on local environment in MICs, HICs; little attention to vulnerable areas or global issues	Focus on local environment with obvious benefits to well-being, little concern with global problems
Policy orientation	Toward sustainable development	Weak focus on sustainability	Oriented toward security	Toward the benefit of the political and business elite	Toward development, free markets, human capital
Institutions	Effective at national and international levels	Uneven, modest effectiveness	Weak global institutions/ natl. govts. dominate societal decision-making	Effective for political and business elite, not for rest of society	Increasingly effective, oriented toward fostering competitive markets

Rao *et al.* (2018) estimated the quantitative projections of population, GDP and within country income distribution under the five SSPs. Based on this study' result for Brazil, two steps were taken to select the results used in this dissertation. Firstly, to identify those with the most extremes income distributions. Table **3.2.3** summarizes the projections of population, GDP and Gini for Brazil in 2030 under seven scenarios, five estimated by Rao *et al.* (2018) and two built by the author. The SSP4 presented the more substantial inequality with a Gini index of 55.1. The SSP1 and SSP5 were both good candidates for low inequality scenarios with the same Gini Index of 50.2. In the second step, the SSP1 was selected because it has the lowest variation in projected population and GDP when compared with SSP4. In order to amplify the impacts of income distribution on the household emissions, another scenario was added with sharp improvements in the distribution. The SSP1-F maintains the narratives, projections for population, and GDP from SSP1, but assumes that the Brazilian economy will have in 2030 the same Gini coefficient as France in 2015. France is among the top 30 countries with regarding income distribution, and its household consumption and footprint were extensively compared with Brazil in the context of the ECOPA project (*Evolution of consumption patterns, economic convergence and carbon footprint of development. A comparison Brazil – France*)[17]. The results of this project are well documented in a series of publications (COELHO *et al.*, 2014, 2015; GROTTERA, C. *et al.*, 2018; SANCHES-PEREIRA; TUDESCHINI; COELHO, 2016; TEIXEIRA COELHO *et al.*, [S.d.]; TUDESCHINI, 2016). The SSP41 have the same income distribution as SSP4 but assumes population and GDP growth rates of SSP1. This last scenario serves to isolate the impact of the income distribution on the household's footprints.

Table 3.2.3 -Projected values of the Brazilian population, GDP, and Gini Index of SSPs.
Source: (RAO, N D *et al.*, 2018)

Scenarios	*Population – 2030 (million)*	*GDP 2030 (BI US$2005/YR)*	*Gini index - 2030*
SSP1	216	3,996	**50.2**
SSP1-F	216	3,996	**32.7**
SSP2	222	3,776	52.0
SSP3	230	3,616	53.5
SSP4	217	3,693	**55.1**
SSP41	216	3,996	**55.1**
SSP5	215	4,239	50.2

[17] Binational Project funded by the French National Research Agency (ANR) and São Paulo Research Foundation (FAPESP).

In the SSP1, the sustainability scenario, the world is making relatively good progress towards sustainable development, achieving the development goals, increasing income distribution between and within countries with rapid economic growth in low-income countries and sharp reductions on the number of people below the poverty line (IIASA, 2012; O'NEILL *et al.*, 2014). Conversely, as described by O'Neill *et al.* (2017), the SSP4, is a world with "*highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries*." The narratives and quantitative projections of these two scenarios are better explained and contextualized to the Brazilian society in section 3.3.1.

To model the income distribution for the scenarios was assumed a lognormal density distribution with the standard deviation deriving from the Gini Coefficient. This distribution form has properties that simplify the estimation, for instance, the inequality, the Lorenz curve, and the Gini coefficient depends on a single parameter (LUBRANO, 2017). However, the lognormal distribution is usually more convenient for modeling small and median range income, underrepresenting affluent groups. This bias needs to be tackled in future studies by combining other distribution for such as the Pareto distribution as recommend in Lubrano (2017).

Ten income classes are determined by fixed income thresholds presented in Table 3.2.4. Here, larger groups that aggregate the income groups are used to facilitate the analysis. The large group B50 aggregate the income groups from G1 to G5, with the income per capita varying from $0 to $12.7/day. M40 combine groups from G6 to G9, with income per capita ranging from $12.8 to $48.4/day. T10 is the equivalent of the income group G10 and contain households with income per capita higher than $48.5. It is important to note that, while the income thresholds (which defines the groups) are constant, the number of people in each income group changes under the different distribution and GDP scenarios. These distribution changes under the chosen scenarios are shown in figures 3.3.1Figure 3.3-2Figure 3.3-3Figure 3.3-4.

Table 3.2.4 –Income Thresholds of the household groups (USD2007/cap/day)
Source: Calculated by the author based on POF2008/2008

Large Groups	Income Groups	Income Threshold
B50	G1	3.6
	G2	5.7
	G3	7.7
	G4	10.0
	G5	12.7
M40	G6	16.0
	G7	21.0
	G8	28.7
	G9	48.4
T10	G10	1946.0

Although the income level and distribution changes across scenarios, the consumption composition (X_{ij}) is assumed the same, for example, the share of income that a person in G1 spends in Food is maintained across time in all scenarios. This consumption structure by income group is based on the 2009 survey and is shown in Table **2.3.1**. To isolate the effects of changes in income distribution, the industrial structure, and energy matrix are also assumed constant, which means that components of D (emission coefficients) are constant.

However, it is important to note that the results are sensitive to changes in the emissions intensity of the energy sector. Over the past 25 years, the emissions intensity from this sector decreased from 1.86 $kgCO_2e$/toe in 1991 to 1.57 $kgCO_2e$/toe in 2015 (EPE, 2016; FERREIRA *et al.*, 2018). For the year 2025, the Brazilian government projects an expansion on the share of renewables in the energy matrix, reducing its emission intensity to 1.36 $kgCO_2e$/toe (MME/EPE, 2017). Further research could explore the impacts these projected changes on the total household carbon footprint.

3.3. Results: Population and Emissions Under Inequality Scenarios

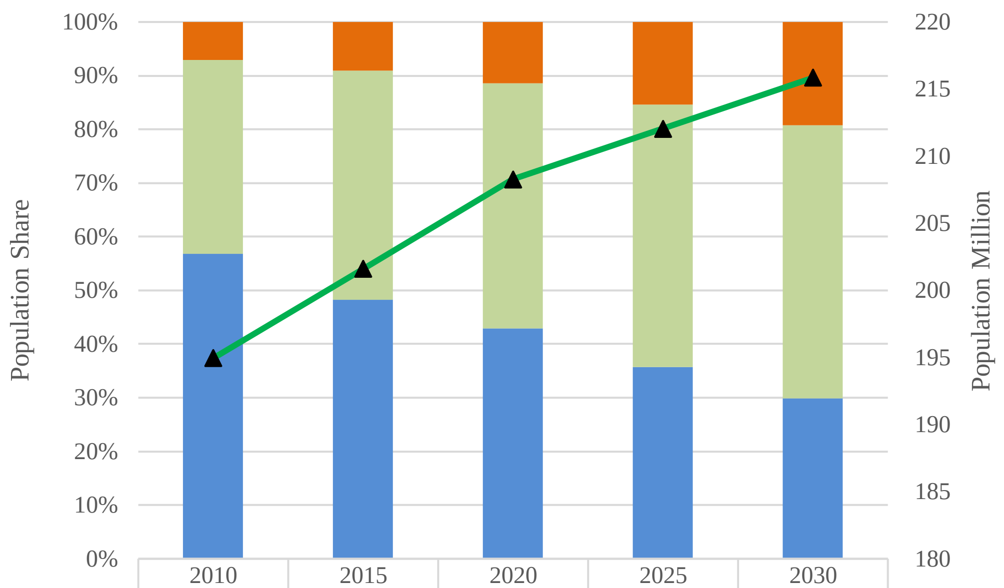
3.3.1. Windows to the future: Population and Inequality

This section describes the narratives and resulting projections of population and economic growth of the four scenarios chosen: SPP1 - *Sustainability Scenario, SSP1-F – Sustainability (Gini France)*, and SPP4 - *Inequality Scenario*. As mentioned before, the narratives, GDP and population from SSP1-F, are the same as SSP1. Note that the SSPs presents storylines of distinct roads built to reach different future outcomes (desirable or not). In this dissertation, the SSPs narratives are used to picture the socioeconomic frameworks that would conduct the Brazilian society to contrasting inequality levels. Additionally, the analysis of household emissions from 2010 to 2030 adopt the corresponding projections of the population, and GDP estimated by Dellink *et al.*, 2017; KC&Lutz, 2017.

