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# The energy transition history of fuelwood replacement for liquefied petroleum gas in Brazilian households from 1920 to 2016

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ABSTRACT

In Brazil, there are almost ten million people relying on traditional use of biomass for cooking, which correspond to about five percent of the country's population. The vast majority lives in poor municipalities away from urban centers. The replacement of fuelwood for LPG is the result of an intense urbanization process and governmental intervention based on price regulation and subsidies. In 2015, the energy demand for cooking in the Brazilian households was 46 TJ, LPG covered 51% of the demand and the remaining 49% relied on fuelwood to supply the demand for energy. This study shows that there are enormous variations in the level of consumption and the types of fuels used due to the regional complexity of Brazil. In addition, it also shows the transition from fuelwood for cooking to modern fuels such as LPG does follow a consistent pattern in Brazil. Decisions related to energy consumption and fuel type are strongly influenced by accessibility, affordability and the convenience of the fuel.

## 1. Introduction

There were 1.1 billion people without energy access worldwide and 2.8 billion people – 38% of the world's population – using mostly fuelwood for cooking and heating in 2015 (IEA, 2017a, b). To address these problems, the UN Secretary General established the Advisory Group on Energy and Climate Change (AGECC), which recommended the ambitious goal of ensuring *"access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses"* by 2030 in poor countries (UN AGECC, 2010). Later, this ambitious initiative was consolidated by the Sustainable Development Goals (SDG), in particular by the SDG 7 that is to ensure access to affordable, reliable, sustainable and modern energy for all by 2030 (UN, 2017).

Currently wood-based energy makes up more than 65% of the global share of renewable energy. In some developing countries, more than 90% of their inhabitants rely exclusively on fuelwood, charcoal and crop residues for cooking and heating (Sepp et al., 2014). In addition, the traditional use of fuelwood is often not sustainable as it is not only energy inefficient and contributes to deforestation but also contributes to indoor air pollution, which is a considerable health hazard (Carvalho et al., 2016; Sepp et al., 2014; Traeger et al., 2017).

In Brazil there are almost ten million people relying on traditional use of biomass for cooking, which corresponds to about five percent of the country's population (IEA, 2017a, 2017b). The clear majority lives in poor municipalities away from urban centers. These low-income families lack access to modern fuels and are exposed to indoor air pollution during cooking, which has a wide range of negative health impacts. In Brazil, the access to clean fuels and technologies for cooking has increased 23% (e.g. from 76% to 95%) between 1990 and 2015 and the death rate from diseases related to indoor air pollution in Brazil has declined 70% in the same period (IHME, 2016; WBG, 2017). Therefore, a one-percentage point increase in access to clean fuels and technologies for cooking in Brazil leads to a three-percentage point decrease in the death rate from diseases related to indoor air pollution, which is a noteworthy benefit.

In this context, the main objective of this analysis is to review the energy transition history of fuelwood replacement for liquefied petroleum gas (LPG) for cooking in Brazilian households from 1920 to 2016 and its impacts in the country to identify key factors of this energy transition. It is important to mention that this analysis focuses only on energy consumption and does not cover in-depth the impacts on health.

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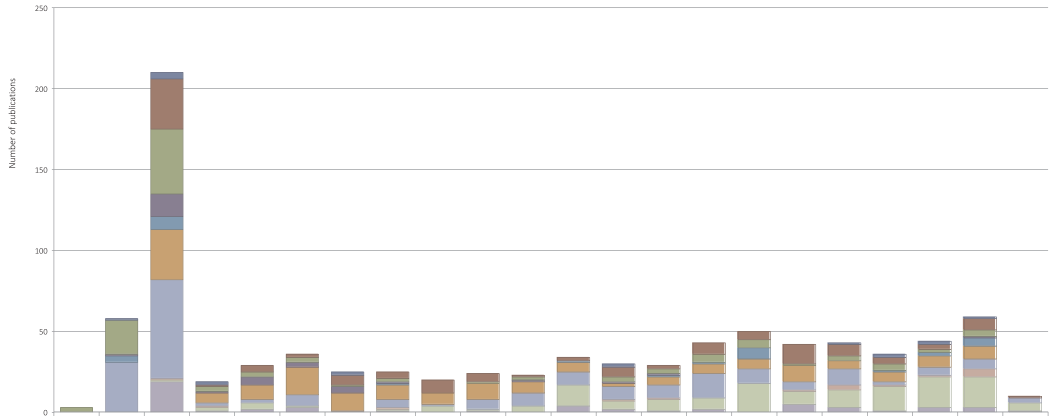



| | 1970s | 1980s | 1990s | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 Manuscripts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Applied Energy | 0 | 1 | 4 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 1 | 0 |
| Biomass and Bioenergy | 0 | 0 | 31 | 1 | 4 | 2 | 6 | 4 | 8 | 5 | 1 | 2 | 6 | 2 | 7 | 5 | 12 | 7 | 4 | 3 | 7 | 1 |
| Energy | 3 | 21 | 40 | 3 | 3 | 3 | 1 | 2 | 0 | 1 | 2 | 0 | 3 | 3 | 5 | 5 | 1 | 3 | 4 | 2 | 4 | 0 |
| Energy Conversion and Management | 0 | 1 | 14 | 1 | 5 | 3 | 4 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Energy Economics | 0 | 4 | 8 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 7 | 0 | 0 | 1 | 2 | 5 | 0 |
| Energy for Sustainable Development | 0 | 0 | 31 | 6 | 9 | 17 | 11 | 9 | 7 | 10 | 7 | 6 | 2 | 5 | 6 | 6 | 10 | 5 | 6 | 7 | 8 | 0 |
| Energy Policy | 0 | 31 | 61 | 2 | 2 | 7 | 0 | 5 | 1 | 6 | 8 | 8 | 8 | 8 | 15 | 9 | 5 | 10 | 2 | 5 | 6 | 3 |
| Journal of Cleaner Production | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 3 | 1 | 1 | 5 | 0 |
| Renewable and Sustainable Energy Reviews | 0 | 0 | 1 | 2 | 4 | 1 | 0 | 1 | 4 | 1 | 4 | 13 | 5 | 7 | 7 | 18 | 8 | 11 | 15 | 19 | 19 | 5 |
| Renewable Energy | 0 | 0 | 19 | 1 | 2 | 3 | 1 | 1 | 0 | 1 | 0 | 4 | 2 | 1 | 2 | 0 | 5 | 3 | 1 | 3 | 3 | 1 |

**Fig. 1.** Distribution of published papers per publication title between 1978 and 2017, plus accepted manuscripts for publication in 2018.

### *1.1. Methodological approach*

There is great uncertainty around fuelwood consumption in Brazil, especially when it covers long periods (Brito, 1997; Nogueira et al., 2004; Uhlig, 2008). Therefore, the review of the Brazilian fuelwood consumption since the 1920s suffers from lack of data and unreliable conversion factors. While lack of data is a straightforward limiting factor, unreliable conversion factors for accounting cover primary data from various sources that often do not use same measurement units, especially in the case fuelwood consumption in Brazil. Energy sources should be measured in mass or weight or even in volume but an essential factor is the amount of energy contained in these sources, which is hardly covered. Uncertainty in conversion factors limits the possibility of comparison and exchange of data among these sources. For example, the lack of identification of the unit of volume, if it is in *cubic meter solids* or *cubic meter stère*, can represent a difference of 20% (Uhlig, 2008). To tackle these problems, the methodological approach taken in this analysis relied on two methods.

