Poverty and energy transition: a multinomial analysis for rural households in Brazil

Abstract

Energy poverty is a broad concept for which there are many different definitions, although all the definitions are based on households or individuals that do not meet minimum conditions of energy adequacy and suffer a certain degree of deprivation. This work aims to analyze the relationship between income and inadequate access to cooking fuels, such as firewood and charcoal, for Brazilian rural families. For this purpose, we use the 2016 PNAD *Contínua* (IBGE) microdata and estimate a multinomial logit, controlling for characteristics related to the families' preferences, for a set of three possible alternatives for choosing fuel for food preparation: LPG, biomass, and LPG and biomass, under the concept of energy poverty based on the technological approach. Among the main results of the study, we highlight that an increase in per capita household income reduces the probability of using the combination of biomass and LPG and further reduces the probability of exclusive use of biomass, in relation to the probability of exclusive use of LPG. Moreover, the fact that exclusive use of biomass is more frequent among extremely poor families and the combined use of LPG and biomass is more frequent among poor households shows that the energy transition process in which families gradually migrate from biomass for the consumption of clean fuels occurs in parallel with a broader movement of gradual and general improvement in the welfare conditions of families, that is, energy poverty would be only one of the faces of multidimensional family poverty.

Key words: Energy poverty; biomass; rural households; multinomial logit

1 Introduction

The phenomenon of poverty is a frequent and central theme in the academic research, national governments and international agencies agenda. The development of refined studies for the analysis of this phenomenon led to a consensus on its multidimensional characteristic. Then, one of the dimensions of deprivations that determines whether a household is poor in a particular region and period may be the energy poverty.

Energy poverty is a broad concept for which there are many different definitions, although all deal with the situation where a family or individual does not meet minimum conditions of energy adequacy and suffers a certain degree of deprivation in this dimension of poverty. One of the most widespread definitions of energy poverty called the technological approach defines as poor the households without adequate access to energy services, such as clean fuels for cooking. This approach does not provide information on household energy consumption levels and distinguishes poor and non-poor households in terms of their decisions on which fuels to use (in terms of efficiency, convenience, availability, pollution, etc.) [1].

In recent years, the idea that access to and consumption of clean or modern fuels is a key factor for sustainable development has become a global consensus. In 2015, United Nations (UN) Member States included the target of achieving universal access to clean fuels by 2030 in a set of measures to eradicate poverty, protect the planet and ensure prosperity for all as part of a new sustainability agenda, known as Sustainable Development Goals (SDO).

Efforts to access clean fuels and combat energy poverty can have significant impacts on dimensions beyond sustainable development, as the use of traditional biomass by households has serious impacts on the health and well-being of individuals. The low combustion efficiency of these sources increases the levels of carbon monoxide and suspended particles [8]. According to the World Health Organization (WHO) [11], the indoor air pollution from the use of these fuels increases the risk of pneumonia, chronic lung diseases, cardiovascular diseases and cancer, especially in women, children and the elderly, who spend more time indoors.

Access to and consumption of clean fuels often involves replacing traditional biomass fuels, such as firewood and charcoal, for modern and more efficient fuels such as liquefied petroleum gas (LPG) in a process known as energy transition. The literature on the determinants of fuel choice by households and the energy transition is wide. According to the more traditional view of the literature known as Energy Ladder theory, when household income increases, low quality fuels are replaced by higher quality ones. However, the most recent literature shows that the energy transition is not a linear or unidirectional process since households can consume a portfolio of multiple fuels with different physical characteristics. These latter theory is called Energy Stack [2]. Households may have many reasons for using multiple fuels, such as source availability and costs, risks associated with supply disruption, and cultural, social, or preference issues.

In this context, it important to highlight that a large literature points to the problem of the use of traditional biomass for cooking in households as one of the most relevant aspects of energy poverty. According to the International Energy Agency (IEA) [4], one-third of the world's population depends on traditional biomass sources for food preparation. In Brazil, the use of traditional biomasses in rural areas is still relevant and reaches 59 % of families in 2016, according to data from the Continuous National Household Sample Survey (PNADC) of the Brazilian Institute of Geography and Statistics (IBGE).

In spite of the magnitude of the problem of energy poverty, especially in its dimension related to the access of clean fuels for cooking, González-Eguino (2015) [2] points out that little attention has been given to this issue in terms of research and inclusion in countries' political agenda. According to Pereira, Freitas and Silva (2011) [6], one of the main challenges when analyzing the issue of energy poverty is the total absence or insufficiency of reliable data that allow more complex measurements to be taken that jointly consider access and consumption. In Brazil,

[1] For a detailed description and criticisms of the other definitions of energy poverty more disseminated in the literature, see González-Eguino (2015) [2].

insufficient data can also be one of the main constraints to more complex analyzes of energy poverty. In the case of information on access to clean fuels for cooking, the PNAD (IBGE) raises a question about the fuel predominantly used in the stove, that is, the family reports only the main fuel, which makes it impossible to analyze the portfolio or combination of energy sources. However, the Consumer Expenditure Survey (POF/IBGE) despite providing the information on which fuels the households used in the stove, allowing the family to report more than one source, until the present moment only presents the available data for 2008/2009. The recent release of data for the General Characteristics of Households of the 2016 PNADC, with questions about the possible combinations of fuels used by households for food preparation, allows analyzes about the current situation of energy poverty in Brazil with a focus on household access fuels.