3.3.1.1. SSP 1- Sustainability – Taking the green roads

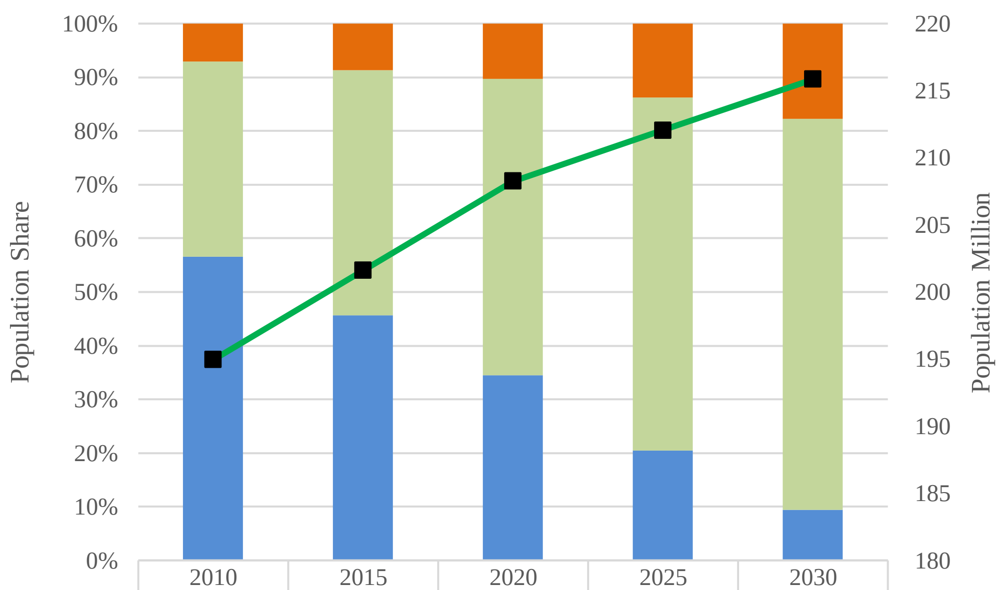
The SSP1 scenario portrays a gradual societal "shift toward a more sustainable path" focusing on inclusive development and respecting the environmental limits. The fundamental concern of global society is to achieve the development goals, which conduct the developed countries to support green growth strategies for developing countries, including financial, technological and human development supports. Thus, income is assumed to converge fast between countries and be better distributed within countries (CRESPO CUARESMA, 2017). Substantial investments in education reduce the fertility rate and, consequently, the population grow relatively less in this scenario. (O'NEILL *et al.*, 2017).

In the SSP1, the Brazilian economy grows from US$ 1,968 bi in 2010 to US$ 3,996 bi in 2030, resulting in an average growth rate of 5% per year. According to The World Bank (2018), before the recent economic crisis, the Brazilian economy was growing 4% per year (from 1994 to 2014). However, due to the economic and political crisis, the Brazilian economy shrank by about 6% in three years (2014-2017). This means that in the SSP1 would need to get back on track fast and develop a steady growing economy. Under this scenario, the population growth rate would decelerate from 1.25% a year, registered from 1997 to 2017, to 0.536% per year. Thus the total Brazilian population is projected to reach 216 mi in 2030, which is 4% smaller the official government projections (225 mi) (IBGE, 2018). As shown in Table **3.3.1** and 5, the Gini index reduces from 53.3 in 2010 to 50.2 in 2030, similar to today's Gini of Panama (50.8). As results of these changes in distribution, the share of the population living at the middle (M40) and at the highest income group (G10) increase, from 36% to 51% for the middle 40%, and from 7% to 19% the top 10%, while it reduces from 57% to 30% for the five lowest income groups (B50), from 2010 to 2030 (Figure **3.3-1**).



	2010	2015	2020	2025	2030
T10	7%	9%	11%	15%	19%
M40	36%	43%	46%	49%	51%
B50	57%	48%	43%	36%	30%
Total	194.95	201.60	208.26	212.05	215.84

Figure 3.3-1 – SSP1- Total population (green line) and its distribution across income classes (bars): T10 (G10), M40 (G6 – G9), and B50 (G1 – G5)



	2010	2015	2020	2025	2030
T10	7%	9%	10%	14%	18%
M40	36%	46%	55%	66%	73%
B50	57%	46%	34%	20%	9%
Total	194.95	201.60	208.26	212.05	215.84

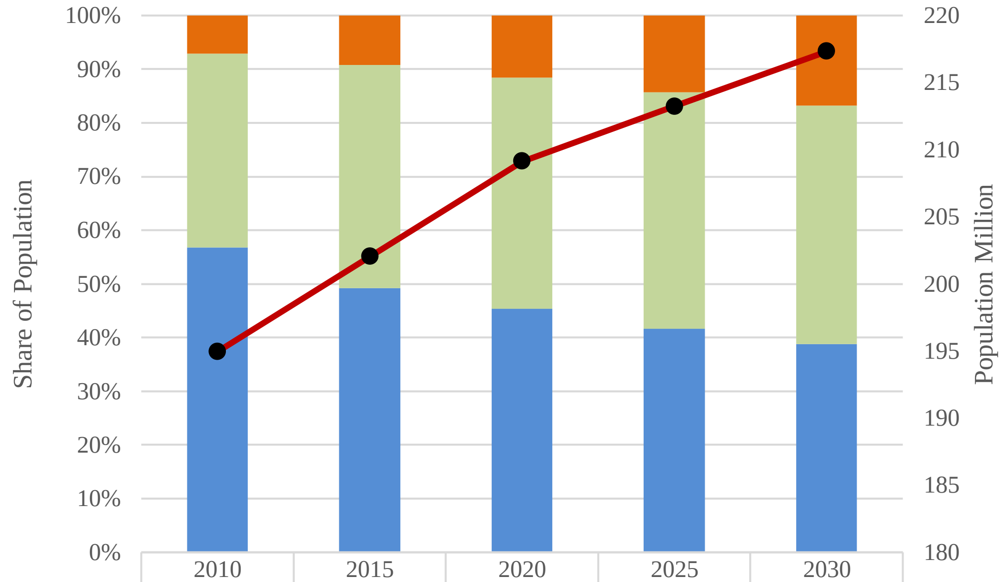
Figure 3.3-2 – SSP1-F - Total population (green line) and its distribution across income classes (bars): T10 (G10), M40 (G6 – G9), and B50 (G1 – G5)

Under SSP1-F, the Gini index reduces sharply from 53.3 in 2010 to 32.7 in 2030. This represents the average reduction of 10 points per decade, which is close to the reduction rate experienced in China since 1980 (7 points per decade) but unprecedented (RAO, NARASIMHA D.; MIN, 2018). As shown in Figure **3.3-2**, there is a drastic ascension of the population from the B50 to the middle (M40) and upper (T10) groups. The population share is living at the bottom 50% shrinks from 57% in 2010 to 9% in 2030, while the increases in the middle 40% from 36% in 2010 to 73% in 2030. Here the population living below the poverty line (US$2/day) drops to nearly zero, the population with less than US$10/day represents less than 2%. The percentage of the population that lives in the top 10% more than doubles from 7% to 18% (Figure **3.3-2**).

3.3.1.2. SSP4 – Inequality – Divided Roads

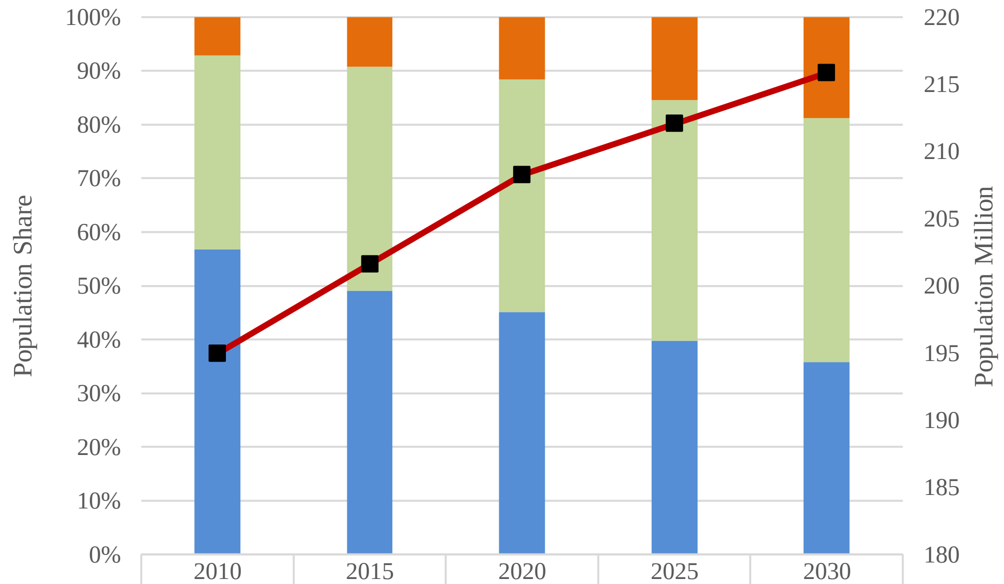
The SSP4 scenario assumes *"highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries"*(O'NEILL *et al.*, 2017). The industrialized and middle-income countries (as Brazil) are expected to have moderate economic growth with medium-pace convergence between countries. The stratification increases between countries and groups with high educational levels and poorly educated that only have access to the low-skill labor market. As a consequence, the fertility rates continue high in today's high fertility regions and continue low in regions with low fertility regions today (KC; LUTZ, 2017b).