The first method was exploratory research to cover the period before official publications and collected data from informs, historical accounts, population census and news about fuel consumption in the country between 1920 and 1969. Data gathering used meta-analytic statistical techniques, which combined the results from multiple historical sources in an effort to improve estimates and to reduce uncertainty (Shields and Rangarajan, 2013). From 1970 onwards, secondary data were collected from governmental institutions, statistical databases (e.g. energy balance reports, household sample surveys, and consumer expenditure surveys), and reports from relevant stakeholders. These documents were used to complement and validate processed information about fuel consumption for cooking in Brazil (Searcy and Mentzer, 2003).

The second method was archival research, which aims at providing an in-depth account of fuelwood and LPG consumption figures based on academic publications. In addition, the archival research method was used to conduct a literature review. This method comprises the following steps (Searcy and Mentzer, 2003):

- *Defining the database source:* the chosen database was the *ScienceDirect*, which is the world's leading platform for peer-reviewed journals of high quality and full-text books. The Anglo-Dutch publisher Elsevier operates the database and it is a platform for access to nearly 2500 academic journals and over 26,000 books.
- *Delimitation of scope:* the range of 42 years delimits the research. The material collection was conducted between the years 1975 and 2017. It included also manuscripts that are accepted for publication in 2018.
- *Defining unit of analysis:* the analytical unit chosen was a single research paper written in English.
- *Classification context:* during the classification steps, we defined three analytical samples. For example, the first sample was defined by selecting the following terms and Boolean connectors, "residential" OR "household" AND "fuelwood" AND "cooking". The second sample contained the highest ranked publications in a given subject area. Finally, the third sample used search filters focused on two topics: "modern fuels" and "clean fuels".

The first sample contained 1735 published papers in high-quality peer-reviewed journals between 1975 and 2017, from which 20 were manuscripts accepted for publication in 2018. The second sample selected 901 research papers based on the *SCImago Journal Rank* (SJR indicator). The SJR indicator is a measure of scientific influence of academic journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where such citations come from. Hence, the second sample limited research papers from publication titles with high SJR indicator in energy as the subject area. The requirement was that all selected publication titles must be classified as Q1, which means the highest values or the top 25% journals in a given subject area. Fig. 1 shows the distribution of published papers per publication title from 1978 to 2017, plus ten selected manuscripts accepted for publication in 2018.

The third and final sample is to look at the abstract and conclusions of the remaining articles and categorize them by content and determine which articles are most relevant for the Brazilian context. In doing so, the literature review showed that a considerable number of works has been published. However, among the 901 selected published papers, only 17 of them assess energy consumption in Brazil and are listed in Table 1.

Amongst all 17 published papers, only four of them – Brito (1997), Lucon et al. (2004), Sgarbi et al. (2013), and Sanches-Pereira et al. (2016) – directly mentioned fuelwood consumption for cooking and provided relevant information for assessing its replacement for LPG in the country (Brito, 1997; Lucon et al., 2004; Sanches-Pereira et al., 2016; Sgarbi et al., 2013). However, it is still imperative to review and compile updated information not only from energy consumption for cooking in Brazilian households but also from underlying key factors behind the energy transition pattern (i.e. replacement of fuelwood for

**Table 1**
Published papers on energy consumption in Brazil.

| Publication Title | Year | Author | Title |
|---|---|---|---|
| Energy Policy | 1991 | Graca, G et al. (Graca and Ketoff, 1991) | $CO_2$ savings in Brazil: The importance of a small contribution |
| Biomass and Bioenergy | 1991 | Better, D et al. (Betters et al., 1991) | Short rotation woody crop plantations in Brazil and the United States |
| Energy Policy | 1992 | Hall, D et al. (Hall et al., 1992) | Biomass energy: Lessons from case studies in developing countries |
| Energy Policy | 1994 | La Rovere E (La Rovere E et al., 1994) | Alternative energy strategies for abatement of carbon emissions in Brazil A cost-benefit analysis |
| Biomass and Bioenergy | 1997 | Brito, J (Brito, 1997) | Fuelwood utilization in Brazil |
| Renewable Energy | 2001 | Tiba, C (Tiba, 2001) | Solar radiation in the Brazilian Northeast |
| Energy for Sustainable Development | 2002 | Goldemberg, J et al. (Goldemberg et al., 2002) | Brazilian energy matrix and sustainable development |
| Energy Policy | 2004 | Goldemberg, J et al. (Goldemberg et al., 2004) | How adequate policies can push renewables |
| Energy Policy | 2004 | Geller, H et al. (Geller et al., 2004) | Policies for advancing energy efficiency and renewable energy use in Brazil |
| Energy for Sustainable Development | 2004 | Lucon, O et al. (Lucon et al., 2004) | LPG in Brazil: lessons and challenges |
| Biomass and Bioenergy | 2006 | Wright, L (Wright, 2006) | Worldwide commercial development of bioenergy with a focus on energy crop-based projects |
| Biomass and Bioenergy | 2013 | Sgarbi, F et al. (Sgarbi et al., 2013) | Fuelwood as an energy source for the commercial cooking sector – An overview analysis focused in the city of São Paulo, Brazil |
| Renewable and Sustainable Energy Reviews | 2016 | Sanches-Pereira, A et al. (Sanches-Pereira et al., 2016) | Evolution of the Brazilian residential carbon footprint based on direct energy consumption |
| Energy Policy | 2017 | Hunsberger, C et al. (Hunsberger et al., 2017) | Unbundling" the biofuel promise: Querying the ability of liquid biofuels to deliver on socio-economic policy expectations |
| Renewable and Sustainable Energy Reviews | 2017 | Pereira, E et al. (Pereira et al., 2017) | Pyrolysis gases burners: Sustainability for integrated production of charcoal, heat and electricity |
| Biomass and Bioenergy | 2017 | Cervone, C et al. (Cervone et al., n.d.) | Resident perceptions of the impacts of large-scale sugarcane production on ecosystem services in two regions of Brazil |
| Energy Policy | 2017 | Troncoso, K et al. (Troncoso and Soares da Silva, 2017) | LPG fuel subsidies in Latin America and the use of solid fuels to cook |

LPG), particularly because of the limited number of publications in the topic and their time gaps.

Systematization of data gathered about direct energy consumption for cooking per income level used consumer expenditure surveys and household sample surveys as guideline to divide the number of households into income deciles (Uchôa, 2014). These income deciles are groupings that are the result of ranking all households in ascending order according to income and dividing them into ten equal groups. Each group comprises approximately ten 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 ten percent (Sanches-Pereira et al., 2016).

The research structure is presented as follows; Section 1 highlights the problem, objective, and methodological approach. Section 2 presents a historical overview of the household energy consumption for cooking in Brazil and its regional disparities. Section 3 presents the key factors for energy transition and its impacts on cooking fuel consumption. In addition, this section shows an analysis and discussion about their relevance in the Brazilian context. Section 4, finally, presents the concluding remarks and policy implications.