Considering the magnitude of the problem of energy poverty in Brazilian rural regions and the absence of studies that explore this subject, this work aims to analyze the relationship between income and monetary poverty of households and inadequate access to cooking fuels. Through the estimation of a multinomial logit model, using the recently released PNADC data for households, allows us to understand the role of several households characteristics, including income and situation relative probability of using certain combinations of fuels for cooking.

A wide literature uses the multinomial approaches to understand the household fuel choice determinants in the context of Energy Ladder and Energy Stalk theories [2] . However, in order to collaborate with the literature, we use the multinomial approach to study the fuel choice by households as one of the dimensions of a greater situation of welfare deprivation. The main results suggest that an increase in per capita household income reduces the probability of using biomass, even when we consider the household preferences. Moreover, we find evidence that the energy transition process in which households migrate gradually from the exclusive of biomass for the consumption of clean fuels occurs in parallel with a broader movement of gradual welfare improvement of households. In other words, the energy poverty may be only one of the sides of a multidimensional poverty in Brazil.

This study has five sections, including this introduction. In the second section, we present some historical data on the consumption of cooking fuels in Brazil. In the third section, we describe the database and show some exploratory analysis for the sample. In the fourth section, we discuss the empirical strategy. The fifth section contains the results. Finally, we highlight the main conclusions in the sixth section.

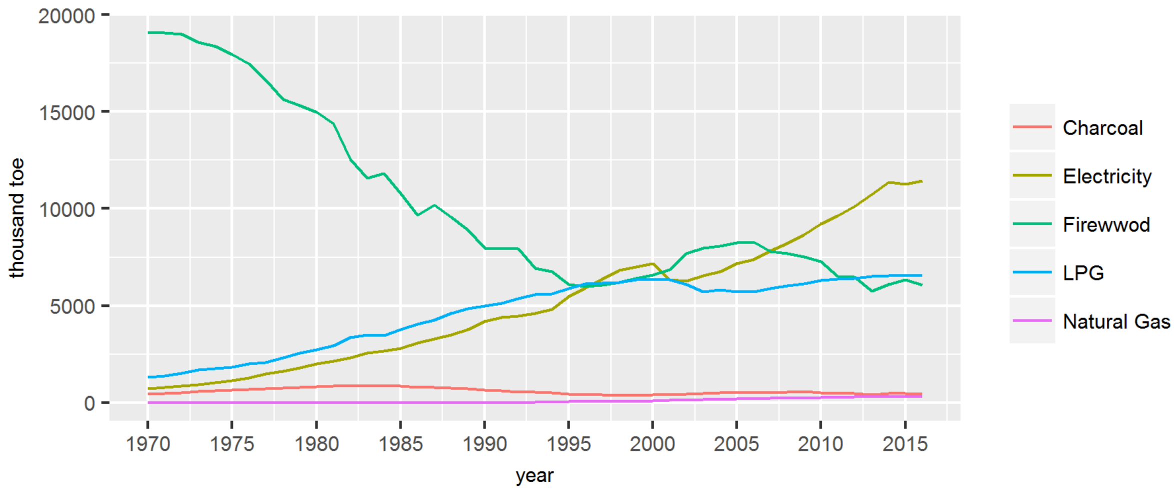
2 Consumption of cooking fuels in Brazil

The main fuels used by Brazilian families for cooking are firewood and LPG. Until the mid-1990's, firewood is the main source of energy used in dwellings. According to the National Energy Balance (BEN) of the Energy Research Office (EPE), in 1970, the consumption of biomass

[2]For a studies review about the multinomial approaches applied to fuel choice determinants by households, see Van der Kroon, Brouwer and Van Beukering (2013) [10].

corresponds to approximately fifteen times the consumption of LPG in the Brazilian residences. Over the following decades, the consumption of this energy source reduces, as shown in Figure 1, until it reaches the LPG consumption in the mid-1990s, a ratio that remains on average, nowadays.

Figure 1: Residential energy consumption



Source: EPE - Energy Research Office.

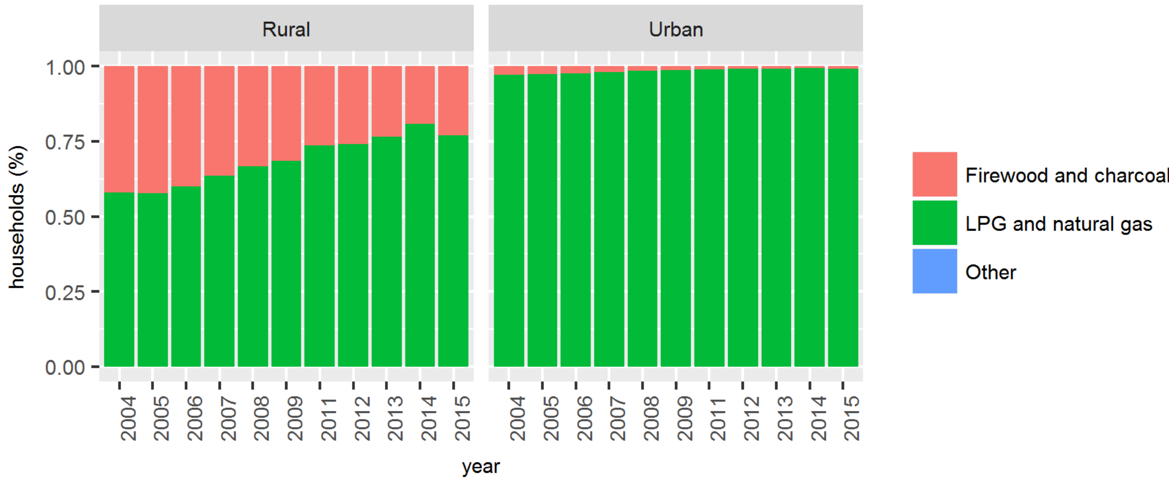
The increase in LPG consumption and the reduction of firewood consumption in Brazil are associated with policies implemented throughout this period. The Federal Government regulated the price of LPG from 1950 to 2001. In 2001, price of LPG was liberalized and the firewood consumption increased. Between 2002 and 2016, it was established differentiation policies for prices by type of LPG cylinders that aimed to reduces the 13 kilograms cylinders price, the most used by households [3].