Under the SSP4, the Brazilian economy is expected to from US$1,968 in 2010 to US$3,694 in 2030, corresponding in an average growth rate of 4.4% a year. This rate is closer to the pre-2014 crisis, but more than the double when considering the past three years. The population grew on average 0.57% a year, going from 195 mi inhabitants in 2010 to 217 mi in 2030. The inequality increases from 53.3 in 2010 to 0.551 in 2030. As a result, in 2030, 39% of the population lives in the bottom 50% income groups, 44% in the middle 40%, and 17% lives at top 10% (Figure **3.3-3**).



	2010	2015	2020	2025	2030
T10	7%	9%	12%	14%	17%
M40	36%	42%	43%	44%	44%
B50	57%	49%	45%	42%	39%
Total	194.946	202.033	209.12	213.217	217.314

Figure 3.3-3 – SSP4 - Total population (red line) and its distribution across income classes (bars): T10 (G10), M40 (G6 – G9), and B50 (G1 – G5)



	2010	2015	2020	2025	2030
T10	7%	9%	12%	15%	19%
M40	36%	42%	43%	45%	45%
B50	57%	49%	45%	40%	36%
Total	195	202	208	212	216

Figure 3.3-4 – SSP41- Total population (red line) and its distribution across income classes (bars): T10 (G10), M40 (G6 – G9), and B50 (G1 – G5)

The SSP41 illustrates a future where the economy and population grows at the same pace as the SSP1 but without the changes that lead to more income distribution (Figure **3.3**-**4**). As a result, the share of the population living at the most affluent group (T10) IS still the same as in SSP1, but 6% more people live at the bottom 50%, descending from the middle class (M40). These distributional changes reduce the total expenditure level by 1.6% in comparison with SSP1.

3.3.1.3. The four windows compared

Table**Table 3.3**.**1Table 3.3**.**2** compares the changes in population and GDP across the scenarios from 2010 to 2030. As discussed before, the scenarios SSP1, SSP1-F, and SSP41 aim to isolate the impacts distributional shifts. For this reason, the variables *Population* and *GDP* in these three scenarios present the same values. Only the scenario SSP4 (Inequality) presents different values following the narratives described in section 3.3.1.2.

Table 3.3.1 – Comparison between the four scenarios – Population (mi), and GDP (bi USD2007)
Source: Prepared by the author based on POF 2008/2009, and RAO, N D *et al.* (2018)

Year	Pop SSP1=SSP1-F=SSP41	Pop SSP4	GDP SSP1=SSP1-F=SSP41	GDP SSP4
2010	195	195	1,555	1,555
2015	202	202	1,883	1,881
2020	208	209	2,211	2,206
2025	212	213	2,685	2,563
2030	216	217	3,159	2,920

Table 3.3.2 shows the total household expenditure and Gini index across the four scenarios. Due to the assumption of log-normal distribution, scenarios with better income distribution present higher expenditure levels since more households are in the middle and upper classes.

Table 3.3.2 – Comparison between the four scenarios – Expenditure (bi USD2007), and Gini coefficient
Source: Prepared by the author based on POF 2008/2009, and RAO, N D *et al.* (2018)

Year	Exp SSP1	Exp SSP1-F	Exp SSP4	Exp SSP41	Gini SSP1	Gini SSP1-F	Gini SSP4=SSP41
2010	850	850	850	850	53.3	53.3	53.5
2015	1,013	1,016	1,011	1,012	50.9	48.2	51.8
2020	1,173	1,181	1,168	1,170	50.7	43.0	52.9
2025	1,399	1,414	1,338	1,395	50.5	37.9	54.1
2030	1,624	1,646	1,508	1,619	50.2	32.7	55.1

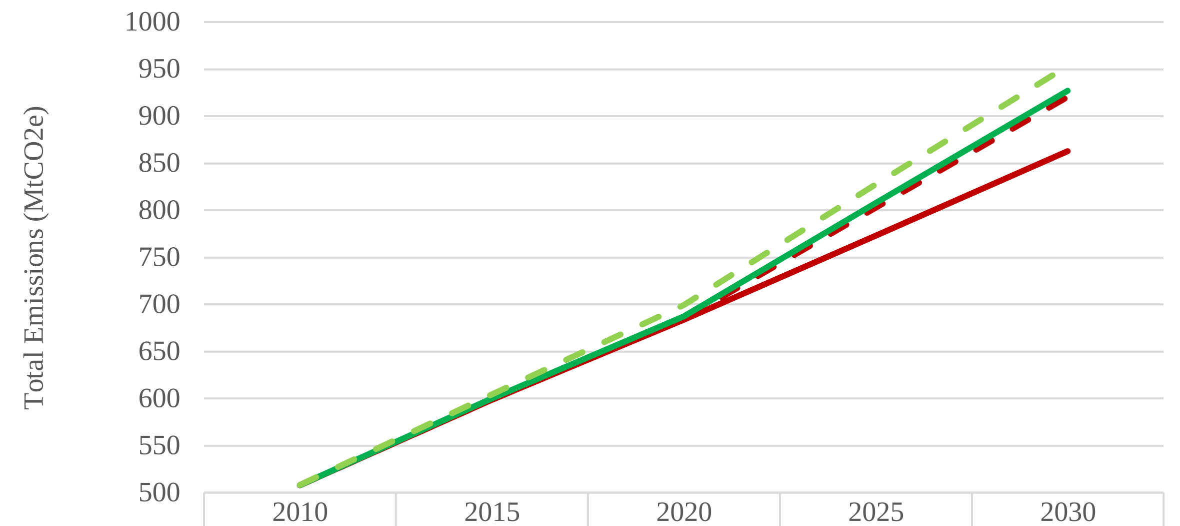
3.3.2. Four windows to the future: Inequality and Emissions

This section aims to answer the third and fourth research questions: what is the emission cost of building a more egalitarian Brazilian society? For this reason, four scenarios were designed, the SSP1 with fast economic growth and moderate improvement in the distribution, the SSP1-F with a sharp transition towards middle-class society, and the SSP4 where the economy grows a bit slower but the inequality flinch and, consequently, the share of the population living at low-income groups are stable. Based on Kaya's Identity (section 3.2.1), the three main components affecting the differences in the total GHG footprint between the scenarios SPP1, SSP1-F, and SSP4 are population, GDP, and income distribution. The next paragraphs analyze the impact of each component on the total emissions, but also focus on "emission cost" of having a more egalitarian society (regarding expenditure and consumption).

The results show that the difference in total household GHG footprint between the extreme inequality scenarios (SSP4 and SSP1-F) is about 12%. In total terms, the emissions increase from 508 $MtCO_2e$ in 2010 to a range of 863 $MtCO_2e$ (SSP4) to 953 $MtCO_2e$ (SSP1-F) in 2030, representing a rise of about 80% in 20 years. Over this period, the average emissions per capita increase about 70% in the high-equality scenario reaching 4.4 tCO_2e/cap/yr which still less than the levels in today's Russia (5.9 tCO_2e/cap/yr) and Germany (6.4 tCO_2e/cap/yr). As shown in Tables 3.3.1 andTable **3.3.2**, the differences in the total population between the four scenarios are small (0.05%), which means that this variable plays a minor role in determining the differences in total emissions. Conversely, GDP, household expenditure, and income distribution are substantially different. In 2030, the Brazilian economy is almost 10% larger under the SSP1, SSP1-F, and SSP41 scenarios than in SSP4, and there is a difference of 22 points in the Gini index between the SSP1-F and SSP4.

Figure **3.3-7** summarizes the evolution of the household footprint under the four scenarios from 2010 to 2030. As expected, the *inequality* scenario (SSP4) presents the lowest future emissions (863 $MtCO_2e$), followed by SSP41 (920 $MtCO_2e$), SSP1 (927 $MtCO_2e$), and SSP1-F (953 $MtCO_2e$). Thus, the difference in the total emission between the high-inequality scenario (SSP4) to the lowest-inequality scenario (SSP1-F) would be 110 $MtCO_2e$. However, most of these differences between the emissions under SSP4 and the other scenarios are driven by the low economic growth and, consequently, lower household expenditure level in SSP4.