## 2. Review of household fuel consumption for cooking and its energy transition patterns since 1920

In 1920, Brazil was a rural country with a total population of 30.6 million people using mainly fuelwood as energy source for cooking. By 1939, only 395 households in the city of Rio de Janeiro used LPG. Due to a successful marketing campaign, in which described the use of LPG as a cleaner and modern way to cook, the number of households reached 5160 in 1942. From then on, companies such as Standard Oil entered the market and consumption reached 10,000 metric tons (t) of LPG in 1949 compared to 30 t in 1939 (Silva, 2007). Until 1955, there was no direct intervention from the Brazilian government in the LPG price. Its price was the result of the sum of costs of importing plus port charges and expenses with distribution and resale (Morais, 2005). During this period, LPG was used mostly in large cities.

From 1955 until 1973, the Brazilian government starts to regulate LPG prices to foster local fossil fuel production. As a result, the government implanted policies encouraging the use of oil derivatives – such as LPG – in more distant regions by adopting the standardization of prices (Morais, 2005).

LPG subsidies started in 1973 and in the 1990s, the LPG price policy began to be adapted to the introduction of a market economy, initiating a gradual process of price liberalization and withdrawal of subsidies by the end of 2000. During this period, between 1973 and 2000, the fuelwood consumption decreased about 65%, which shows the success of governmental intervention on replacing traditional biomass by a cleaner and modern fuel in the Brazilian households. However, with the end of subsidies, there was an increment in fuelwood consumption, which gained momentum until 2006 (Jannuzzi and Sanga, 2004). In fact, the removal of the price subsidy from LPG resulted in an immediate increase of 17% in the average retail price and a decrease of more than five percent in the households' LPG consumption (Jannuzzi and Sanga, 2004). As LPG prices became deregulated and collective subsidies to all customers were eliminated, the Brazilian government implemented a social policy to assist low-income families in purchasing LPG through a voucher (e.g. *auxílio gás*, in Portuguese). Unlike the subsidy system, in which every LPG user in the country was subsidized, the benefits of this new program were only available to low-income families living with an income no higher than half of the minimum-wage (e.g. it corresponds to a family of four living with a little more than USD[1] 2.00 per day in 2002) (Jannuzzi and Sanga, 2004).

The LPG voucher was one of many social programs under the Brazilian Social Protection Network (i.e. *Rede de Proteção Social,* in Portuguese) and consisted in the payment of USD 10.00 every two months for each low-income family. In average, the price for a domestic LPG canister containing 13 kg (kg) during this period was almost USD

[1] All monetary values presented in this work use a fixed exchange rate of 1.00 USD (United States Dollar) to 3.35 BRL (Brazilian Real). In addition, all historical monetary values in BRL were adjusted to real values on December 2016 by using the Extended National Consumer Price Index (IPCA), which measures the change in prices of a fixed set of goods and services that compose the expenditure of average Brazilian families, with income levels between 1 and 40 minimum monthly wages (IBGE, 2017).

20.00. Despite reaching thousands of families, it was concluded that the voucher was not effectively helping and that many low-income families still could not buy LPG canisters regularly, which in turn fostered the return to fuelwood as the primary energy source for cooking in low-income households (Government of Brazil, 2017; MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010).

In late 2003, all programs belonging to the Social Protection Network – including the LPG voucher – were incorporated into a single program, the Family Allowance Program (i.e. *Programa Bolsa Família*, in Portuguese) (Government of Brazil, 2017). The Family Allowance Program is a direct income transfer program that benefits families living in poverty and extreme poverty in the country below the established limits, which are:

- Families in extreme poverty are those with per capita income of up to USD 23.00 per month;
- Poor families are those with per capita income between USD 23.01 to USD 46.00 per month; and
- Those who are poor or extremely poor and have pregnant, nursing mothers, and minors between 0 and 17 years-old receive an allowance value greater than that provided to families without children, adolescents or pregnant women.

It is important to mention that the highest allowance paid in the history of the program was USD 398.00 for a family of 19 members in 2012. Another interesting aspect of the program is that, among the allowance holders, 93% have a woman as the head of the family. Of the total number of people who benefit from the program, 56% are women and 44% are men. According to the Brazilian government, in April 2014, the Family Allowance Program was paid to 14 million families, reaching about 50 million people (Government of Brazil, 2016). Apart from its positive impacts on women's role in society, the Family Allowance Program has also helped to reduce the wage gap in the country. In fact, it contributed to a 28% decrease in total poverty and the fuelwood consumption by 22% (Ali, 2015).

Hence, the replacement of fuelwood for LPG is not only the result of an intense urbanization process and governmental intervention based on price regulation and subsidies but also the result of several strong social development policies such as the Family Allowance Program. Currently, the majority of Brazilian citizens live in urban areas and large cities. Fig. 2 the household energy consumption for cooking per type of fuel between 1920 and 2015 in TJ. It also shows key moments of governmental interventions in the period that fostered the fuelwood replacement for LPG (MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010).

In short, the successful replacement of fuelwood for LPG could only be achieved in Brazil through a system-wide energy transition driven by governmental policies, which can be divided into six well-defined periods until 2016:

- *Period 1*, from 1920 to 1955, in which there were no direct interventions;
- *Period 2*, from 1955 to 1973, in which governmental incentives for fossil fuel consumption, including LPG, were introduced;
- *Period 3*, from 1973 to 2001, in which the government provided LPG subsidies to all citizens;
- *Period 4*, from 2001 to 2002, in which the government removed subsidies and LPG prices became deregulated;
- *Period 5*, from 2002 to 2004, in which the government implemented a social policy to assist low-income families in purchasing LPG through a voucher.
- *Period 6*, from 2004 onwards, in which the government establishes a direct income transfer program that benefits families living in poverty and extreme poverty in the country, the Family Allowance Program.

### *2.1. Regional characteristics of household fuel consumption for cooking in Brazil*

Currently, fuelwood and LPG are the main energy carriers for cooking in Brazil. Essentially, LPG is composed of two fossil-based gases extracted from petroleum, butane and propane; it may also contain in its mixture a trace amount of other hydrocarbons such as ethane. The fuel is colorless and to make handling safer, a sulfur-based compound is added so as to make it perceptible to human smell in case of leakage. These energy carriers correspond in average to about 95% of the fuel sources. Other energy carriers are charcoal, which accounts for about three percent, canalized natural gas amounting to two percent, and kerosene. Kerosene is statistically irrelevant, accounting for less than 0.1% of the overall supply. In 2015, the energy demand for cooking in the Brazilian households was 46 TJ, from which LPG covered 51% of the demand and the remaining 49% relied on fuelwood (MME, 2016).

The fuel consumption in households in Brazil varies significantly not only among regions but also among income levels (MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010; Uchôa, 2014). There are enormous variations in the level of consumption and the types of fuels used due to the regional complexity of Brazil. Each of the five geographic regions of the country has extreme differences in physical environment, patterns of economic activity and population settlement. For example, Brazil's Human Development Index (HDI) value is 0.754, positioning the country at the high human development category. However, the HDI is an average measure of basic human development achievements in a country. Like all averages, the index may mask inequality in the distribution of human development across the population if there is significant HDI fluctuation at the regional and local levels. Currently, there are 32 municipalities located in the North (HDI equals to 0.69) and Northeast (HDI equal 0.66) regions in which people who lack access to cleaner and affordable energy are often trapped in a re-enforcing cycle of deprivation, lower incomes, and lack of means to improve their living conditions (Coelho and Goldemberg, 2013; UNDP, 2014). Their HDI values range between 0.418 and 0.499, which in average is 38% below the national value (GBIO, 2015).