Despite the increased participation of LPG in fuel consumption over the last decades, the use of traditional biomass is still relevant in rural Brazil. In 2016, according to IBGE, 9.5 million households are located in the rural area, which corresponds to 14% of the Brazilian households. Figure 2 shows the percentage of households by type of fuel used predominantly in the stove from 2004 to 2015. It is possible to observe that LPG and natural gas have large penetration in the urban area, reaching 99% of households in 2015. However, in the rural area - where firewood is a predominantly non-commercial source and it can be collected inside the property or near the residence [5] - traditional biomass use reaches 23% of households in 2015. It should be noted that, as mentioned previously, although 23% of rural households predominantly use biomass for cooking, According to PNADC (IBGE) data for 2016, 59% of Brazilian rural families used this fuel for cooking to some extent.

Additionally, Figure 2 shows a decrease in the participation of households that consume

[3]For a review of papers on LPG subsidy policies and the use of traditional biomasses in Brazil and Latin America, see Trancoso e Silva (2017) [9]

Figure 2: Participation of households by type of fuel



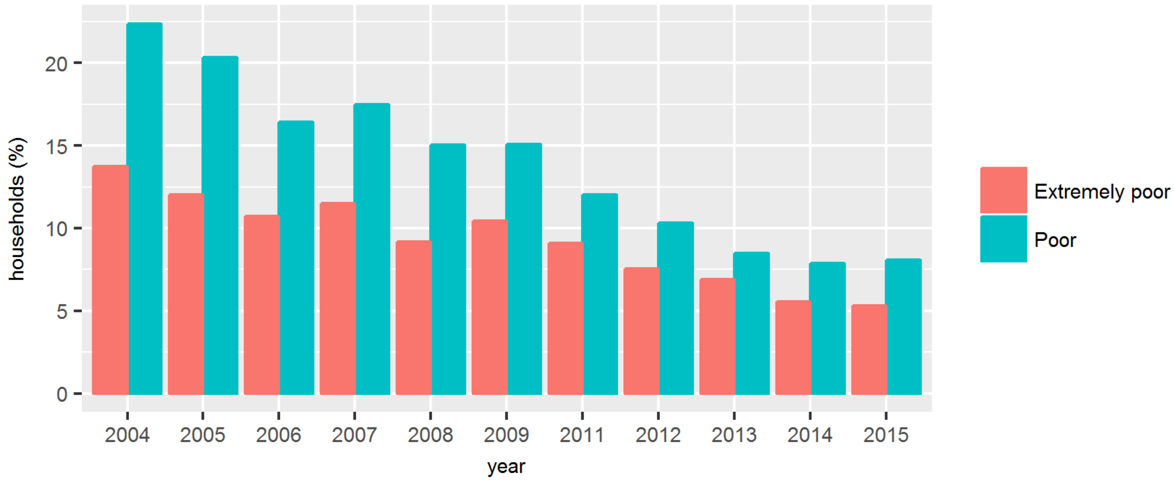
Fonte: Elaborado pelos autores, a partir de dados da PNAD/IBGE 2004-2015.

predominantly firewood and charcoal in the rural area. This reduction may be associated with public policies focused on the dissemination LPG use. Moreover, it may be associated with the household income increase observed during this period in Brazil. Figure 3 presents the percentage of extremely poor and poor household in the rural area. It can be seen that 36.2% were poor or extremely poor in 2004. In the following years, this proportion declined significantly, especially the percentage of poor, that reaches 13.4% by 2015.

According to the literature that aims to study the determinants of the inequality and poverty reductions in Brazil in this period, the improvement in the living conditions of the families, both in the urban area and in the rural area, would be associated with increases in labor income and non-labor income of households [4]. The increase in real labor income may be associated with consecutive increases of the national minimum wage, improved labor market conditions, and economic growth. On the other hand, the increases in non-labor income would be associated with public policies of conditional transfer of income, such as the Bolsa Família Program (PBF), which aimed to help poor and extremely poor families with children and adolescents, and the Benefício de Prestação Continuada (BPC) of the Organic Law of Social Assistance (LOAS), benefit of a monthly minimum wage, adjusted according to the national minimum wage readjustments, for persons with disabilities and elderly people aged 65 or over who prove that they do not have the means to provide their own and have no family help. For the rural area, in addition to the economic growth that could have positively impacted the production and commercialization of household products, PBF and BPC had a significant impact on the increase in non-labor household income. It should also be noted that pensions and retirement, also adjusted according to consecutive increases in the minimum wage, are also affected positively in the period.

[4]Some of these papers that have studied the determinants of the decline in inequality and poverty in Brazil for the period are: Hoffmann (2009) [3], Soares (2006) [7] e Barros, Foguel e Ulyssea (2006) [1].

Figure 3: Percentage of extremely poor and poor households in rural areas



Fonte: Elaborado pelos autores, a partir de dados da PNAD/IBGE 2004-2015.