To isolate the impact of improving income inequality on the total emissions is necessary to assume the same GDP and the population. For this purpose, the scenarios SSP1, SSP1-F, and SSP41 show the emissions cost of adopting contrasted income distributions. The results present that changing from a high inequality future (Gini = 55.1 - SSP41) to a moderate one with (Gini = 50.5 -SSP1) increases the total emission by only 0.7%. Even at the extreme case, with the income distribution improving from Gini 55.1 to 37.9 (SSP1 – F) the “emission cost” would be of 33 $MtCO_2e$, 3.6% higher than the SSP41’s level (Figure **3.3-6**). This small sensitivity of total emissions to inequality is mainly caused by the relationship between household income level, expenditure ratio, and emissions intensity. As discussed in section 2, affluent households tend to allocate a smaller share of its income on expenditure. While families at the G1 allocates more than 100% they income on goods and services, families at G10 tend to spend 60% of their gains. Additionally, the bundle of good and services consumed by the households at G10 is on average 20% less emission-intensive than those consumed by the households at G1.



	2010	2015	2020	2025	2030
SSP4	508	599	683	773	863
SSP41	508	599	684	803	920
SSP1	508	600	688	808	927
SSP1 F	508	604	700	828	953

Figure 3.3-5 – Total Household GHG footprint from 2010 to 2030 under the four scenarios
Source: Prepared by the author based on POF 2008/2009, Wood *et al.* (2013) and IIASA (2016)

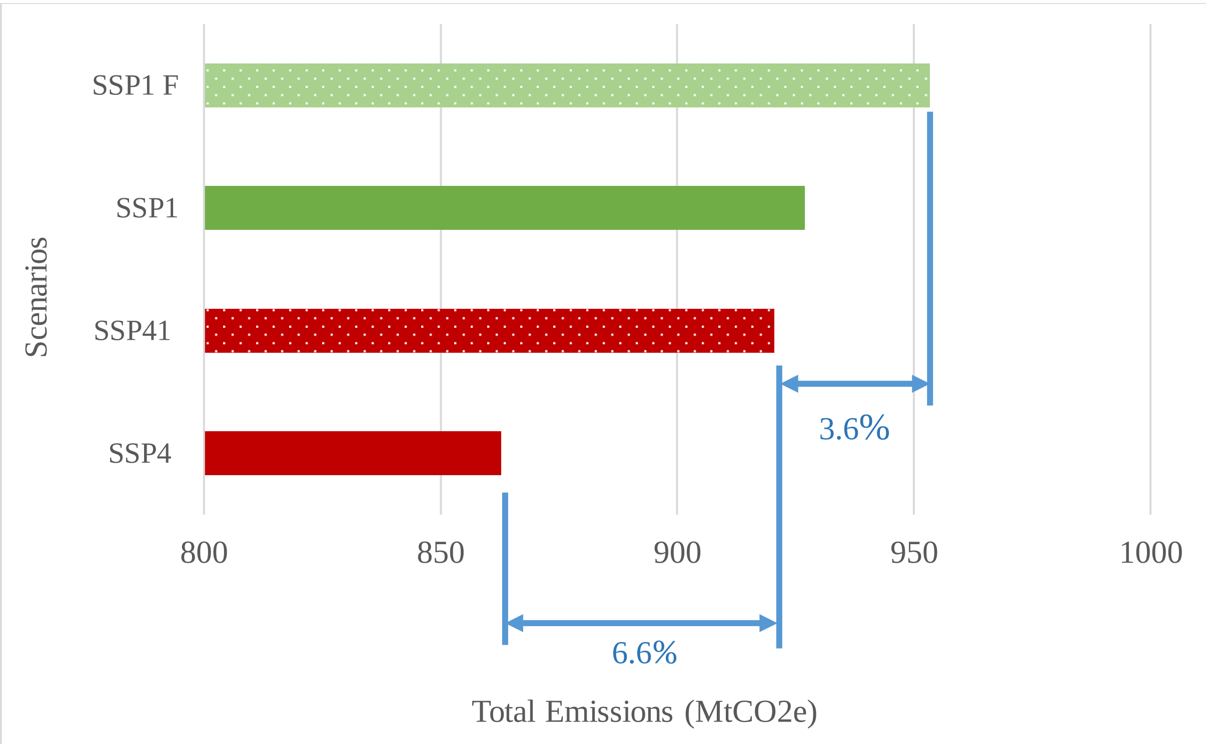


Figure 3.3-6 – Projected total Brazilian Household Carbon Footprint in 2030 under the scenarios SSP1, SSP1-F, SSP41, and SSP4.
Source: Prepared by the author based on POF 2008/2009, Wood *et al.* (2013) and IIASA (2016)

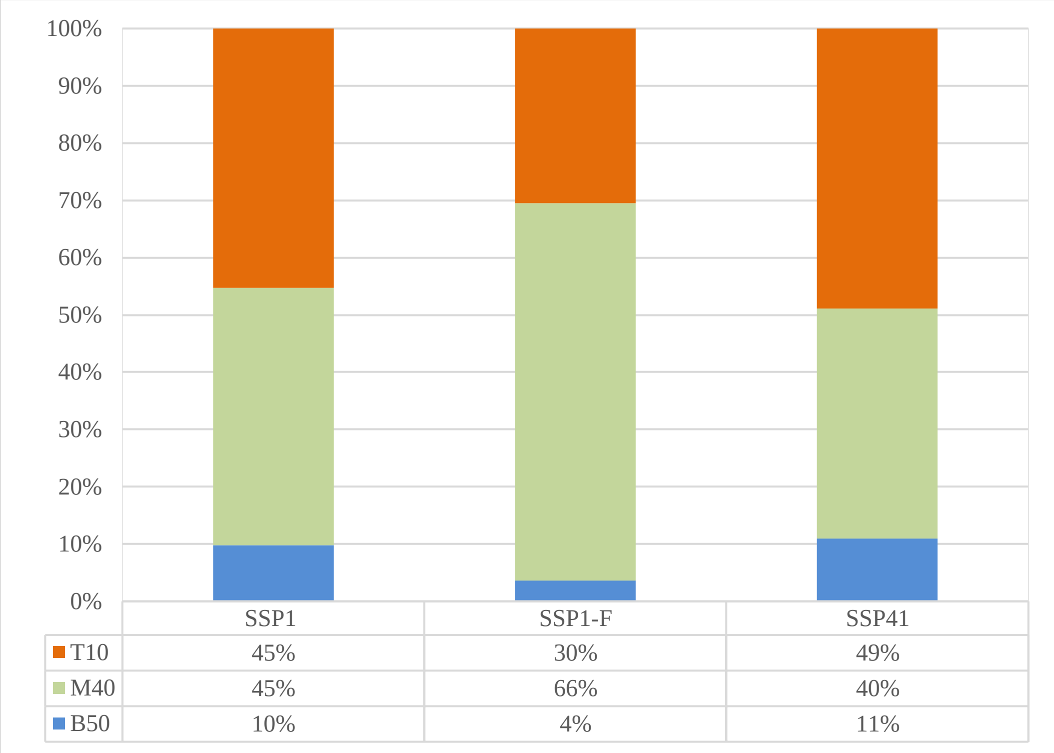


Figure 3.3-7 – Contribution of the income classes to the total emissions in 2030 for the scenarios SSP1, SSP1-F, and SSP4.
Source: Prepared by the author based on POF 2008/2009, Wood *et al.* (2013) and IIASA (2016)

The emission distribution in SSP1 and SSP41 are very similar, 10-11% of the emissions coming from the B50, 40-45% from the M40, and 45-49% from the T10. To conclude, the contribution of the bottom 50% is relatively small in all scenarios indicating that mitigation policies may be more effective when targeting the middle- and high-income groups. Under the high-inequality scenario, the most affluent income group contributes to almost half of the total emissions meaning that shifts in their consumption could represent a substantial emissions impact.

3.3.3. Windows to the future: Consumption and Emissions

As discussed in sections 2.3.2 and 2.3.3, the consumption behavior varies considerably across the income groups. For instance, low-income households tend to allocate half of its expenditure on food, while services and private transport represent half of the expenditure of affluent households. Thus, the shape of the future income distribution will determine the relative importance of the consumption sectors on the total household demand, and consequently on the household emissions. At the production side, understanding these patterns is useful for targeting the key sectors and increase the effectiveness of technology efficiency policies. At the consumption side, policies can encourage shifts to low-carbon consumption behavior, such as recycling and public transportation. This section focuses on answering the last research question: how the improvement or worsening of the income distribution would affect the relative importance of the consumption sectors on the household emissions?

To answer this question, the relative contribution of the consumption sectors to emissions under the scenarios SSP1-F and SSP41 are compared with those in 2009 (calculated in section 2). As presented above, these two scenarios present the extreme cases regarding income distribution. In the SSP1-F, poverty is near zero, and most of the population lives in the middle class. Therefore, the relative importance of consumption sectors expected to shift from food and public transport to services and private mobility. In the SSP41, the B50 (five lower-income groups) still represents 36% of the population, while at the T10 jumps from 7% to 19%. Given the higher purchase power, the 10% most affluent households contribute to almost half of total emissions and consequently shapes the contribution of the consumption sectors.