In general, low-income households do not simply replace one fuel for another as income increases, but instead add fuels in a process of “fuel stacking” (IEA, 2006). Modern forms of energy are usually applied parsimoniously at first and for particular services (e.g. LPG for making coffee) rather than completely supplanting an existing form of energy that already supplies a service adequately (e.g. fuelwood for cooking beans or meat). Hence, the most energy-consuming activities in the household (i.e. cooking and in some cases heating) are the last to switch from traditional biomass to modern fuels. An important aspect of using multiple fuels is the sense of energy security it can provide to low-income households since complete dependence on a single fuel leaves households vulnerable to price variations and unreliable service, especially in isolated communities. Another aspect is based on cultural preferences that create reluctance to discontinue cooking with fuelwood due to taste preferences and the familiarity of cooking with traditional technologies (Carvalho et al., 2016; IEA, 2006; Johnson, 2014). Fig. 3 shows the Brazilian geographic regions and their key figures in 2015, in which is possible to perceive the disparities among them (IBGE, 2016a; MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010; UNDP, 2017).

Fig. 3 displays the evident relation between fuelwood consumption for cooking and regions with low HDI and high inequality. For example, looking exclusively at fuelwood consumption the poorer ten percent of Brazilians households consumed about 5.5 TJ or 24% in 2015 and the wealthiest ten percent only 0.3%, which can be assumed rather as cultural preferences than energy poverty.

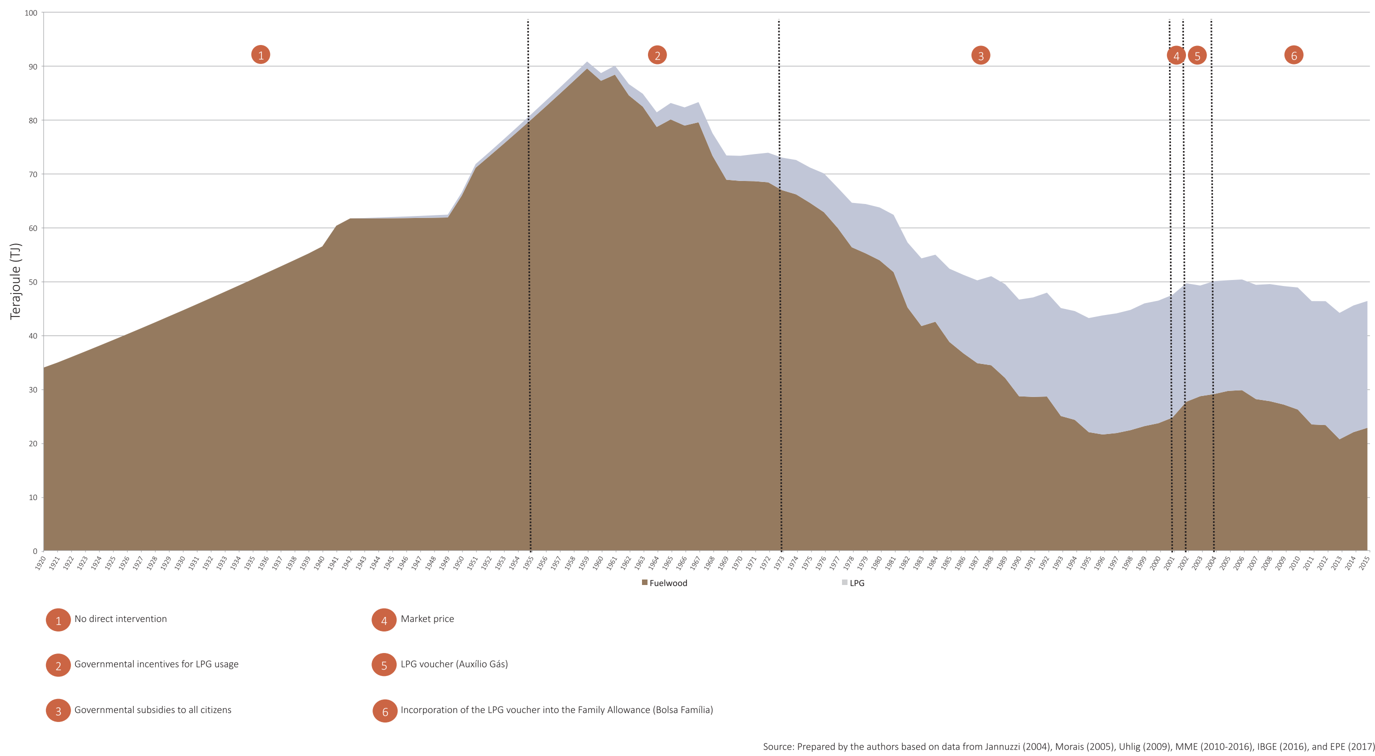



**Fig. 2.** Household energy consumption for cooking per type of fuel between 1920 and 2015 in TJ.

## 3. Key factors for energy transition and its impacts on cooking fuel consumption

Bacon et al. (2010) describes that the share of the household budget, which is allocated to a particular form of fuel or energy source, depends on a number of factors: *income*, *reliability*, *price of fuel*, and *prices of possible substitutes* (Bacon et al., 2010). Other important factor is access to information related to benefits knowledge, security (i.e. fear of explosion), cultural issues (i.e. taste), etc. In Brazil, lack of information is not an issue because local population recognizes the benefits of using clean fuels for cooking and the fear of explosion is perceived as marginal and outweighed by the benefits. For example, in 2013, more than 400 thousands 13 kg canisters of LPG were commercialized in the country and local authorities registered only 183 accidents, from which only 39 accidents were related to inappropriate handling by final-users (SindiGas, 2016).

### 3.1. Income

Studies about household income and their patterns of consumption and expenditure on energy, particularly low-income households, have direct policy implications for several reasons. For example, policies to mitigate or cope with energy price shocks are increasingly focusing on targeted support to low-income households as a way of limiting the fiscal cost of such policies while offering protection to the most vulnerable members of society. Another example is the impact from