3 Data and exploratory analysis

3.1 Data

In this study, we use the General Characteristics of Households from the Continuous National Household Sample Survey (PNADC) for the year 2016. The PNADC is a panel in which a household answer a questionnaire in a month and returns to the sample for the next interview two months later. The process repeats itself until the household answer the questionnaire five times. In summary, IBGE interview a household for five quarters, once in each quarter. However, the General Characteristics of Households are collected only at the first visit. Thus, the database is a polled cross-section, that is, it is a database with all the first interviews of households in 2016.

The PNADC data for the year 2016 covers the entire national territory and contain 459,718 individuals and 151,284 households. The units of analysis of this work are the 40,333 rural households, which declare to use one or some of the four types of fuels for food preparation, are: i) LPG, (ii) biomass, iii) electricity, and iv) other footnote The categories label in the PNADC are: i) bottled or piped gas, (ii) firewood or charcoal, iii) electricity, and i) other. . However, in this work, we consider that electricity and other fuels are predominantly complementary to LPG and biomass in the rural area. On the other hand, LPG and biomass may be a substitute or complementary fuels, as households may make concomitant use of both for food preparation or may stop consuming one of them if their price increases, for instance. Thus, for the food preparation process, LPG and firewood are the fuels that are probably within the rural household choice set. Thus, among the rural households, we chose to keep in the sample those that declare to use at least one of these two fuels, totaling 40,153 households.

3.2 Exploratory Analysis

From the sample of households defined above, we define three types of fuel combinations that the households can use in food preparation: i) exclusively biomass, ii) exclusively LPG, and iii) combination of LPG and biomass. Table 1 shows that about 59% of the households use biomass exclusively or concomitantly with LPG and only 6% use exclusively biomass.

Table 1: Household participation by type and combination of fuels

Fuels	Households (mil)	Participation (%)
LPG and Biomass	5063	53.80
LPG	3816	40.55
Biomass	531	5.64
Sum	9409	100.00

Source: Elaborated by the authors, based on data from the PNADC/IBGE 2016.

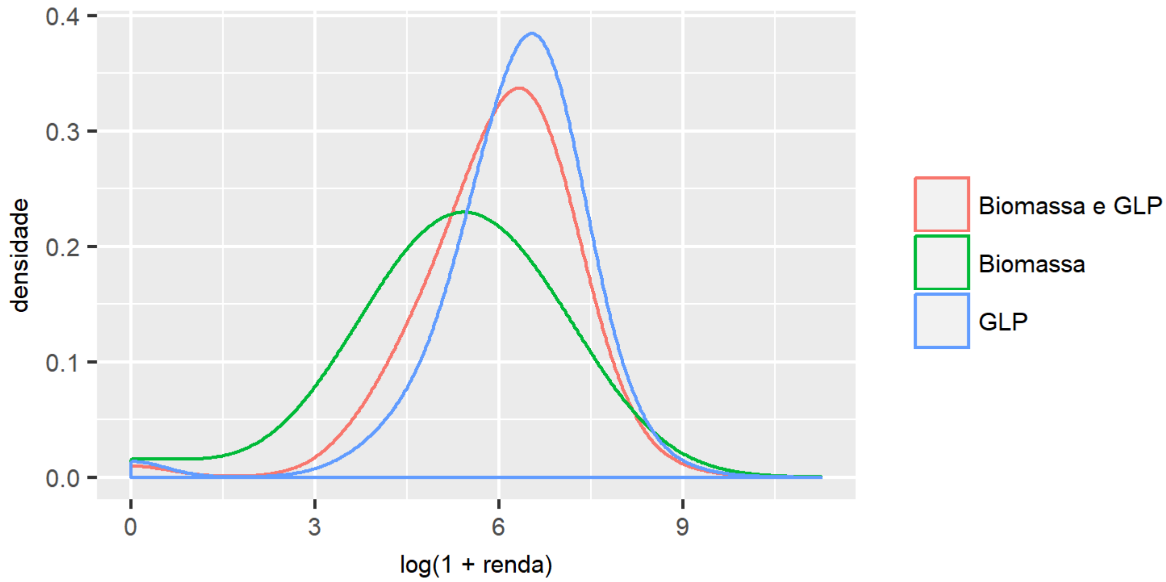
In Figure 4 we present the densities of the per capita household income variable for households that consume each of the three types of fuel combinations. From this figure, it is possible to verify that the frequency distributions of the households' income present different formats for the fuels combinations, both in terms of asymmetry, as well as in terms of kurtosis or density in the tails. Income density for households using exclusively LPG is the rightmost curve on the graph, indicating that the use of exclusively LPG would be more frequent among households with higher incomes. On the other hand, the density curve of households that use exclusively biomass is the one located to the left in the figure, which could show the relationship between monetary poverty and energy poverty. As we observe a gradual shift to the right of the family density curves, as we move from the exclusive use of biomass to the exclusive use of LPG, it would be possible to infer about the relation between the energy transition process and the income level of families. It should also be noted that as we move from the exclusive use of biomass to the exclusive use of LPG, the shape of the curves changes in a process of decreasing kurtosis and increasing the frequency concentration of families around central values. This decrease in kurtosis may indicate a greater homogeneity among the families that consume in some way LPG (either exclusively or concomitantly with biomasses) in terms of income.

A complementary analysis for the relationship between household monetary poverty and the energy poverty situation is presented in the Table 2, where we observe the frequency of poor and extremely poor households by fuels combination for cooking [5].