Table 3.3.3 – Contribution of the consumption sectors to total household GHG footprint

	POF2009	*SSP1 - F*	*SSP41*
Food	**14%**	**12%**	**12%**
Food	12%	10%	10%
Beef	2%	2%	1%
Services	**8%**	**9%**	**10%**
Mobility	**29%**	**33%**	**33%**
Private Transport	15%	18%	18%
Air travel	1%	1%	1%
Public Transport	8%	5%	4%
Dir. Energy Private Transp.	6%	10%	10%
Shelter	**26%**	**24%**	**24%**
Direct energy Housing	23%	21%	20%
Housing	3%	3%	4%
Goods	**22%**	**22%**	**21%**
Appliances	2%	2%	1%
Goods	20%	20%	20%

On the aggregate level, the variations in the sectoral contributions are modest across the scenarios with mobility, shelter, and goods, being responsible for almost 80% of the total emissions. However, some changes in consumption patterns can be highlighted. The contribution form mobility rises from 29% in 2009 to 33% in 2030, most influenced by the decreasing contribution from public transport and increments from direct energy to private transport (Table **3.3**.**3**).

Since people in the middle class use public transportation more often than in the affluent group, the contribution of this transportation is slightly higher in SSP1-F than in SSP41. Within private mobility, the contribution of direct energy (fuels) is almost half of the other goods and services related to private transport (manufacture, maintenance, and others). Thus, fuel-efficiency policies are essential but do not tackle the primary source of emissions from the private transport sector.

The Brazilian NDC target both increasing the share of biofuels in the energy mix, and improving the transport infrastructure and promoting public transport (UNFCCC, 2015a). The National Plan for Biofuels (RenovaBio) is the central government instrument to promote the use of biofuels in the Brazilian energy matrix in order to achieve the goals signed at the Paris agreement (BRASIL, 2017, 2018). In 2012, the Brazilian government approved the National Plan of Urban Mobility that requires cities with more than 20 thousand inhabitants to assemble their local mobility plans promoting public transport (BRASIL, 2012). However, by 2017 only 5% of those municipalities have developed their plan (CNT, 2017).

4. DISSERTATION CONCLUSIONS AND FUTURE RESEARCH

The dissertation explores the link between two crucial development challenges for the Brazilian society: income inequality and climate change. On the one hand, Brazilian society still among the most unequal ones in the world with a Gini coefficient of 53.1 and more than 14 million people living below the poverty line. On the other hand, Brazil pledged to reduce its GHG emissions by 37% by 2025 and 43% by 2030, below 2005 levels. The compatibility between these two challenges are developed through four research questions, and the resulting main conclusions are summarized below:

- What is the impact of prices variations across income classes on GHG footprint estimations?

Firstly, a new methodology was developed to correct the impact of price variations on the household emissions and improve the allocation of emissions (or other resources) across the income classes. This adjustment deals with price homogeneity assumed by the classical standard Input-Output method and can distort resource allocation across the income groups. Using the Brazilian budget survey data, the results show that this is an essential issue since prices vary more than 100% for some consumption items. As a result, households in the top income groups pay on average 57% more for similar products than the low-income group. These price variations distort the emissions distribution across the income groups. The implementation of the price adjustment proposed in this dissertation reduced the total emissions allocation for the most affluent class (G10) by 11% while increased 17% for lower-income one (G1). This adjustment uses the available price information of 43 consumption items. Thus, the lack of price information for other 54 consumption items is one of the caveats of this method.

- How the consumption patterns of households in different income groups affect the Brazilians GHG footprint?

Secondly, the high inequality of the Brazilian society is shown in both income and expenditure. For the analyzed year, 75% of the population lived with an income below the national average, and the average income of the 10% richer households was 41 times higher than the average income of the 10% poor ones, indicating the skewness of the income distribution. This results in high unequal expenditure level, but the structure of the expenditure also changes substantially with people consuming proportionally more services and private transport, and less food as their income rise.

The results on emissions per income group allow identifying two challenges of increasing the household's income level, one related to extreme poverty and other to the impact of the upper-income class. Due to its low emission per capita in the low-income groups the emission cost of increasing families income to a level just above the poverty threshold is relatively small, which supports previous studies for Brazil, and China. Tackle this problem and move the whole Brazilian population above the poverty line is one of the crucial Sustainable Development Goals (SDG).

However, the human development requires more ambitious societal goals given that the poverty line measures only the minimum amount of money required to provide one's subsistence which not necessarily is sufficient afford the requirements for a decent living standard such as shelter, mobility, education, and health. Although economic growth and rise in the income levels are not sufficient for improvements in human development, they are necessary. The understanding of consumption patterns and resulting emissions from each income help to learn more about the mitigation challenges associated with desirable improvements in human development. On the other hand, the ascension of households to the upper-income group (G10) induces a significant impact on the total consumption and related emission, since the emission per capita of this group (10 tCO_2e) is almost five times higher than the national average.

- What is the emission cost of building a more egalitarian Brazilian society?

To understand the impacts on climate change of building a more egalitarian Brazilian society this dissertation runs four scenarios with different income distribution. The results show that the most egalitarian scenario (SSP1-F) would emit about 12% (110$MtCO_2e$) more GHG than in the least egalitarian one (SSP4). However, most of this difference is driven by the lower economic growth projected for the SSP4, and after isolating the effect of economic growth, the difference in the emissions drops to 3.6%. In comparison, the abatement curves for Brazil shows that the low-cost (“low hanging fruit”) options to reduce the emissions, such as recycling and transportation efficiency, could reduce the country’s emission by 150 $MtCO_2e$ in 2030. Also, this emission increment would be a “fair price” to pay given the social benefits of reducing inequality.

- How the improvement or worsening of the income distribution would affect the relative importance of the consumption sectors on the household emissions?

At the consumption side, there are no significant changes in the contribution of the consumption categories, with Mobility, Shelter, and Goods being the primary drives of the household GHG emissions. This indicates that these consumption categories must be prioritized in mitigation policies regardless of the inequality scenario. Within mobility, with the rise in income level more families shift from public to private transport increasing the emissions from fuels and private transport-related activities. However, the contribution of direct energy (fuels) is almost half of the other goods and services related with private transport (manufacture, maintenance, and others), showing the mitigation policies in this area should not rely only on renewable fuels policies.

- Future research

The results from this dissertation assume that the consumption behaviors of the income groups are constant. However, more could be explored on the link between the inequality and consumption behavior in Brazil given that some studies indicate changes in the inequality may affect social values, environmental awareness, and therefore consumption behavior. Additionally, the design of mitigation policies would benefit from further research exploring forces that influence changes towards green consumption patterns.

The survey-based estimations of income inequality that are based on surveys underestimate the wealth and income of the affluent household. Consequently, the tax income data could be used to represent the contribution of those families to climate change better.

The distribution shape influences the results of the Gini scenarios. This dissertation uses the lognormal distribution that has properties that simplify the estimation, for instance, the inequality, the Lorenz curve, and the Gini coefficient depend on a single parameter. However, the lognormal distribution is usually more convenient for modeling small and median range income, underrepresenting affluent groups. This bias should be addressed in future studies by combining other distribution for such as the Pareto distribution.

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APPENDICES

APPENDIX A. Descriptive analysis of price variation

Table 0.1 - Consumption categories prices: Mean, Variance and Standard Variation in US$2010PPP

Item	***Mean***	***Var***	***SD***
Coffee, tea and cocoa	8.46	198.19	14.08
Eggs and egg-based products	3.63	55.25	7.43
Food products n.e.c.	5.35	40.70	6.38
Frozen, preserved or processed fruit and fruit-based products	6.83	39.91	6.32
Spirits	5.04	36.11	6.01
Confectionery, chocolate and ice cream	4.53	32.06	5.66
Sugar	2.06	23.42	4.84
Cheese	8.81	17.73	4.21
Mineral waters, soft drinks, fruit and vegetable juices	2.84	13.43	3.66
Preserved or processed fish and seafood	9.82	12.58	3.55
Fresh, chilled or frozen fish and seafood	4.91	10.79	3.29
Wine	4.69	8.77	2.96
Frozen, preserved or processed vegetables and vegetable-based products	5.38	8.71	2.95
Other edible oil and fats	2.71	8.50	2.92
Fresh or chilled potatoes	1.71	7.68	2.77
Other cereals, flour, and other products	2.63	7.10	2.66
Preserved milk and other milk products	2.35	7.06	2.66
Other meats and meat preparations	5.62	6.68	2.58
Fresh or chilled fruits	1.39	5.64	2.38
Beef and veal	6.03	4.96	2.23
Lamb, mutton, and goat	5.41	4.40	2.10
Other bakery products	4.79	4.06	2.01
Pasta products	3.06	3.88	1.97
Pork	5.14	3.87	1.97
Poultry	3.52	3.71	1.93
Butter and margarine	4.25	3.61	1.90
Fresh or chilled vegetables other than potatoes	2.03	2.45	1.57
Bread	3.13	0.90	0.95
Beer	2.49	0.83	0.91
Rice	1.45	0.78	0.88
Kerosene	1.82	0.30	0.55
Ethanol	2.01	0.23	0.48
LPG	1.76	0.09	0.29
Charcoal/coal/briquette/coke	0.83	0.07	0.27
Fresh milk	0.78	0.07	0.26
Gasoline	1.94	0.07	0.26
Non-durable household goods	0.53	0.06	0.25
Diesel	1.56	0.05	0.23
Electricity	0.27	0.04	0.19
Other biomass	0.33	0.01	0.07
Natural gas	0.00	0.00	0.00
Jams, marmalades and honey	5.41	0.00	0.00
Firewood and other fuels	0.33	0.00	0.00

Table 0.2 - Average price per consumption category and income group (US$2010PPP). G1 is the lowest decile and the G10 the highest.

