Household composition effects on electricity consumption in the US and Brazil

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Introduction

As one of the defining challenges of the 21st century, the actions necessary to combat climate change have taken center stage in environmental debates. As climate change takes place, it becomes ever more pressing the issue of the provision of goods and services needed to ensure the basic needs of its population. Those should be managed in order to ensure the quality of life of these people, providing education, health, transportation, food, water, housing, and energy, which strongly depend on the use and appropriation of natural resources such as soil and water bodies (Hummel et al., 2008). In this dynamic, the environmental dimension has great influence, since the preservation of natural resources must be ensured in order to guarantee the supply of dependent goods and services and ensure the reproduction of society and its development. Given the social importance of a commodity as basic as energy, problems of security are of such magnitude that the sustainability of the energy provision becomes weakened to the point of collapse, not only in terms of the natural environment but also in economic and social ones (Hummel et al., 2008).

Demography, like no other social science, is equipped with tools to explore the tendencies and possible solutions to emerging problems such as the consumption of natural resources. Demography is an essential analytical lens in understanding this process because: "[n]o human population exists without production and consumption" (Lutz, Prskawetz & Sanderson, 2002, p. 5).

Often, the presented solutions call on changes in policy individual consumption e.g., in water, consumer goods, or energy. However, the focus is often on the macro perspective and highlights the effect of population growth on the environment. But other aspects of demographic changes that influence consumption and policy changes at the macro and micro levels are necessary to fully comprehend the challenges in the future provision (O'Neill & Chen, 2002). The relationships between population and environment do not happen in a linear way, or as autonomous and independent systems (Lutz, Prskawetz & Sanderson, 2002). This is because the processes go beyond simple correlations of demographic variables, it is essential to understand how different populations, with their cultural, economic, and ecological diversity, appropriate and manage natural resources (Hogan, 1993, Sherbinin et al., 2007).

The issue of energy production and consumption are amongst the most debated ones, particularly regarding the current strategic issues, such as the geopolitical crisis involving gas production in Europe, as well as emerging issues on climate change. Residential energy consumption also lends itself to a good example of environmental impacts associated with population change. Domestic energy use accounts for over 20% of total energy consumption worldwide (IEA, 2017), although uses such as industrial ones account for the greater share it is important to understand the mechanisms through which the population consumes natural resources.

The United States, the second-biggest energy consumer in the world, produces most of its energy from non-renewable energy sources. Over two-thirds are provided by oil (35%) and gas (34%), whereas the remainder is made up of smaller portions of renewables (12% total, out of which 26% wind and 22% hydro), as well as coal (10%) and nuclear energy (9%) (EIA, 2022). Albeit socioeconomic differences in CO_2 emissions profiles, this predominantly fossil energy mix negatively impacts the country's overall per capita emissions. Despite a recent downward trend and sinking per capita CO_2 emissions due to innovation, the United States continues to be among the highest emitters in the world (Goldstein et al., 2020).

Unlike most countries, Brazilian CO_2 emissions are historically based on changes in land use and agriculture. However, in the last decade, a new configuration of emissions has been taking shape, with an increase in emissions from energy generation. Whilst the energy sector is only the third emitting source – as the Brazilian energy mix is still mostly based on hydroelectric power generation which provides lower emissions compared to e.g., coal - other sectors such as land-use change and the agriculture and livestock sector together account for more than 70% of emissions (Barbieri et al., 2018). Two-thirds (66%) of the Brazilian energy mix is produced only by hydropower, fossil-fuel-powered plants in total accounted for only 12% of the country's produced energy in 2021 (EIA, 2021). Other renewable energies like wind power (8%), solar (1%), and biomass (8%) are also starting to play a bigger role in the Brazilian energy mix. However, when considering the resource-rich country's domestic consumption profile, the picture changes drastically. In the pre-pandemic year of 2019, Brazil was the eighth-largest oil producer in the world and the third largest in the Americas behind the United States and Canada. Despite its relatively clean production matrix, the consumption of non-renewables like petroleum (38%), gas (11%), and coal (5%) represented 54% of Brazil's domestic energy consumption (EIA, 2021).