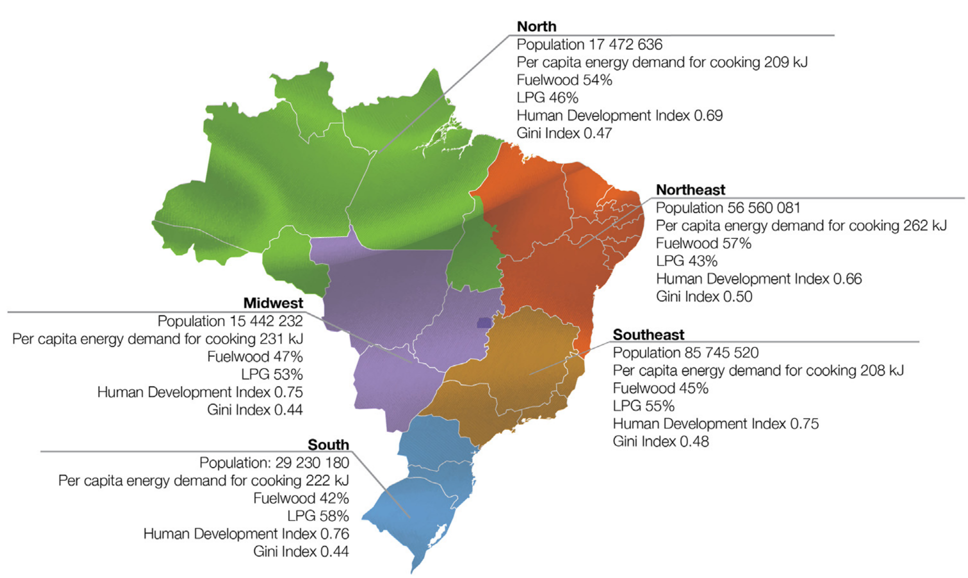
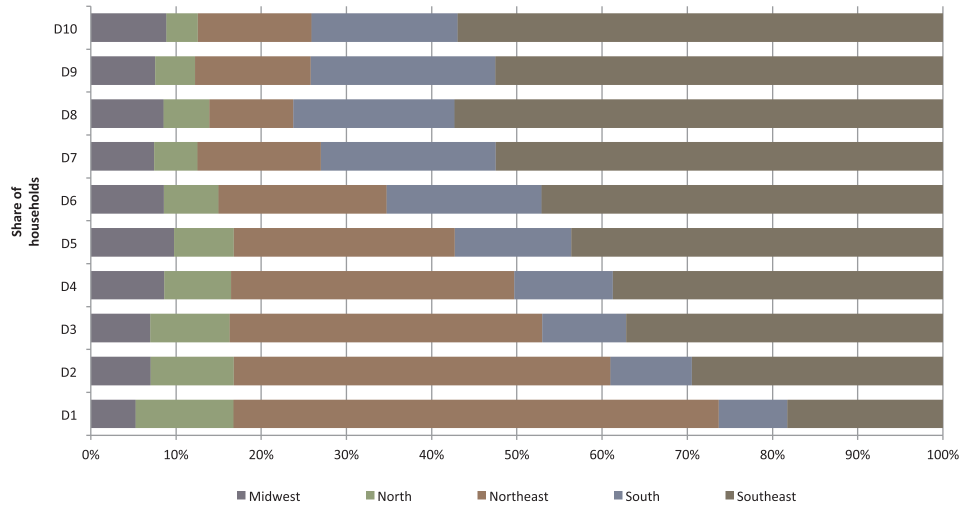



**Fig. 3.** Brazilian geographic regions and their key figures in 2015.




Source: Prepared by the authors based on data from IBGE (2010) and Sanches-Pereira *et al.* (2016)

**Fig. 4.** Share of households per income level and geographic region in 2015.

reforming energy price subsides, in which the effects – especially effects on poor families – of price increases resulting from subsidy reduction or removal can hinder household welfare levels (Bacon et al., 2010).

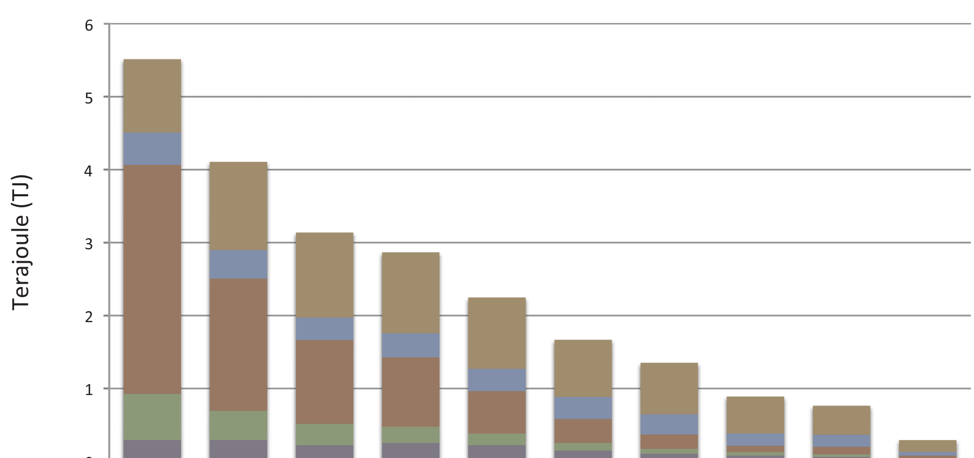
In Brazil, there are two directly opposing regions regarding income, which are the Northeast and Southeast regions. These two regions not only share challenges in common but also present specific challenges due to their individual characteristics (see Fig. 3). The Northeast region concentrates the largest number of low-income houses, whereas the Southeast region has the largest number of high-income households. Fig. 4 shows the share of households per income decile and geographic region in 2015 (IBGE, 2016b, 2010; Sanches-Pereira et al., 2016).

Regarding income level, about 57% of the households with the lowest income decile (e.g. D1) is located in the Northeast region. The highest income decile (e.g. D10), on the other hand, has the majority of the households – more than 50% – located in the Southeast region.

LPG consumption, obviously, follows a different trend than the consumption for fuelwood and it is understandably higher on regions with improved HDI values and income such as Southeast, South and Midwest regions of Brazil (see Fig. 3). Fig. 5 shows the fuelwood consumption for cooking per income decile and geographic region in 2015 (MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010; Sanches-Pereira et al., 2016).

Lowest income households in Brazil rely almost entirely in fuelwood as source of energy for cooking. In fact, about 73% of the energy consumption for cooking is covered with fuelwood, 21% with LPG, and six percent with charcoal (MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010). Highest income households rely on LPG to supply their energy demand for cooking. The remaining demand is covered with natural from gas grids by 14%, 12% with fuelwood and one percent with charcoal (MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010). In this case, the use of traditional technologies for cooking is rather the result of cultural preferences than income restrictions (IEA, 2006).

Income level plays an important role in defining the fuel choice for cooking. Hence, the lower the income, the higher the reliance on fuelwood is. In average, the relation between fuelwood consumption and income level (see Fig. 5) shows that as the income level increases,




| | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Southeast | 1.01 | 1.21 | 1.17 | 1.11 | 0.98 | 0.78 | 0.71 | 0.51 | 0.40 | 0.16 |
| South | 0.44 | 0.39 | 0.31 | 0.33 | 0.31 | 0.30 | 0.28 | 0.17 | 0.16 | 0.05 |
| Northeast | 3.14 | 1.81 | 1.15 | 0.95 | 0.58 | 0.33 | 0.20 | 0.09 | 0.10 | 0.04 |
| North | 0.63 | 0.40 | 0.29 | 0.22 | 0.16 | 0.11 | 0.07 | 0.05 | 0.04 | 0.01 |
| Midwest | 0.29 | 0.29 | 0.22 | 0.25 | 0.22 | 0.14 | 0.10 | 0.08 | 0.06 | 0.03 |

Source: Prepared by the authors based on data from MME (2010-2016)

**Fig. 5.** Fuelwood consumption for cooking in TJ per income decile and geographic region in 2015.

the fuelwood consumption decreases by around 26%. However, some income level increments have more significant impacts than do others. For example, moving from D9 to D10 the fuelwood consumption decreases by 62%. Other income level increment such as from D3 to D4 presents a smaller impact and fuelwood consumption decreases only by nine percent.