From our sample, 20.1% of the rural households are poor and 10.1% are extremely poor. Among the poor families, approximately 11% use biomass exclusively and 63% use LPG and biomass for cooking. These figures are, respectively, 15% and 57 % for extremely poor households. Among the non-poor, only 4% use biomass, but a high percentage (52%) use both fuels

[5] The poverty and extreme poverty is defined using the eligibility criteria of the Bolsa *Família Program* for 2016, respectively, 170.00 BRL (48.57 USD) and 85.00 BRL (24.29 USD).

Figure 4: Per capita income density by fuel



Source: Elaborated by the authors, based on data from the PNADC/IBGE 2016.

concomitantly. In this sense, the table shows that the main group of households dependent on biomass use are poor and extremely poor households and that the exclusive use of LPG between these families is considerably lower (26% and 28%) respectively than among non-poor households (44%). In addition, we carried out the same analysis for beneficiary families of the *Bolsa Família* Program (PBF), the Continuous Cash Benefit Program (BPC) [6], and families receiving income from pensions. Through these analyzes, it is possible to verify that the PBF and BPC beneficiary families are less dependent on the exclusive use of biomass. However, the beneficiary families present a greater participation in the concomitant use of firewood and LPG when compared to the totality of poor and extremely poor.

Table 2: Fuels by household groups (%)

Group	LPG and Biomass	Biomass	LPG
Extremely poor	57.26	14.78	27.96
Poor	62.90	11.30	25.80
PBF Beneficiary	60.98	8.08	30.94
BPC Beneficiary	59.80	7.88	32.32
Retirees and pensioners	61.76	4.47	33.77
Non-poor	52.40	4.00	43.60

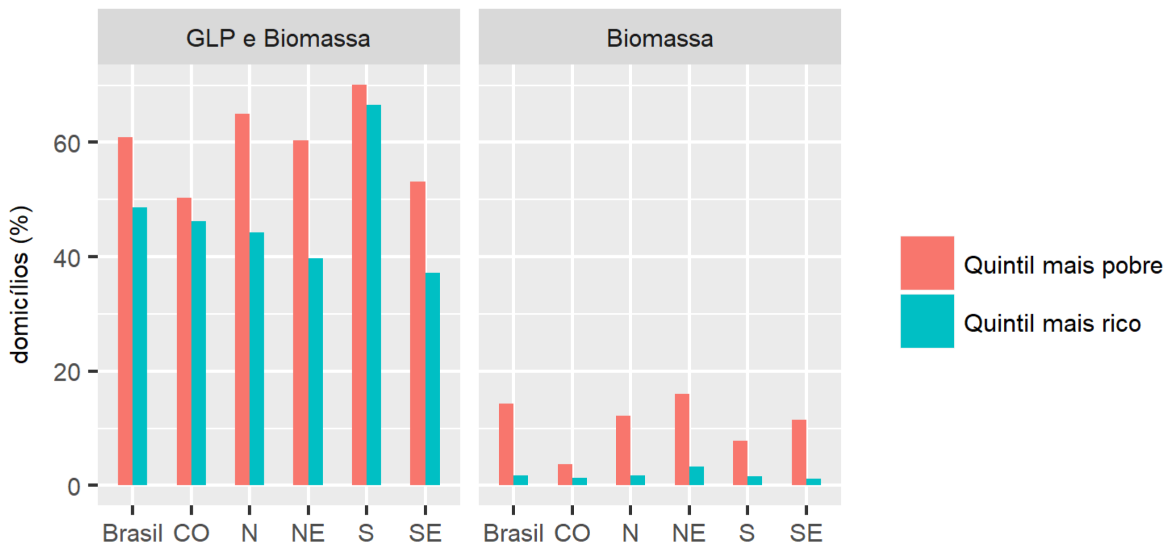
Source: Elaborated by the authors, based on data from the PNADC/IBGE 2016.

Finally, we analyze the relationship between household income and the cooking fuel use,

[6] To be eligible for the BPC, it is necessary that the households per capita income be less than 1/4 of the current Brazilian minimum wage.

for the five Brazilian regions, as shown Figure 5. The analysis is performed considering the distribution of the households of the richest quintile and the poorest quintile of the income distribution, by fuels combination and region. For all Brazilian regions, we observed that the dependence on the exclusive use of biomass is greater for the families of the poorest quintile of the income distribution, with the greatest differences among the quintiles found for the North (N) and Northeast (NE) regions of Brazil. This behavior is repeated for the dependence of the concomitant use of biomass and LPG, however, the differences in the participation of the poorest quintile and the richest quintile are lower in the South (S), Southeast (SE) and Center-West (CO) regions.

Figure 5: Fuel dependency by income quantile and region



Source: Elaborated by the authors, based on data from the PNADC/IBGE 2016.

4 Empirical Strategy

This study aims to analyze the relationship between monetary poverty and inadequate access to cooking fuels by households. We consider the technological approach for energy poverty that distinguishes poor and non-poor households in terms of their decisions on which fuels to use. [7].

In this context, among the several possible combinations of fuels, families choose the one that maximizes their indirect utility, subject to the family budget constraint. The choice of a particular combination of fuels will depend, among other factors, on the specific characteristics

[7]It should be highlighted that the access to a fuel by households, whether adequate or inadequate (in terms of efficiency, pollution, etc.) reflect theirs decision to use this fuel. That is, the supply is given and we observe an equilibrium result.

of each household. Thus, the regression equation is such that the dependent variable can be defined as a set of three possible fuel alternatives for food preparation: i) LPG, ii) firewood, and iii) LPG and firewood.