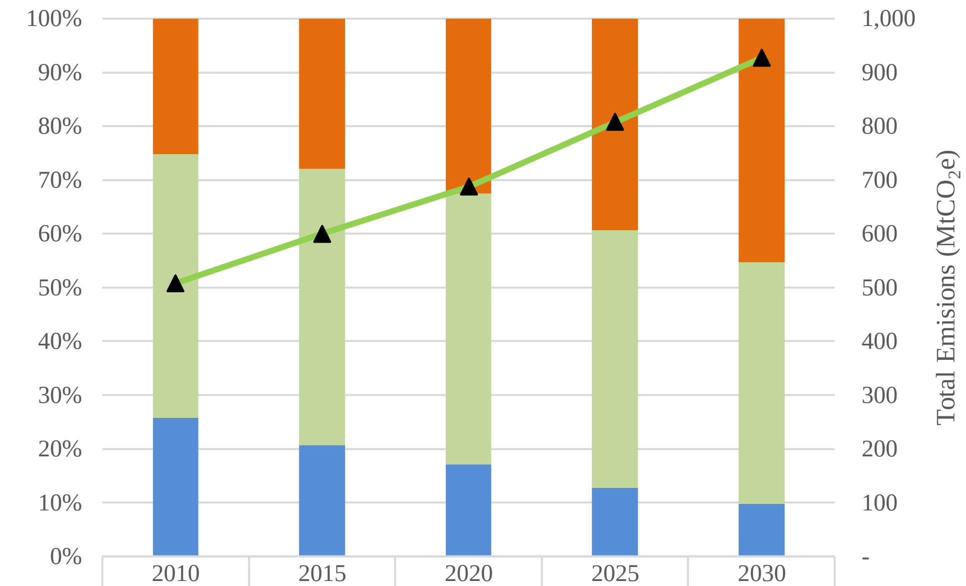
Item	*G1*	*G2*	*G3*	*G4*	*G5*	*G6*	*G7*	*G8*	*G9*	*G10*
Beef and veal	4.86	5.13	5.51	5.63	5.80	5.99	6.07	6.46	6.75	7.80
Beer	2.38	2.44	2.46	2.35	2.39	2.46	2.52	2.48	2.51	2.59
Bread	2.70	2.76	2.88	2.91	2.99	3.11	3.22	3.31	3.42	3.77
Butter and margarine	3.73	3.74	3.95	4.07	3.96	4.13	4.19	4.33	4.88	5.39
Charcoal/coal/briquette/coke	0.64	0.71	0.74	0.79	0.75	0.87	0.91	0.86	0.85	0.86
Cheese	7.60	7.88	8.32	8.27	8.42	8.33	8.31	8.64	9.00	9.99
Coffee, tea and cocoa	6.65	7.15	7.61	7.06	7.76	8.37	8.65	8.90	9.79	10.93
Confectionery, chocolate and ice cream	2.58	2.87	3.18	3.26	4.07	4.44	4.73	5.39	5.94	7.00
Diesel	1.61	1.53	1.55	1.56	1.62	1.52	1.41	1.46	1.36	1.40
Eggs and egg-based products	4.24	3.80	4.23	3.55	3.69	3.17	3.19	3.51	3.32	3.54
Electricity	0.22	0.25	0.26	0.27	0.27	0.27	0.29	0.29	0.30	0.32
Ethanol	1.81	2.16	2.12	1.90	1.90	1.97	1.88	2.06	1.94	2.35
Firewood and other fuels	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Food products n.e.c.	4.19	4.39	5.02	4.93	4.89	5.32	5.19	5.91	5.92	6.87
Fresh milk	0.75	0.76	0.69	0.78	0.75	0.78	0.73	0.79	0.94	1.20
Fresh or chilled fruits	1.40	1.36	1.41	1.40	1.33	1.38	1.30	1.31	1.43	1.57
Fresh or chilled potatoes	1.32	1.34	1.36	1.40	1.38	1.50	1.79	1.80	1.89	2.63
Fresh or chilled vegetables other than potatoes	2.03	1.96	2.07	1.99	2.00	1.97	1.98	2.04	2.06	2.17
Fresh, chilled or frozen fish and seafood	3.33	3.59	3.95	4.31	4.87	4.62	5.21	6.00	6.42	7.85
Frozen, preserved or processed fruit and fruit-based products	4.05	4.55	4.80	5.28	5.01	5.70	6.06	7.07	7.73	10.32
Frozen, preserved or processed vegetables and vegetable-based products	3.55	4.10	4.43	5.13	5.47	4.67	4.99	5.43	5.22	6.28
Gasoline	1.88	2.00	1.99	1.95	2.18	2.27	2.05	1.69	2.01	1.88
Jams, marmalades and honey	NA	NA	NA	NA	NA	NA	5.41	NA	NA	NA
Kerosene	1.73	1.75	1.83	1.88	1.99	2.21	1.73	1.83	2.20	1.70
Lamb, mutton and goat	4.25	4.91	5.38	5.42	5.53	5.08	5.18	5.59	6.05	6.52
LPG	1.78	1.77	1.76	1.76	1.74	1.75	1.74	1.75	1.75	1.80
Mineral waters, soft drinks, fruit and vegetable juices	4.33	3.68	3.58	3.00	2.91	2.62	2.44	2.37	2.11	1.93
Natural gas	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-durable household goods	0.51	0.49	0.50	0.53	0.44	0.65	0.56	0.78	0.65	0.72
Other bakery products	4.03	4.10	4.33	4.37	4.55	4.73	4.97	5.21	5.37	5.90
Other biomass	0.33	0.26	0.39	0.30	0.36	0.36	NA	0.34	0.35	NA
Other cereals, flour and other products	1.74	1.98	2.12	2.21	2.50	2.59	2.69	3.04	3.46	4.13
Other edible oil and fats	2.22	2.13	2.27	2.28	2.32	2.62	2.61	2.70	3.56	4.86
Other meats and meat preparations	4.68	4.86	5.02	5.07	5.34	5.34	5.71	5.89	6.34	7.09
Pasta products	2.59	2.70	2.75	2.88	3.03	3.09	3.38	3.42	3.46	3.76
Pork	4.23	4.63	4.69	4.90	5.04	5.04	5.21	5.38	5.59	6.08
Poultry	3.18	3.12	3.21	3.19	3.18	3.41	3.45	3.57	3.80	5.05
Preserved milk and other milk products	3.23	2.76	2.47	2.34	2.17	2.09	2.01	2.06	2.12	2.53
Preserved or processed fish and seafood	8.68	9.04	8.95	9.53	9.72	9.85	10.25	9.91	10.53	10.69
Rice	1.42	1.42	1.43	1.38	1.41	1.41	1.41	1.42	1.50	1.80
Spirits	3.47	3.47	4.38	4.46	4.22	4.41	4.08	5.82	6.50	7.88
Sugar	0.83	0.88	1.41	1.28	1.68	2.67	2.55	3.21	4.79	6.00
Wine	3.33	3.60	2.97	3.19	3.74	4.03	4.18	4.74	4.42	6.25