Those overall figures do however configure differently when analyzed more closely e.g. at the household level. This unit of analysis has been found to be useful for the analyses in Population-Environment (P-E) research, especially on the topic of consumption (Sherbinin et al., 2007). Survey data on household levels are vital in understanding how household size, composition, income, etc. are related to environmental impacts (Thiede, 2022). Studies on energy consumption have identified a range of household characteristics as key determinants including for example factors like heating, cooking, and domestic appliances (Schipper, 1996; Carlsson-Kanyama & Linden, 1999; van Diepen, 2000; Pachauri, 2004)

One of the factors that calls into question the linearity of the relationship between population and consumption is the fact that the provision of water, and other goods, does not occur to isolated individuals, but to private households (Hummel, 2005). This is due to economies of scale, which, also at the household level, mean that each additional individual represents a smaller and smaller addition to total consumption. Cooking, washing clothes and dishes are examples of activities that are usually organized collectively in each household, thus reducing individual consumption. A growth in the total number of households can intensify these effects of relatively increased water consumption in smaller households (Lux, 2008).

Here, we aim to investigate the effect of changes in electricity consumption (EC) in the US and Brazil in relation to the tendency for smaller households. Due to economies of scale "smaller households have lower efficiency of resource use per capita because goods and services are shared by more people in larger households" (Liu et al. 2003, p. 532). This underlying process might add an extra burden on already complex energy mixes, still relying on energy sources that negatively impact climate change. The incidence of living alone is currently the highest in aging societies of Europe, North America, and East Asia (Esteve et al., 2020), adding up to high levels of consumption in those regions.

Furthermore, the US is at an advanced stage of a demographic transition process while Brazil is expected to go through this transition with important implications for the number of households and their compositions. The composition of households has undergone substantial changes as a result of processes and dynamics associated with the demographic transition theory. But the demographic transition model must be considered from the unfolding of heterogeneous temporal and spatial patterns (Hummel, 2008), and thus a multiplicity of possible differentials must be considered.

Although they are most commonly used, population volume, and such aggregate rates as per capita consumption are not sufficient to explain the dynamics of these processes (HUMMEL, 2005). By applying decomposition techniques, we aim to further contribute to the discussion about the effect of changes on electricity consumption, complexing the simple analyses of aggregated consumption rates as demographic trends are often overlooked when planning the use of natural resources. Therefore, we aim to estimate how much the changes in the composition of households were attributable to driving up consumption levels, known to be relevant factors both in the near future and in the past, depending on the countries' stage in the demographic transition.

For this study, we have chosen the US and Brazil as two of the continent’s biggest populations and biggest energy consumers. With the available data, we compare an advanced and an emerging economy to trace how demographic processes such as changes in household size and energy consumption are related. This makes the comparison of electricity consumption at the household level between the US and Brazil an interesting case study for demographic P-E research.

The US is at an advanced stage of a demographic transition process while Brazil is expected to go through this transition with important implications for the number of households and their compositions. The hypothesis for this research is that these changes in the US are not as expressive as they are in Brazil – at an earlier stage of the demographic transition and consumption levels associated with demographic changes are still expected to increase in the coming decades. We also aim here to investigate the decomposed effects other variables, namely gender and race of householder, and age of the dwellers.

Data

The data used in this study is composed of two different publicly accessible sources. As the aim of this research combines both demographic and environmental aspects, more specific datasets were used for the analysis. Both datasets are household-level surveys that, among others, have electricity consumption as available variables.

The Brazilian Household Budget Survey (POF - *Pesquisa de Orçamentos Familiares,* in Portuguese) is a national household survey by the Brazilian Institute of Geography Statistics (IBGE) to obtain nationwide information on household income and expenditures, nutritional status, and living conditions. The first survey to document such data was conducted as the National Study of Family Expenditure in 1974 and in later years was changed into the comprehensive Household Budget Surveys (1987, 1995, 2002, 2008, 2017) that primarily updated the IBGE's consumer structure and price indices for metropolitan regions (IBGE, 2018). The POF survey is mainly used here to study the evolution of household consumption habits and expenditure (Johansen et al., 2018).