Assuming that a household i chooses one of these three possible combinations, the utility under the choice of the j combination can be given by:

$$y_{ij}^* = x_i\beta + \varepsilon_i j, j = 0, 1, 2 \tag{1}$$

where x_i is the vector of household observable characteristics, β is the vector of coefficients and ε are the household unobservable characteristics, which we assume to be independent and identically distributed, that is, we assume that the explanatory variables of the model are exogenous and not correlated with the unobservable characteristics of the households [8].

If the household chooses to consume the fuel or combination of fuels j, it maximizes its utility such that $y_{ij}^* > y_{ik}^*$, $\forall j \neq k$, or be y_i is the family i choice that maximizes its utility:

$$y_i = argmax(y_{i0}^*, y_{i1}^*, y_{i2}^*) \tag{2}$$

In the case of the present study, the observed choice is defined by a matrix with three binary, where each binary assumes a value equal to 1, whether the family choose is equal to j, and zero, otherwise. Such a set of choices may correspond to a multinomial logit model that presents a probability function given by [12]:

$$P(y = j|x) = \frac{exp(x\beta_j)}{1 + \Sigma_{h=1}^{j} exp(x\beta_h)}, j = 1, 2 \tag{3}$$

In estimating the regression equation of this model, we obtain a set of relative probabilities for the three choices, that is, the probability of choosing one fuel or set of fuels over another, which is the reference category. In this work, we chose as the baseline or reference category the exclusive use of LPG, for which we must then assume $\beta = 0$. It is important to say that since it is a nonlinear model, we estimate the equations of the model by the maximum likelihood method. Thus, a simpler interpretation of the coefficient β_j can be given by:

$$\frac{p_j(x, \beta)}{p_0(x, \beta)} = exp(x\beta_j), j = 1, 2 \tag{4}$$

where $p_j(x, \beta)$ is the probability given by the equation (3). Thus, a change in $p_j(x, \beta)/p_0(x, \beta)$ is approximately equal to $\beta_{jk} exp(x\beta_j)\Delta x_k$ for the x_k variable.

[8] It is important to highlight that the exogeneity hypothesis is strong, especially in the case of the variable of interest for which we aim to understand its role in energy poverty and income, and it may not be met, in which case we would be estimating the correlation between income and energy poverty of families and not a causal effect. However, this possibility does not disqualify the results found, since this study aims to understand how this relationship occurs, without the focus on an identification strategy.

Finally, it should be said that the set of family characteristics present in the vector x_i, is composed of some demographic and socioeconomic variables of the head of the family, such as: sex (binary for male), race/color (binary for white), age (continuous variable), marital status (binary for married), and years of study (continuous variable). In addition, we have introduced controls for the geographical regions of Brazil and for the quarters of the year, since it is a pool data of the first visits of the PNADC, it is possible that the data collection was carried out at any one of the year. In addition, this variable for quarters allows controlling for any unobservable events or seasonalities associated with any particular period.

5 Results

Table 4 shows the logit multinomial results. In Model (1), the variable of interest is the logarithm of the per capita household income, while in the Model (2) the variables of interest are the binary for poverty and extreme poverty. As detailed in the empirical strategy section, the estimated parameters, both for the combined use of LPG and biomass and for the exclusive use of biomass, are based on the exclusive use of LPG, that is, the latter category is omitted.

The parameters of the Model 1 variable of interest, per capita household income, are negative and statistically significant. The results show that the increase in household income per capita, controlling for other family characteristics and other variables, reduces the probability of using the combination of biomass and LPG. Moreover, the increase in household income per capita reduces, even more, the probability of exclusive use of biomass in relation to the probability of exclusive use of LPG. If we consider the energy transition towards the exclusive use of LPG as an indication of energy poverty reduction, it would be possible to infer that the energy poverty decreases when the household income increases. In other words, the results suggest a positive relationship between monetary poverty and energy poverty.

In the Model 2, where we replace the per capita household income by the binary for poverty and extreme poverty, the relationship between monetary poverty and energy poverty is even more evident. The positive parameters for extreme poverty indicate that the relative probability of exclusive use of firewood and the relative probability of combined use of the two fuels increases whether a household income is less than 85 BRL (24 USD). For poor households, with per capita household income up to 170 BRL (48 USD), the relative probabilities are also positive. It is important to point that extremely poor household presents a higher relative probability of exclusive use of firewood, while poor household presents a greater relative probability of combined use of fuel. Therefore, as the households have higher levels of income and distance themselves from a situation of more severe monetary poverty, they start to consume clean fuels in some measure and decrease their dependence on biomass towards to a situation of less energy deprivation.

As indicated in the previous section, it is difficult to interpret the coefficients values of Table