Moving up in the economic ladder reduces the reliance on fuelwood for cooking and encourages a shift away from fuelwood use. However, these factors can produce very different sets of impacts in different situations because there is a need to differentiate between use of fuelwood by rural people who gather mostly twigs and branches for their daily fuel needs and those users who purchase their fuelwood, for example, in urban areas and higher income levels. Melrose *et al.* (2015) identified that fuelwood gathering also occurs in urban areas, among low-income families who gather their wood from dumpsites, construction sites and even from trees planted along roadsides and rivers (Melorose et al., 2015). Low-income families in urban areas of Brazil also use the same practices for gathering fuelwood (Carvalho et al., 2014, 2016; Specht et al., 2013).

Looking at the relation between LPG consumption and income level shows that, as the income level increases so does the LPG consumption. However, overall LPG consumption is more uniform among income levels than fuelwood consumption. Fig. 6 the fuelwood consumption for cooking per income decile and geographic region in 2015 (MME, 2016, 2015, 2014, 2013, 2012, 2011, 2010; Sanches-Pereira et al., 2016). Moving up in the economic ladder increases LPG consumption but its variance among income level is less substantial than it is for fuelwood consumption.

Comparing both consumptions and their relation income level, the analysis shows that moving from D1 to D2, the LPG consumption increment is almost 14% and fuelwood consumption decreases almost 26%. Fig. 7 shows the rate of consumption change for fuelwood and LPG per income level in 2015.

Interestingly, the consumption rate change from D9 to D10 presents a decrease in LPG since higher income groups tend to adopt natural gas grids, which are often available in large urban areas. In addition, eating out habits of higher income groups plays a significant role in decreasing LPG consumption (Sanches-Pereira et al., 2016).

### 3.2. Fuel availability

Access to modern cooking fuel – such as LPG – plays a crucial role in replacing fuelwood. Residential consumers use a 13 kg canister of LPG, mainly for cooking. Currently, there are 5 570 municipalities in Brazil, from which only 227 (e.g. less the one percent) of them have no local distributor of LPG (see Table 2) (ANP, 2016).

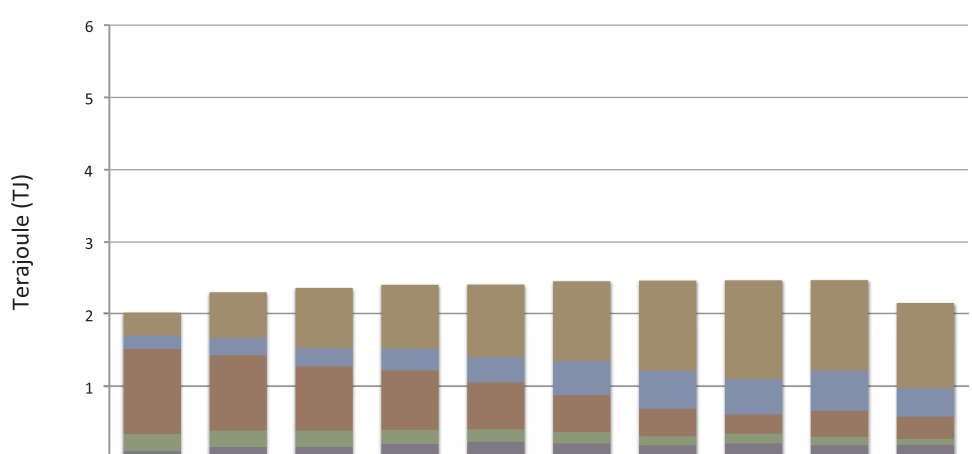
In general, one can assume that fuel availability is well covered around the country since less than one percent of municipalities do not have an LPG distributor. In addition, Table 2 shows – as expected – those regions lacking LPG distributors rely more on fuelwood than do others. For example, there is a high dependence of the local population on forest wood as a source of energy in the Northeast region, both for domestic consumption and for economic purposes (Travassos and Souza, 2014).

The distribution of LPG in Brazil is an activity regulated by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) and comprises acquisition, storage, packaging, transportation, marketing, quality control and technical assistance to the consumer. The distributors receive the product from the refineries and supply the LPG resellers or sell directly to large consumers in industry and commerce through tank trucks. More than 190 bases located in the five geographic regions of Brazil give support to this operation (ANP, 2016).

Regarding natural gas grids, they are an important substitute for LPG due to convenience and price. However, there is a lack of infrastructure offering this option because most of the grids are located in specific areas of large cities in Brazil. In 2013, less than four percent of Brazilian households had access to gas grids (ABEGAS, 2013).

The availability of unsustainable fuelwood is high since forest covers around 59% of the national territory. The Brazilian large territory comprises different biomes, such as the Amazon rainforest, recognized for its abundant biological diversity, with the Atlantic Forest and the *Cerrado* (e.g. Brazilian savannah), sustaining the greatest biodiversity. In the South and parts of the Southeast region, the Araucaria pine forest grows under temperate conditions. Fig. 8 shows the Brazilian vegetation distribution and biomes (Segers, 2015).

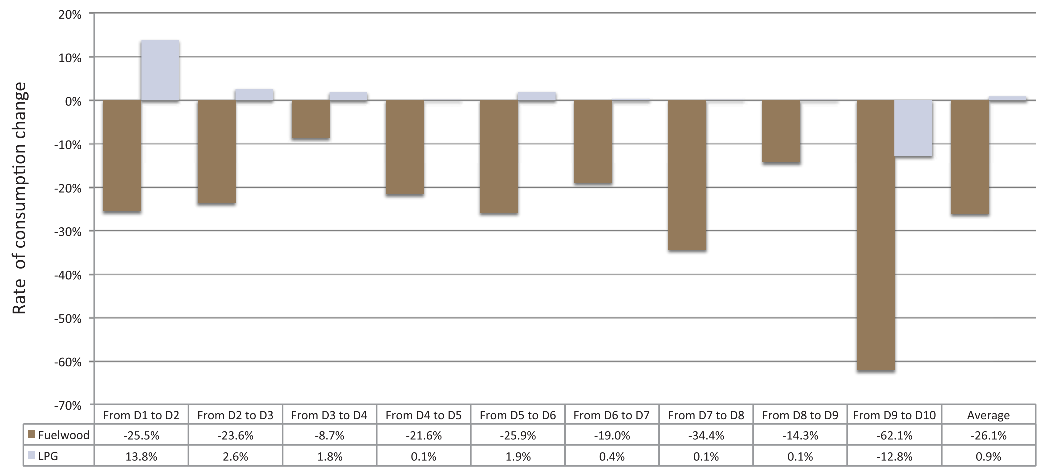
Fuelwood is obtained not only from native forests but also from forestry plantations, which supply the pulp and paper sector with raw material and the iron and steel industries with charcoal. Fig. 8 also shows that native forests are spread throughout the country. The North




| | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Southeast | 0.32 | 0.63 | 0.83 | 0.88 | 1.00 | 1.11 | 1.25 | 1.37 | 1.25 | 1.18 |
| South | 0.18 | 0.24 | 0.25 | 0.30 | 0.35 | 0.47 | 0.53 | 0.49 | 0.56 | 0.39 |
| Northeast | 1.18 | 1.04 | 0.89 | 0.82 | 0.65 | 0.51 | 0.38 | 0.27 | 0.36 | 0.31 |
| North | 0.23 | 0.23 | 0.22 | 0.19 | 0.17 | 0.16 | 0.13 | 0.14 | 0.12 | 0.08 |
| Midwest | 0.11 | 0.17 | 0.17 | 0.21 | 0.24 | 0.22 | 0.19 | 0.22 | 0.19 | 0.20 |