The United States Residential Energy Consumption Survey (RECS) has been conducted since 1979 by the Energy Information Administration (EIA). The RECS is a national survey that has collected energy-related data on a household level (Estiri & Zagheni, 2019) with fewer demographic characteristics when compared to the Brazilian survey, but far more technical measures related to energy.

Common variables among the two datasets are the number of household members, age of household members, household income, race, and energy consumption. For the present study, the two variables used were: household size and electricity consumption. The Brazilian survey has comparability limitations with the older rounds (1987-88, 1995-96), therefore our investigation is limited to the periods from the year 2000 onwards.

Furthermore, the sample sizes of both surveys vary significantly. In the 2020 round of the RECS, the sample size is estimated to increase to over 18,000 households, which is a great improvement from n = 12,083 in 2009 and n = 4,822 in 2001. The sample for the Brazilian POF survey has consistently been over 50,000 households, reaching a maximum of 57,920 in the latest round (2017-2018). Another difference between the two surveys is that the US survey provides data on yearly consumption while the Brazilian survey inquiries about consumption and expenses with reference to the month of August. As that fall into the winter month in the southern hemisphere, this reference point could have an impact on the levels of energy use that distorts effects when compared with the US yearly average.

Also is important point out that both datasets, there is missing information in the sample for large household sizes due to the fact that they are less frequent and eventually are not included in the sample. For this reason, the analysis is limited to households some certain number dwellers given some combinations of age and a second category. In the second part of the analysis, the age of dwellers was not measured the same over the years of the RECS. For that reason, the cuts in age for the group of children was until age 12 in 2001, 15 years for 2009 and for the year 2015 the information is not available. For the group of the elderly it was possible to use the same age, 65 years, to both periods. For Brazil the data on age is complete for all household members and not aggregated in age groups in all year of the POF.

Methods

First, we present the data with a descriptive analysis of the variables of composition, in terms of household size, and consumption. The data on EC per household size show evidence of strong effects of scale on the levels of consumption. To further evaluate household composition's effect on domestic electricity use, we apply the decomposition method proposed by Kitagawa (1995). The decomposition methods aim to differentiate the contribution to a rate, considering a given composition. Applying such methods allows attributing de changes in the rate of interest in two major components: a combined and a residual one (Kitagawa, 1995).

The combined component (CC) is attributable to differences in composition held at constant specific rates, and the residual component (RC) represents changes in the specific rates held at constant composition. The two terms are represented in equation 1, the first sum accounts for the CC and the later one for RC. As Kitagawa (1995) suggests the average composition and specific rates of populations p and P to be used as standard population, the decomposition equation used in this analysis is

$$\Delta EC = \sum_x \frac{EC_x(P)+EC_x(p)}{2} . \left(\frac{N_x(P)}{N(P)} - \frac{N_x(p)}{N(p)}\right) + \sum_x \frac{EC_x(P)+EC_x(p)}{2} . \left(\frac{N_x(P)}{N(P)} - \frac{N_x(p)}{N(p)}\right) \quad (1)$$

Where,
EC is the electricity consumption per capita in kWh/month,
ECx is the electricity consumption per capita household size specific,
Nx is the population living in households of size x,
N is the total population,
and P and p refer to the two populations that could be either the same country at different times or two distinct countries.

Kitagawa (1995) also describes how to incorporate a second variable to the decomposition. To further investigate the differences in consumption we then incorporate another 3 variables: age of dwellers, gender of head of household, and householder race. The equation 2 was used for this second round of analyses.

$$\Delta EC = \sum_x \sum_y \frac{EC_{xy}(p)+EC_{xy}(P)}{2} . \left(\frac{N_{xy}(P)}{N(P)} - \frac{N_{xy}(p)}{N(p)}\right) + \sum_x \sum_y \frac{EC_{xy}(p)+EC_{xy}(P)}{2} . \left(\frac{N_{xy}(P)}{N(P)} - \frac{N_{xy}(p)}{N(p)}\right) \quad (2)$$

Given that the indexes x and y refer to the variables referent to the composition and respective electricity consumption per capita rates. Together with household size we combine successively age, gender, and race.