APPENDIX B. GHG and Global Warming Potential

Table 0.3 - The GHG considered and their global warming potential

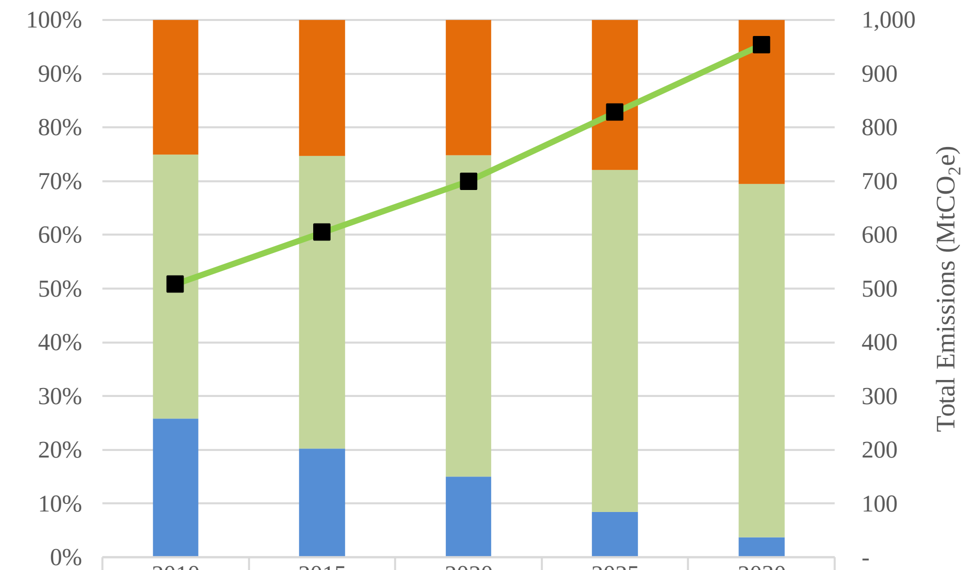
GHG_item	*GWP100*	*Chemical_name*
CO2	1	Carbon dioxide
CH4 - combustion	34	Methane
N2O - combustion	298	Nitrous Oxide
SF6	23500	Sulfur hexafluoride

APPENDIX C. Total Household GHG footprint and the relative contribution of each income group to the footprint



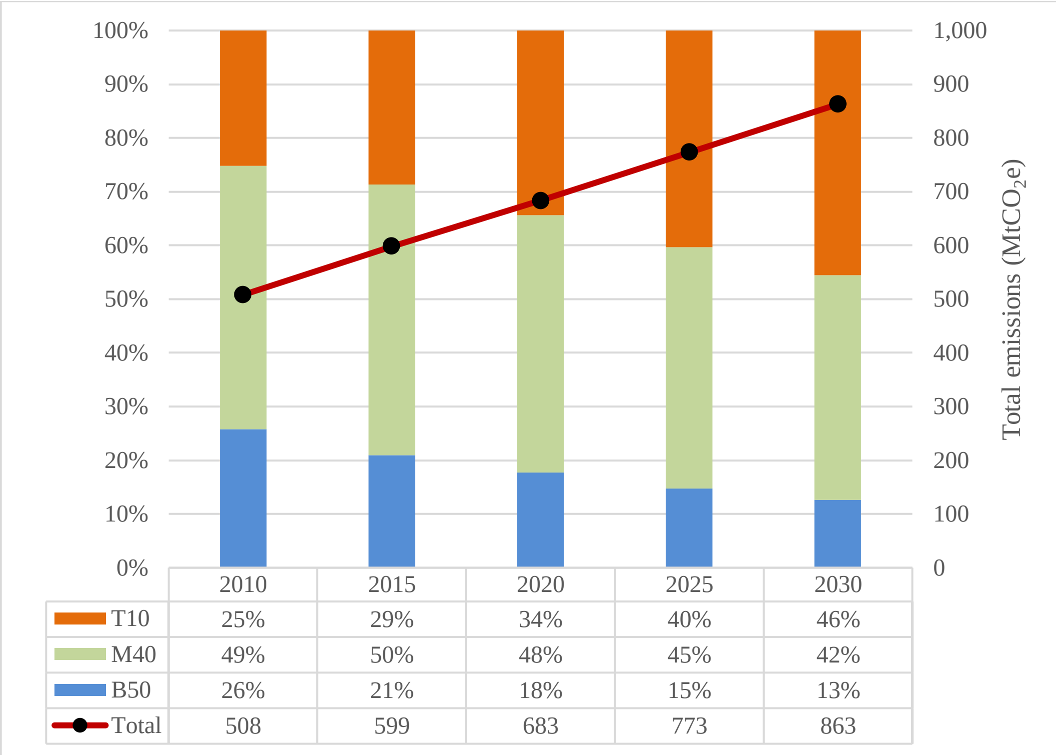
	2010	2015	2020	2025	2030
T10	25%	28%	33%	39%	45%
M40	49%	51%	50%	48%	45%
B50	26%	21%	17%	13%	10%
Total	508	600	688	808	927

Figure 0-1 – SSP1 – Total Household GHG footprint and the relative contribution of each income group to the footprint.



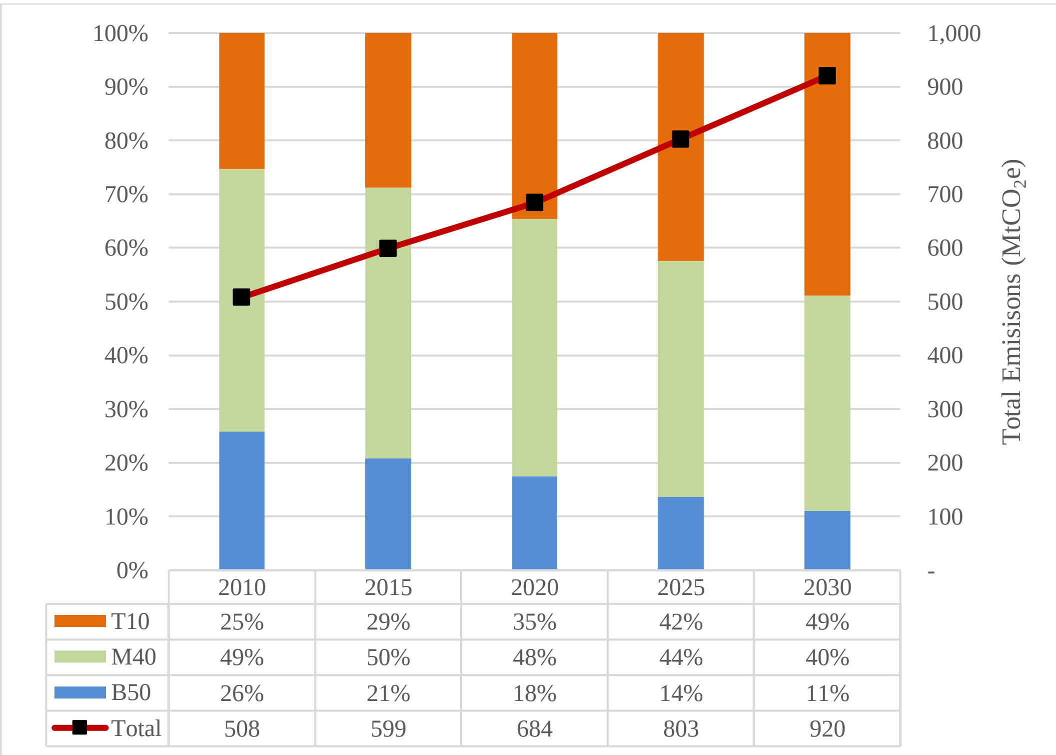
	2010	2015	2020	2025	2030
T10	25%	25%	25%	28%	30%
M40	49%	54%	60%	64%	66%
B50	26%	20%	15%	8%	4%
Total	508	604	700	828	953

Figure 0-2 – SSP1-F – Total Household GHG footprint and the relative contribution of each income group to the footprint.



	2010	2015	2020	2025	2030
T10	25%	29%	34%	40%	46%
M40	49%	50%	48%	45%	42%
B50	26%	21%	18%	15%	13%
Total	508	599	683	773	863

Figure 0-3 – SSP4 – Total Household GHG footprint and the relative contribution of each income group to the footprint



	2010	2015	2020	2025	2030
T10	25%	29%	35%	42%	49%
M40	49%	50%	48%	44%	40%
B50	26%	21%	18%	14%	11%
Total	508	599	684	803	920

Figure 0-4 – SSP41 – Total Household GHG footprint and the relative contribution of each income group to the footprint

APPENDIX D. Consumption items and its aggregation map into 11 categories

Table 0.4 – Consumption items and its respective ID numbers.