Table 3: Resultados do Logit Multinomial

Variáveis	(1)		(2)	
	Biomassa e GLP	Biomassa	Biomassa e GLP	Biomassa
Renda per capita(log)	-0.218***	-0.417***	-0.216***	-0.415***
	(0.0118)	(0.0150)	(0.0117)	(0.0148)
Preço do GLP			2.443***	3.917***
			(0.136)	(0.259)
Chefe homem	0.0684***	0.420***	0.0663***	0.417***
	(0.0240)	(0.0530)	(0.0240)	(0.0531)
Chefe branco	-0.159***	-0.584***	-0.149***	-0.571***
	(0.0228)	(0.0516)	(0.0229)	(0.0515)
Idade do chefe	0.0158***	-0.0111***	0.0157***	-0.0114***
	(0.000806)	(0.00168)	(0.000805)	(0.00168)
Chefe casado	0.485***	-0.340***	0.480***	-0.351***
	(0.0250)	(0.0494)	(0.0250)	(0.0495)
Anos de estudo do chefe	-0.0955***	-0.226***	-0.0961***	-0.228***
	(0.00301)	(0.00748)	(0.00301)	(0.00746)
regiao = 1, N	0.909***	0.486***	0.703***	0.175**
	(0.0358)	(0.0818)	(0.0377)	(0.0863)
regiao = 2, NE	0.309***	0.343***	0.405***	0.507***
	(0.0275)	(0.0648)	(0.0275)	(0.0628)
regiao = 4, S	1.210***	0.891***	1.177***	0.855***
	(0.0336)	(0.0824)	(0.0335)	(0.0824)
regiao = 5, CO	0.353***	-0.679***	0.0184	-1.228***
	(0.0411)	(0.130)	(0.0462)	(0.142)
trimestre = 2, 2	0.0788***	0.140**	0.0802***	0.148**
	(0.0274)	(0.0574)	(0.0273)	(0.0573)
trimestre = 3, 3	0.0827***	0.122**	0.0872***	0.135**
	(0.0273)	(0.0566)	(0.0273)	(0.0567)
trimestre = 4, 4	0.136***	0.0310	-0.0209	-0.225***
	(0.0276)	(0.0568)	(0.0293)	(0.0598)
Ano = 2017	0.145***	0.124***	0.0283	-0.0543
	(0.0195)	(0.0403)	(0.0205)	(0.0427)
Constant	0.404***	1.530***	-9.470***	-14.31***
	(0.0818)	(0.147)	(0.559)	(1.049)
Observações	80,163	80,163	80,163	80,163

Desvio Padrão robusto em parênteses
*** p<0.01, ** p<0.05, * p<0.1

4. Thus, we calculate the relative risk ratio for the variables of interest, as shown in Table **??**. Relative risk greater than one indicates that the probability of choosing a particular fuel combination increases as the value of the variable of interest increases, relative to the probability of using LPG alone, the reference category. On the other hand, if the relative risk is less than

Table 4: Resultados do Logit Multinomial

Variáveis	(1)		(2)	
	Biomassa e GLP	Biomassa	Biomassa e GLP	Biomassa
estrato = 1, extpobre	0.709***	1.633***	0.710***	1.633***
	(0.0397)	(0.0590)	(0.0395)	(0.0588)
estrato = 2, pobre	0.805***	1.482***	0.804***	1.476***
	(0.0413)	(0.0645)	(0.0412)	(0.0646)
Preço do GLP			2.475***	3.933***
			(0.137)	(0.262)
Chefe homem	0.0641***	0.480***	0.0623***	0.477***
	(0.0240)	(0.0533)	(0.0239)	(0.0534)
Chefe branco	-0.177***	-0.601***	-0.167***	-0.586***
	(0.0228)	(0.0516)	(0.0229)	(0.0515)
Idade do chefe	0.0142***	-0.0100***	0.0142***	-0.0103***
	(0.000754)	(0.00172)	(0.000754)	(0.00172)
Chefe casado	0.503***	-0.390***	0.497***	-0.401***
	(0.0248)	(0.0492)	(0.0248)	(0.0493)
Anos de estudo do chefe	-0.101***	-0.226***	-0.102***	-0.227***
	(0.00291)	(0.00749)	(0.00291)	(0.00747)
regiao = 1, N	0.913***	0.438***	0.701***	0.127
	(0.0359)	(0.0825)	(0.0379)	(0.0867)
regiao = 2, NE	0.316***	0.281***	0.413***	0.445***
	(0.0272)	(0.0653)	(0.0272)	(0.0631)
regiao = 4, S	1.178***	0.855***	1.145***	0.819***
	(0.0332)	(0.0813)	(0.0332)	(0.0814)
regiao = 5, CO	0.329***	-0.691***	-0.00990	-1.242***
	(0.0408)	(0.128)	(0.0458)	(0.141)
trimestre = 2, 2	0.0842***	0.149***	0.0856***	0.156***
	(0.0274)	(0.0574)	(0.0274)	(0.0574)
trimestre = 3, 3	0.0853***	0.128**	0.0897***	0.141**
	(0.0274)	(0.0568)	(0.0274)	(0.0569)
trimestre = 4, 4	0.142***	0.0497	-0.0170	-0.207***
	(0.0276)	(0.0569)	(0.0293)	(0.0598)
Ano = 2017	0.142***	0.125***	0.0243	-0.0556
	(0.0196)	(0.0404)	(0.0205)	(0.0429)
Constant	-0.945***	-1.294***	-10.94***	-17.19***
	(0.0618)	(0.137)	(0.556)	(1.059)
Observações	80,163	80,163	80,163	80,163

Desvio Padrão robusto em parênteses
*** p<0.01, ** p<0.05, * p<0.1

one, the relative probability decreases.