Results

The In order to investigate the household sizes in the US and Brazil and their influence on EC, we present in table 1 a summary of the variables of consumption and composition for both countries. The data for Brazil shows an overall increase in all variables but at different rates: while the population growth rate (2% per year) was less than the one of households (3.5% p.a.), total electricity consumption, average electricity consumption per capita, and per household increased at annual rates of 3%, 5,5%, and 1,6% respectively from 2002 to 2008.

The US data did not show such expressive growth rates, the greater being the population (1.01% p.a.), followed by households (0.96% p.a.) between 2001 and 2005. Those two rates also presented positive growth between the years 2005, 2009, and 2015. And at the latter period, the households' growth rate (0.67% p.a.) even surpassed population growth rates (0.51% p.a.). The variables for consumption, on the other hand, showed only a decrease from 2005 to 2009 and 2009 to 2015, except in total EC which decreased only from 2009 onwards. The consumption rates reached values close to negative 1% p.a., as the EC per capita had a decrease of 0.73% p.a. and the average EC per household had an even greater decrease of 0.88% p.a. between 2009 and 2015.

Country	Year	Population (in millions)	Households (in millions)	Total electricity consumption (GWh/month)	Average EC per capita (kWh/month)	AEC per household (kWh/month)
Brazil	2002	147.32	41.32	6,084.4	41.3	147.3
	2008	164.83	49.98	8,068.4	48.9	161.4
	2017	191.28	63.80	11,208.2	58.6	175.7
US	2001	274.21	106.99	94,988.1	346.4	887.8
	2005	285.34	111.09	106,274.2	372.4	956.6
	2009	292.20	113.62	107,176.0	366.7	943.3
	2015	301.09	118.21	105,602.9	350.7	893.4

Table 1. Estimated population, households, and measures of electricity consumption.
Source: POF 2002-2003, 2008-2009, and 2017-2018; RECS 2001, 2005, 2009, and 2015.

It is noticeable that the US consumption levels are several times higher than in Brazil, the average per person consumption reaching around eight times as much. Few states of Brazil would have a considerable increase in consumption during the winter months, as in summer air-conditioning, cooling, and additional refrigeration would increase in several states. In the US, there are regions with cold climates in which more energy might be demanded during winters. However, some non-electric sources of heating are counted separately in the database and could therefore not be considered in this analysis. The effect of seasonality could be further modulated for a better comparison, but the variations across times of the year are not enough to explain such differences between countries in the years 2001 and 2002, 2008 and 2009.

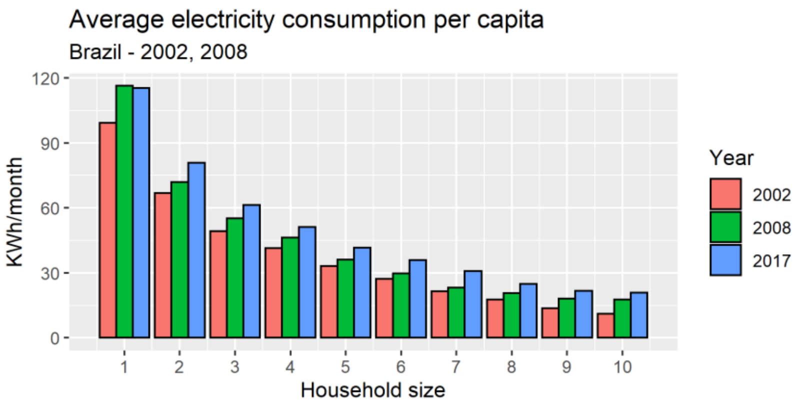

Figure 1. Average electricity consumption per person and household composition in Brazil.
Source: IBGE, POF 2002-2003, 2008-2009, and 2017-2018.