Source: Prepared by the authors based on data from MME (2010-2016)

**Fig. 6.** LPG consumption for cooking in TJ per income decile and geographic region in 2015.




Source: Prepared by the authors based on data from MME (2010-2016)

**Fig. 7.** Rate of consumption change per type of fuel and income level in 2015.

**Table 2**
Municipalities without LPG distribution in Brazil.

| Region | Number of municipalities | Share in the region | Per capita energy demand for cooking | Share of cooking fuel demand covered by fuelwood |
|---|---|---|---|---|
| Southeast | 41 | 2.5% | 208 kJ | 45% |
| South | 1 | 0.1% | 222 kJ | 42% |
| Northeast | 161 | 9.0% | 262 kJ | 57% |
| North | 16 | 3.6% | 209 kJ | 54% |
| Midwest | 8 | 1.7% | 231 kJ | 47% |

region, in which the Amazon forest is located, presents the highest density of forest coverage in Brazil (Nogueira et al., 2004).

A frequent misunderstanding is the apparent contradiction about fuelwood replacement – perceived as renewable source – for LPG – a fossil fuel. Fuelwood used for cooking in developing countries is not a renewable fuel since it comes from deforestation and it is inadequately used, causing indoor air pollution and deaths (Coelho et al., 2014). Furthermore, Smith (2017) argues that modern biomass cookstoves are far better than in the past, but they have not advanced enough to become equivalent to gas cookstoves in terms of reliability, flexibility, durability, efficiency, and cleanliness (Smith, 2017).

### 3.3. Price of fuel

Between 1973 and 2001, the government used subsidies to equalize LPG price throughout the country (see Fig. 2). However, during the 1990s, the Brazilian government – as mentioned previously – adopted a gradual process of economic liberalization, which lead to total withdraw of subsidies and price linearization (Lucon et al., 2004; Morais, 2005). In 1994, the Brazilian government introduced the Brazilian real (BRL) to replace the old currency aiming to put an end to three decades of rampant inflation. The new currency has since been in a gradual recovery until 2014, when Brazil started to experience an economic downturn that has been lasting until now. Fig. 9 shows the LPG prices between 1973 and 2017 in USD values and key moments of governmental interventions in the period that fostered the fuelwood replacement for LPG (ANP, 2017a, b; EPE, 2017).

After the market liberalization, the LPG price has increased 27% in the period of two years as the result of increases in the retail margin and the end of subsidies (see Fig. 9). After 2003, the average price started to decline due to the governmental intervention (Khanna et al., 2016). However, it has recently started to increase due to the economic recession. In 2017, the average price of LPG reached USD 20.20 for a 13 kg canister, an increment of almost 24% between 2016 and 2017. Table 3 presents the currently price composition of LPG (ANP and ANP (National Agency of Petroleum, Natural Gas and Biofuels), 2017).

The Brazilian Petroleum Corporation (PETROBRAS) is the largest fossil fuel producer, importer and refiner in Brazil, whose price strategy controls the national market of fuel and production costs for the whole market in the country. PETROBRAS is a semi-public multinational and has 65% of its shares owned by the Brazilian government. Between 2002 and 2015, PETROBRAS kept the nominal production costs virtually steady by reducing about 40% the production costs in the period, which can be interpreted as an indirect subsidy helping to stabilize domestic prices of LPG and maintaining its affordability (Pedrosa and Corrêa, 2016).

Affordability plays a decisive role in the fuel choice for cooking. Considering that many households can collect firewood for free, it will remain the cheapest energy source for cooking in Brazil. If firewood is purchased at markets, poor households can choose to only acquire small amounts of wood, which allows for a degree of financial flexibility.

In the year 2000, buying a 13 kg canister of LPG would required about 18% of the minimum wage. In recent years, systematic increases in the minimum wage aligned with governmental fuel and social policies reduced the burden from 18% in 2000 to six percent in 2016. In fact, these policies contributed to reduce the burden to around seven percent of the minimum wage on average during the last decade. However, the current Brazilian economic downturn and government austerity measures have increased not only the unemployment rate, which unexpectedly rose to the highest on record at the end of 2016, but also poverty in the country. At some time, the recent changes in the pricing policy for LPG caused a spike in price for this fuel.

### 3.4. Price of substitutes

Fuel substitutes are not available equally for all income groups since price and infrastructure plays an important role. Looking at fuelwood substitutes, fuel price is the key factor since most of low-income households gather fuelwood for free. As a result, the relative price for cooking with fuelwood remains substantially below that of potential substitute fuels.

Several household surveys have shown fuel stacking as common practice in low-income households in Brazil and worldwide (Carvalho et al., 2014; Goldemberg and Lucon, 2007; Lucon et al., 2004; Sepp, 2014; Sepp et al., 2014). Sepp (2014) argues that fuel stacking provides a sense of energy security, especially for low-income households. Since complete dependence on a single fuel or technology could leave these households vulnerable to price variations and unreliable distribution


**Fig. 8.** Brazilian vegetation distribution and biomes.

services (Sepp, 2014). For example, when the price of LPG reaches a certain threshold, it forces poor users to return to fuelwood as the main energy source for cooking (Goldemberg and Lucon, 2007; Lucon et al., 2004; Sepp, 2014). Although fuel stacking embodies the dynamic interplay among household behavior, local culture, socioeconomic aspects, energy access conditions, technology, and the environment, these interactions have received little attention (Ruiz-Mercado and Masera, 2015). In Brazil, low-income deciles concurrently use different fuels for cooking (e.g. fuelwood, charcoal, and LPG). Hence, these households primarily use LPG for quick cooking purposes such as boiling water and/or frying food and fuelwood for cooking meals. Charcoal, which is not free as fuelwood, is used during rain seasons substituting the wet