Items **NUMBERS**	Items **NAMES**
1	UNBR Food and non-alcoholic beverages
2	UNBR Food
3	UNBR Bread and cereals
4	Rice
5	Other cereals, flour and other products
6	Bread
7	Other bakery products
8	Pasta products
9	UNBR Meat
10	Beef and veal
11	Pork
12	Lamb, mutton and goat
13	Poultry
14	Other meats and meat preparations
15	UNBR Fish and seafood
16	Fresh, chilled or frozen fish and seafood
17	Preserved or processed fish and seafood
18	UNBR Milk, cheese and eggs
19	Fresh milk
20	Preserved milk and other milk products
21	Cheese
22	Eggs and egg-based products
23	UNBR Oils and fats
24	Butter and margarine
25	Other edible oil and fats
26	UNBR Fruits
27	Fresh or chilled fruits
28	Frozen, preserved or processed fruit and fruit-based products
29	UNBR Vegetables
30	Fresh or chilled vegetables other than potatoes
31	Fresh or chilled potatoes
32	Frozen, preserved or processed vegetables and vegetable-based products
33	UNBR Sugar, jam, honey, chocolate and confectionery
34	Sugar
35	Jams, marmalades and honey
36	Confectionery, chocolate and ice cream
37	Food products n.e.c.
38	UNBR Non-alcoholic beverages

39	Coffee, tea and cocoa
40	Mineral waters, soft drinks, fruit and vegetable juices
41	UNBR Alcoholic beverages, tobacco and narcotics
42	UNBR Alcoholic beverages
43	Spirits
44	Wine
45	Beer
46	Tobacco
47	Narcotics
48	UNBR Clothing and footwear
49	UNBR Clothing
50	Clothing material, other articles of clothing and clothing accessories
51	Garments
52	Cleaning, repair and hire of clothing
53	UNBR Footwear
54	Shoes and other footwear
55	Repair and hire of footwear
56	UNBR Housing, water, electricity, gas and other fuels
57	Actual and imputed rentals for housing
58	Maintenance and repair of the dwelling
59	UNBR Water supply and miscellaneous services relating to the dwelling
60	Water supply
61	Miscellaneous services relating to the dwelling
62	UNBR Electricity, gas and other fuels
63	Electricity.COICOP
64	Gas
65	Other fuels
66	UNBR Furnishing, household equipment and routine household maintenance
67	UNBR Furniture and furnishings, carpets and other floor coverings
68	Furniture and furnishings
69	Carpets and other floor coverings
70	Repair of furniture, furnishings and floor coverings
71	Household textiles
72	UNBR Household appliances
73	Major household appliances whether electric or not
74	Small electric household appliances
75	Repair of household appliances
76	Glassware, tableware and household utensils
77	UNBR Tools and equipment for house and garden
78	Major tools and equipment

79	Small tools and miscellaneous accessories
80	UNBR Goods and services for routine household maintenance
81	Non-durable household goods
82	Domestic services
83	Household services
84	UNBR Domestic services and household services
85	UNBR Health
86	UNBR Medical products, appliances and equipment
87	Pharmaceuticals products
88	Other medical products
89	Therapeutic appliances and equipment
90	UNBR Out-patient and hospital services
91	UNBR Out-patient services
92	Medical services
93	Dental services
94	Paramedical services
95	Hospital services
96	UNBR Transport
97	UNBR Purchase of vehicles
98	Motor cars
99	Motor cycles
100	Bicycles
101	Animal drawn vehicles
102	UNBR Operation of personal transport equipment
103	Fuels and lubricants for personal transport equipment
104	Maintenance and repair of personal transport equipment
105	Other services in respect of personal transport equipment
106	UNBR Transport services
107	Passenger transport by railway
108	Passenger transport by road
109	Passenger transport by air
110	Passenger transport by sea and inland waterway
111	Combined passenger transport
112	Other purchase transport services
113	UNBR Communication
114	Postal services
115	Telephone and telefax equipment
116	Telephone and telefax services
117	UNBR Recreation and culture
118	UNBR Audio-visual, photographic and information processing equipment
119	Audio-visual, photographic and information processing equipment

120	Recording media
121	Repair of audio-visual, photographic and information process. equipment
122	UNBR Other major durables for recreation and culture
123	Major durables for outdoor and indoor recreation
124	Maintenance and repair of other major durables for recreation and culture
125	UNBR Other recreational items and equipment, garden and pets
126	Other recreational items and equipment
127	Garden and pets
128	Veterinary and other services for pets
129	UNBR Recreational and cultural services
130	Recreational and sporting services
131	Cultural services
132	Games of chance
133	Newspapers, books and stationery
134	Package holidays
135	Education
136	Catering services
137	Accommodation services
138	UNBR Miscellaneous goods and services
139	UNBR Personal care
140	Hairdressing salons and personal grooming establishments
141	Appliances, articles and products for personal care
142	Prostitution
143	UNBR Personal effects n.e.c.
144	Jewellery, clocks and watches
145	Other personal effects
146	Social protection
147	Insurance
148	UNBR Financial services n.e.c.
149	FISIM
150	Other financial services n.e.c.
151	Other services n.e.c.
152	Biogas
153	Charcoal/coal/briquette/coke
154	Diesel
155	Electricity
156	Ethanol
157	Firewood and other fuels
158	Other biomass
159	Fuel oil, generator
160	Gasoline

161	Kerosene
162	LPG
163	Natural gas
164	Other household fuel

Table 0.5 – Mapping from the Items to the 11 categories

Categories **NAMES**	Ite**MS NUMBERS**
FOOD	1 to 9, 11 to 47
BEEF	10
GOODS	48 to 51, 53, 54, 86 to 89, 115, 118 to 120, 122 to 127, 133, 141, 143 to 145 # Excluding mobility and housing goods
SERVICES	52, 55, 85, 90 to 95, 113, 114, 116, 117, 121, 128 to 132, 134 to 140, 142, 146 to 151 # Excluding mobility and housing services
PRIVATE TRANSPORT	96 to 102, 104 to 106
AIR-TRAVEL	109
PUBLIC MOBILITY	107, 108, 110 to 112 # All passenger transport services, including road, rail, water
HOUSING	61, 66 to 71, 76 to 84
Household ap**PLIANCES**	72 to 75
ENERGY HOUSING	56 to 59, 60, 62 to 65, 152, 153, 155, 157 to 159, 161 to 164
ENERGY PRIVATE TRANSPORT	103, 154, 156, 160

APPENDIX E. Household income distribution in 2009 - Brazil

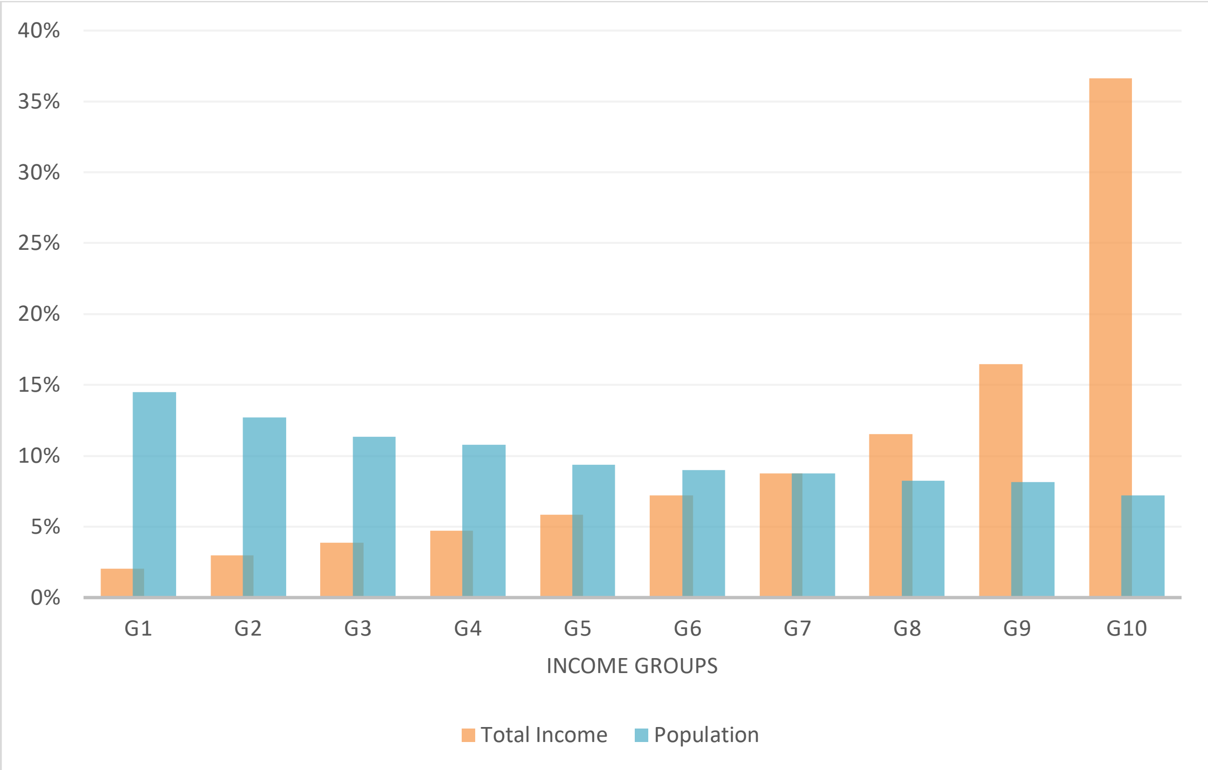


Figure 0-5 – Brazilian Income and Population distribution by decile in 2009 (USD 2007)
Source: Elaborated by the author based on POF2008/2009