Figures 1 and 2 show the average electricity consumption for both countries, by household size and across years. In the case of Brazil (Figure 1), the unipersonal households increased from around 100 kWh/month to almost 120, the other sizes of households also show consistent increases, but to a lesser extent. In the US (Figure 2), those changes are less consistent. An overall increase in the year 2005 and to several household sizes there are decreases in the following years. For the last period analyzed the consumption of unipersonal dwellings is on average 600 kWh/month and households with two people are on average around 450 kWh/month.

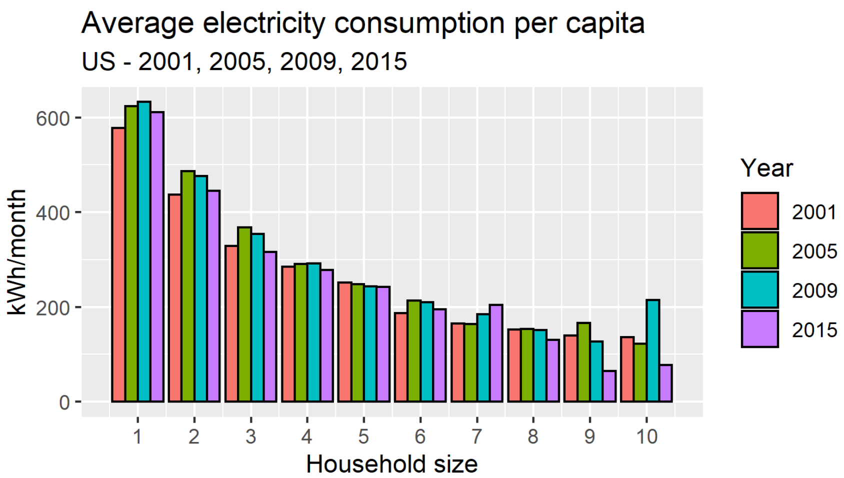

Figure 2. Average electricity consumption per person and composition of household in the US. Source: EIA, RECS 2001, 2005, 2009, and 2015.

Table 2 shows the decomposition for the selected years of the Brazilian and American data. For Brazil, between the periods of 2002-2003 and 2008-2009 the EC per capita increased by 7.48 kWh/month. Of that amount, 4.81 is attributed to the residual component and 2.67 to the composite component, which corresponds to 64.3% and 35.7% respectively.

Decomposition	Residual Component	Composite Component	Diff. in EC per capita (kWh/month)
BR 2008-2002	4.81 (64.3%)	2.67 (35.7%)	7.48
BR 2017-2008	5.76 (60,6%)	3.74 (39,4%)	9.51
US 2005-2001	26.97 (106.2%)	-1.58 (-6.2%)	25.39
US 2009-2005	-4.09 (86.8%)	-0.62 (13.2%)	-4.71
US 2015-2009	-21.80 (131.5%)	5.22 (-31.5%)	-16.58
US-BR 2001-02	270.13 (88.4%)	35.37 (11.6%)	305.50
US-BR 2008-09	289.58 (90.9%)	29.12 (9.1%)	318.70

Table 2. Decomposition of EC per capita for Brazil and the US in several periods. Source: POF 2002-2003, 2008-2009, and 2017-2018; RECS 2001, 2005, 2009, and 2015.

For the US the change in EC per capita was 25.39 kWh/month for the first time period (from 2001 to 2005), -4.71 for the second period (from 2005 to 2009), and -16.58 for the last period (from 2009 to 2015). In the first period, the decomposition shows RC of 26.87 and CC of -1.58. In the second period, RC is -4.09 and CC -0.62, and in the third period, RC is -21.80 and CC 5.22.

The decomposition across countries in the first period (2002-2003 for Brazil and 2001 for the US) shows that from the difference in EC per capita of 305.50 kWh/month, RC is 279.13 and CC 35.37. For the second period (2008-2009 for Brazil and 2009 for the US), the total difference is 318.70 of which 289.58 is attributed to RC and 29.12 to CC.

The inclusion of other variables brought to light other aspects of demographic change. When considering age together with household size the composition shows different trends comparing the two countries. While in the US comparing 2009 and 2001 the composition in age groups had contributed to decrease the electricity consumption per capita (-12,6%), in Brazil that influence as to increase. Comparing 2017 to 2009, the composite component represented 28% of the change in the rate.