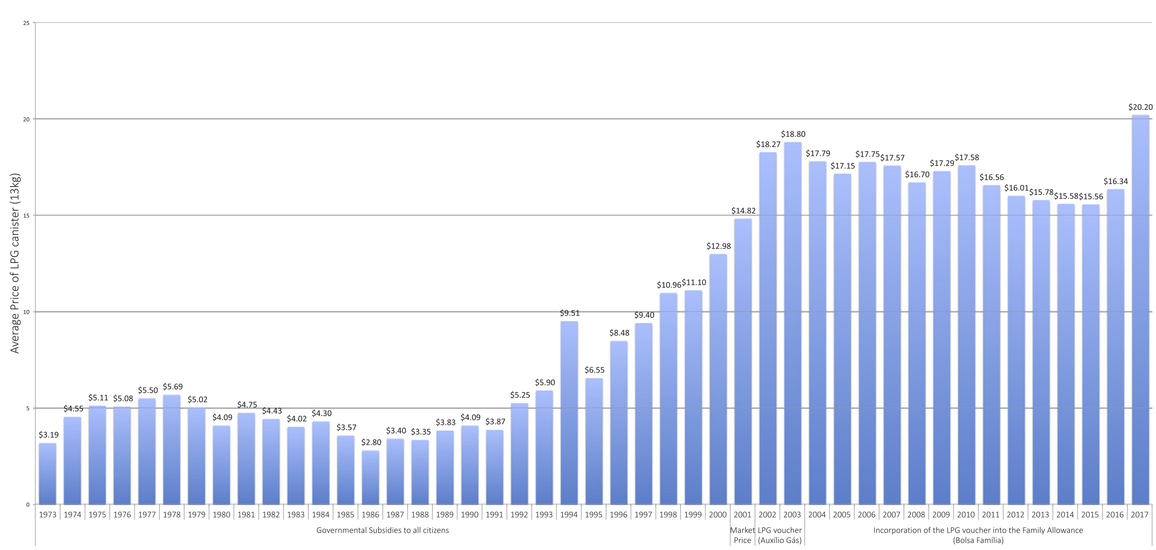



**Fig. 9.** Average price of 13 kg canister of LPG between 1973 and 2017.

**Table 3**
Price breakdown for a 13 kg canister of LPG in 2017.

| Type | Share | Value |
|---|---|---|
| **Production Costs** | 25% | USD 5.05 |
| **Taxes & Fees** | 16% | USD 3.23 |
| **Distribution Costs** | 29% | USD 5.86 |
| **Retail Margin** | 30% | USD 6.06 |
| Final Price | **100%** | **USD 20.20** |

fuelwood for cooking meals. This fuel use pattern also happens in other developing countries (Sepp, 2014). Typically, one kilogram of fuelwood corresponds to 0.1–0.3 kg of charcoal when comes to energy conversion. However, its price is fourfold higher than commercialized fuelwood (Carvalho et al., 2016; Sepp, 2014). Depending on the type of fuelwood and cookstove, between 7.3 and 29.7 kg of fuelwood would be required to provide the same amount of useful cooking energy found in one kilogram of LPG (Carvalho et al., 2016; EPE, 2017; Sepp, 2014; Uhlig, 2008). In this case, LPG is more expensive then commercialized fuelwood by a factor of 16 in Brazil (EPE, 2017).

Brazilian high-income deciles do not rely on fuel stacking for energy security. In fact, the use of different fuels is rather a result of cultural preferences or convenience than vulnerabilities. These households mainly use LPG for cooking and in some cases natural gas (e.g. urban areas with natural gas grids such as São Paulo City and Rio de Janeiro). Typically, a high-income household uses 10 kg of LPG per month, which corresponds to 12.6 cubic meters ($m^3$) of natural gas (SCGÁS, 2017). When gas grids are available, the natural gas can be 20% cheaper than LPG (SCGÁS, 2017). Convenience is also one of the main reasons why gas grids have been growing in large Brazilian cities. When infrastructure is available, natural gas is not only cheaper than LPG but also can be controlled more precisely to match the user's requirements (e.g. cooking and/or heating water). However, LPG is more versatile since it can be transported, stored and used virtually anywhere in the country (Lucon et al., 2004; Sepp, 2014; SindiGas, 2016).

Currently, Brazil is facing the third year of an economic downturn. Unfortunately, these policy instruments are not enough to reduce the return of low-income household on relying on fuelwood for cooking. Ferreira (2016) argues that the current economic recession is fostering fuelwood use in low-income households and, at the same time, LPG consumption in high-income households. Whilst low-income households save money by gathering fuelwood, high-income households discontinue eating out habits which in turn increase their LPG consumption (Ferreira, 2016).

## 4. Concluding remarks

The main objective was to review the energy transition history of fuelwood replacement for LPG in Brazilian households and its impacts in the country between 1920 and 2016 to identify its key policy implications. This study identified that the transition from fuelwood for cooking to modern fuels such as LPG in Brazil followed a consistent pattern. In general, decisions related to energy consumption and fuel type are strongly influenced by affordability, accessibility and the convenience of the fuel. However, the Brazilian replacement of fuelwood for LPG became strongly related to affordability after 1973. Since then, the country followed this consistent pattern of fuelwood replacement and has reduced 66% of its fuelwood consumption by 2015.

The analysis about the replacement of fuelwood for LPG in Brazilian households showed that fuel choice is vulnerable to economic changes, especially nowadays when LPG prices have spiked throughout the country. Systematic increases in the minimum wage aligned with governmental fuel and social policies (see Fig. 2) were the main drivers for replacing fuelwood with LPG, which ratifies affordability as a key parameter to understand cooking fuel consumption in Brazil. Consequently, the current economic downturn compromises not only LPG's affordability but also fuel choice for cooking in low-income households. Hence, the increment of collected firewood regains momentum as the cheapest energy source for cooking in Brazil.

### 4.1. Policy implications

LPG is a well-established fuel for cooking and offers a mature option for Brazilian households since there are adequate supply and distribution (e.g. less than one percent of Brazilian municipalities do not have an LPG distributor). However, the current national socioeconomic context requires local government to develop and implement new policies that can provide a more equitable access to LPG, in especial for low-income groups under the Family Allowance Program (Bruce et al., 2017). On the one hand, the energy transition history of fuelwood replacement for LPG in Brazil shows that policies and planning were able to address key challenges related to supply, regulation, distribution, and affordability for the poor. On the other hand, recurrent removal of subsidies without other forms of financial support for the poor has impacted affordability of Brazilian households when it comes to fuel choice for cooking.

Until 2016, governmental interventions were successful not only by improving the quality of life in poor regions of the country, which in turn have fostered the replacement of fuelwood for LPG, but also by reducing carbon emissions from unsustainable fuelwood (Sanches-Pereira et al., 2016). However, current governmental fuel and social policies are no longer effective in supplying the remaining fuelwood demand (e.g. 23 TJ) with LPG. In fact, changes in the current fuel policy ended subsidies and began to follow more closely international prices of oil and gas. As a result, it has increased the cooking gas prices by 68%.

Governmental cuts of social policies – especially in the direct income transfer program – have also fostered the return to fuelwood in low-income groups. For example, for households under the Family Allowance Program, a 13 kg canister of LPG accounts for 37% of their total income while for households earning a minimum wage the very same canister accounts for seven percent of the budget. Hence, this new context opens room for discussions on a new mechanism for fostering fuelwood replacement, especially in low-income groups that are facing once again fuel poverty for cooking in Brazil.

Clearly, the current stagnated economy in the country, which has strained the national budget, hinders the government's ability to enforce stronger measures and creates an opportunity for fuelwood replacement, especially in the North and Northeast regions. However, the results show that the LPG as replacement for fuelwood as energy source for cooking in Brazil was on the right track by adopting governmental interventions, which in turn have enabled LPG affordability. Finally, the study concludes that Brazil must go beyond its current governmental fuel and social policies by introducing smart subsidies or other forms of financial support to fully replace fuelwood with LPG as the fuel choice for cooking.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2018.08.041.

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