According to the table, the relative risk of consuming some biomass (exclusively or combined

Table 5: Relative Risk Ratio

Variables	LPG and Biomass	Biomass
Per capita income (log)	0.797***	0.651***
	(0.0141)	(0.0145)
Extremely poor	1.996***	4.923***
	(0.1209)	(0.4265)
Poor	2.186***	4.025***
	(0.1252)	(0.3595)
Observations	40,153	40,153

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

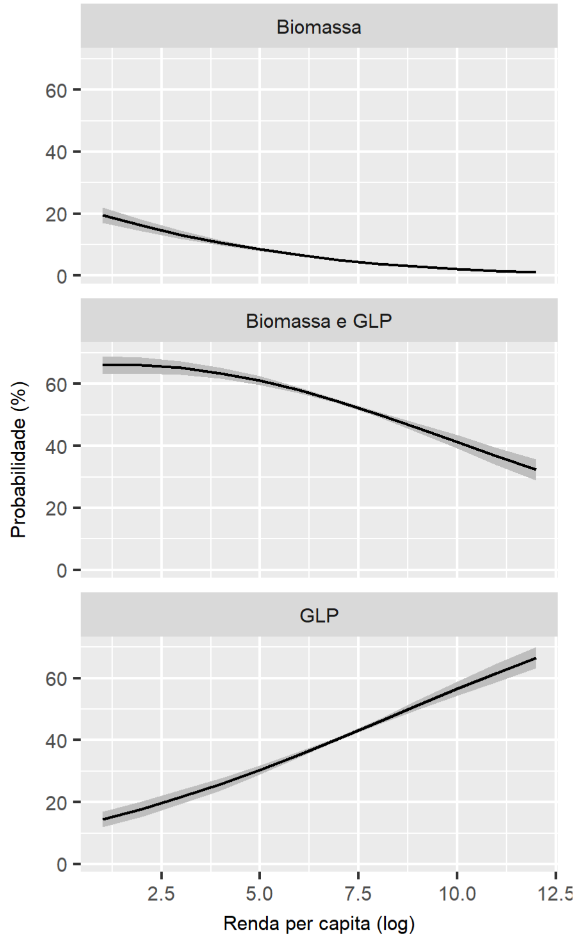
with GLP) reduces when the per capita household income increases, as suggested in 4. However, when we replace the per capita household income by the binary for poverty and extreme poverty, Model 2, the relative chance of extremely poor households to use exclusively biomass is about five times higher than the risk of using exclusively LPG, which, in the case of poor households, is approximately four times greater. In the case of the combined use of biomass with LPG, this relative chance is about twice, for both groups.

Figure 6 shows the marginal effect predicted values for per capita income. We calculate the marginal effect for each per capita income quantile, considering the average value of the other variables. It is possible to note an inverse relationship between household incomes and the probability of using biomass (combined or not with LPG) and a direct relationship between the exclusive use of LPG and income. Household in the first income quantile a probability of about 66.0% of using the combination of biomass and LPG and a probability of 19.5% of using biomass exclusively. It should be noted that with the increase in income because it is a convex curve, the probability of using exclusively biomass reduces faster than the probability of consumption combined with LPG. This latter result can be explained by the heterogeneity of the combined use of LPG and biomass, that is, the participation of the use of each fuel in the total energy use by the families of this group can present great variations.

Therefore, the results of multinomial logit estimation allow us to observe a relationship between income and the choice of cooking fuels used by households. Insofar as we find that households with higher incomes or non-poor are more likely to consume LPG exclusively (a clean fuel, more efficient and lower risks to the health of families) we can infer that energy poverty is one more side of a large and multidimensional phenomenon of deprivation, the monetary poverty of the families, the lack of sufficient resources to guarantee the maintenance and minimum conditions of well-being to the individuals.

However, despite the high relative risk of inadequate fuel use faced by poor and extremely poor families, the results suggest that in rural areas, the probability of exclusive use of biomass, which would reflect a higher degree of deprivation of households is not as high compared with poorer

Figure 6: Marginal effect predicted value with 95% confidence interval



countries in sub-Saharan Africa, even for poor and extremely poor households, for instance. The highest probability is that of concomitant use of solid fuel and clean fuel, that is, of an intermediate situation of energy deprivation, in which families still can not completely replace biomass by LPG. In other words, energy poverty in the country would be characterized by the relatively high chance of families, mainly poor and extremely poor, partially consuming inadequate fuels.

6 Conclusions

This work aims to analyze the relationship between income and inadequate access to cooking fuels in Brazil. We use the PNADC microdata from 2016 with Brazilian households characteristics from the rural area. Under the concept of energy poverty based on the technological approach, we estimate a multinomial logit for a set of three possible alternatives of fuel choice: LPG, firewood, LPG and firewood. The models include several control variables related to household preferences.

The results suggest that the increase in per capita household income reduces the probability of concomitant use of biomass and LPG and reduces, even more, the probability of exclusive use of biomass. The inclusion of binary variables for poverty and extreme poverty in the model makes the relationship between monetary poverty and household energy poverty even more evident since extremely poor households show a greater probability of exclusive use of biomass and poor households show a higher probability of concomitant use of biomass and LPG.

These results allow us to corroborate the hypothesis of a relationship between monetary poverty and household energy poverty. Moreover, as extremely poor households show a greater probability of exclusive use of biomass and poor households show a higher probability of concomitant use of biomass and LPG, we can understand that the energy transition process and a general improvement of household life conditions occur in the same time. In other words, energy poverty is only one of the faces of multidimensional family poverty.

Finally, it important to highlight that, as the international literature on energy poverty point, the major limitation for carrying out more complex studies that take into account consumption and access to cooking fuels is the availability of adequate microdata in Brazil. However, although under the limitation of available data, the results confirm the existence of the relationship between income and energy poverty in the Brazilian rural area.

In future extensions of this study, we intend to include the analysis the role of public policies that have been affected the household income over the last decade, such as conditional cash transfer programs. Hence, it will be possible to discuss policies designs focused on reducing not only household monetary poverty but also policies that could allow the energy transition of the poor and extremely poor household to occur faster.

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