The figure 3 shows the contribution by the composition (CC) of age and household size to the consumption, and the residual component. The composition effect shows an inflection point in households of 4 for adults and children and 5 for the elderly. All the other groups were responsible for increases in consumption. The effects of both CC and RC are bigger on the group of adults, and for the elderly that is associated mostly with smaller households.

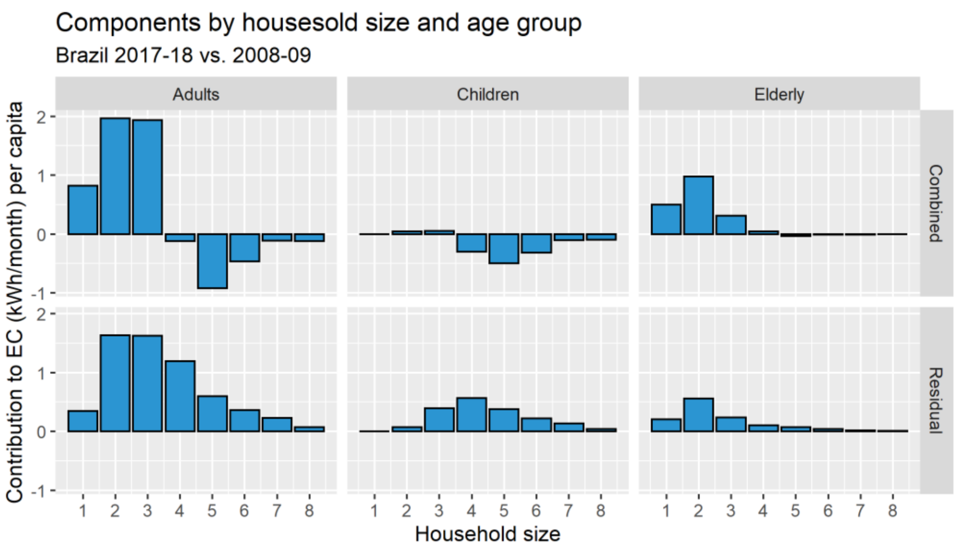

Figure 3. Contribution to electricity consumption by composition in household size and age group. Source: POF 2008-2009, and 2017-2018.

Regarding gender and household size the composition accounts for similar values. Around 30% to Brazil and -10% for the US. While for race and household size the component of the structure (CC) was around 20% in Brazil and close to 0 in the US. In all comparisons across countries the residual component accounted for 90% of the difference.

This analysis of household consumption profiles based on the Brazilian POF and the US RECS databases on energy consumption permits preliminary affirmations about the trend towards smaller households. In industrialized economies, these trends have already taken place and overall energy consumption and respective CO_2 emissions have reached significantly higher levels. Urbanized emerging economies like Brazil can provide interesting insights into the significance of household-level changes and provide possible scenarios for modeling such changes.

In the growing scientific discussions about the mitigation of climate change, population-environment linkages can help to point to more specific policy implications. Moreover, to consider demographic changes in household structure can help structure new policies to address energy use regardless of the stage of the demographic transition. Referring to Erlich's theses on the harmful effects of population growth, the analysis provided by Liu et al. (2003) still assume that "declining fertility rates are necessary" (p. 533). However, these authors also relativize Erlich's initial claims by recognizing that these are "not sufficient to ensure reduced anthropogenic pressure on the environment and natural landscapes [... because the] reduction in household size leads to higher per capita resource consumption and a rapid increase in the number of households, even when population size declines" (p. 533).

It could be argued that for those populations still undergoing the changes in structure, it might be more relevant to keep track of demographic aspects and their relation to consumption to better plan the use of natural goods. For more industrialized countries, it is essential to look attentively at consumption patterns instead of looking for the solution outside their borders with, in parts, alarmist concerns about population growth in the Global South. This is especially true when considering the great disparities in the levels of consumption among countries of higher and lower income.

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