



## Evaluation of baseline firewood consumption for domestic cooking in low-income rural households in Bahia, Brazil

Adriana Gioda<sup>1\*</sup> , Renata Everett Valladares<sup>2</sup> , Ivo Ian Leão Teixeira<sup>2</sup> , Marcus Antônio Gonçalves de Araújo Júnior<sup>3</sup>  and Carlos German Massone<sup>1</sup> 

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### ABSTRACT

Firewood is still a major source of household energy in most parts of the world, including Brazil. This study establishes baseline fuelwood consumption for domestic cooking by rural families in Bahia, Brazil, as part of a socioenvironmental project centered on stove substitution. The project, titled “Fogão do Mar” (Seaside Stove), engaged families in adopting more efficient stoves to replace the traditional open-air, rudimentary models. The study involved household visits and interviews with 103 low-income rural families to estimate firewood consumption for domestic cooking. The results showed that all households have liquid petroleum gas (LPG) stove, but most of the families prefer to use a firewood stove for cooking. The annual per capita consumption of firewood was estimated to be 1,297±952 kg, which is higher than estimate by governmental data (560 kg), as well as other rural regions. Therefore, the consumption of firewood is regionalized. Economic factors are decisive in the choice of fuel for cooking.

**Keywords:** firewood consumption, cookstoves, Quilombola, LPG, solid fuel

### Introduction

According to the World Health Organization (WHO), the use of solid fuels for cooking has been linked to more than 3 millions of premature deaths each year globally, as well as triggering various diseases (WHO 2021). Moreover, the use of solid fuels has several aggravating factors such as the cost of the deaths, the cost of treating diseases, the

increase in deforestation levels, the effects on climate and indoor and outdoor air quality.

The highest rate of firewood users occurs in rural and/or poor regions and close to forests, where firewood can be obtained free of charge, by collecting branches or by removing trees (e.g. Ektvedt 2011; Amoah *et al.* 2015; Negi *et al.* 2018). Low-income families cook by burning wood in open fires, resulting in very low thermal efficiency and high levels of pollution (Larsen & Pierre 2017; Gioda *et al.* 2019).

<sup>1</sup> Departamento de Química, Pontifícia Universidade Católica do Rio de Janeiro, 22451-900, Rio de Janeiro, RJ, Brazil

<sup>2</sup> Instituto Perene, 70070-938, Brasília, DF, Brazil

<sup>3</sup> PETROBRAS Brasileira S.A., Avaliação e Monitoramento Ambiental, 21941-915, Rio de Janeiro, RJ, Brazil

\* Corresponding author: agioda@puc-rio.br

Stoves are open fires built on the ground with bricks or stones used to support cookware (Fig. 1A). This type of device is common across the developing world and generally referred to in literature as the “three-stone fire”. Besides contributing to forest degradation, the use of firewood, mainly in inefficient stoves, also influences outdoor air quality and global climate change as much of the emissions are released into the atmosphere (Jorquera *et al.* 2018; Martinez-Vallejo *et al.* 2021).

To assess the effects on the environment, such as the emission load of polluting gases and particles, it is necessary to estimate or measure the amount of firewood used. In general, an assessment is made of annual consumption per capita or per family. The goal of the study is to gain an in-depth understanding of the use of firewood by rural families in Bahia, Brazil, for whom firewood is the primary fuel for cooking. This study is the first step of a socioenvironmental project called “Fogão do Mar” (Seaside Stove), which aims to replace rudimentary firewood stoves with improved models (Fig. 1B) to decrease the wood consumption and carbon emissions caused by wood-burning stoves.

## Materials and Methods

### Study area

The study area covered eight municipalities surrounding the Marine Extractive Reserve of Baía do Iguape (RESEX) located in the central-eastern portion of the state of Bahia, Brazil (Fig. 2). According to The Chico Mendes Institute for Biodiversity Conservation (ICMBio), the reserve has an area of 10,082.45 hectares (24,914.3 acres) (mangroves and inland water), comprised of a series of vegetation

formations, including the Atlantic Forest on the tops of the hills, secondary forests, mangroves, and sandbanks. The climate is semi-arid. Annual temperatures vary between a maximum of 32 °C and a minimum of 14 °C. Forests are the main sources of firewood. Traditional extractive families are involved in fishing and shellfish collection in mangroves. Fishing is mainly performed by men with canoes, while the collection of shellfish is done by women and children on foot (Prost 2010). Other economic activities include subsistence farming, small animal husbandry, handicrafts, and fish farming. According to the United Nations Development Program Brazil, these municipalities have Human Development Index middle level (0.565-0.659), while in the whole Brazil, the HDI varies between 0.862-0.418 (IBGE 2019).

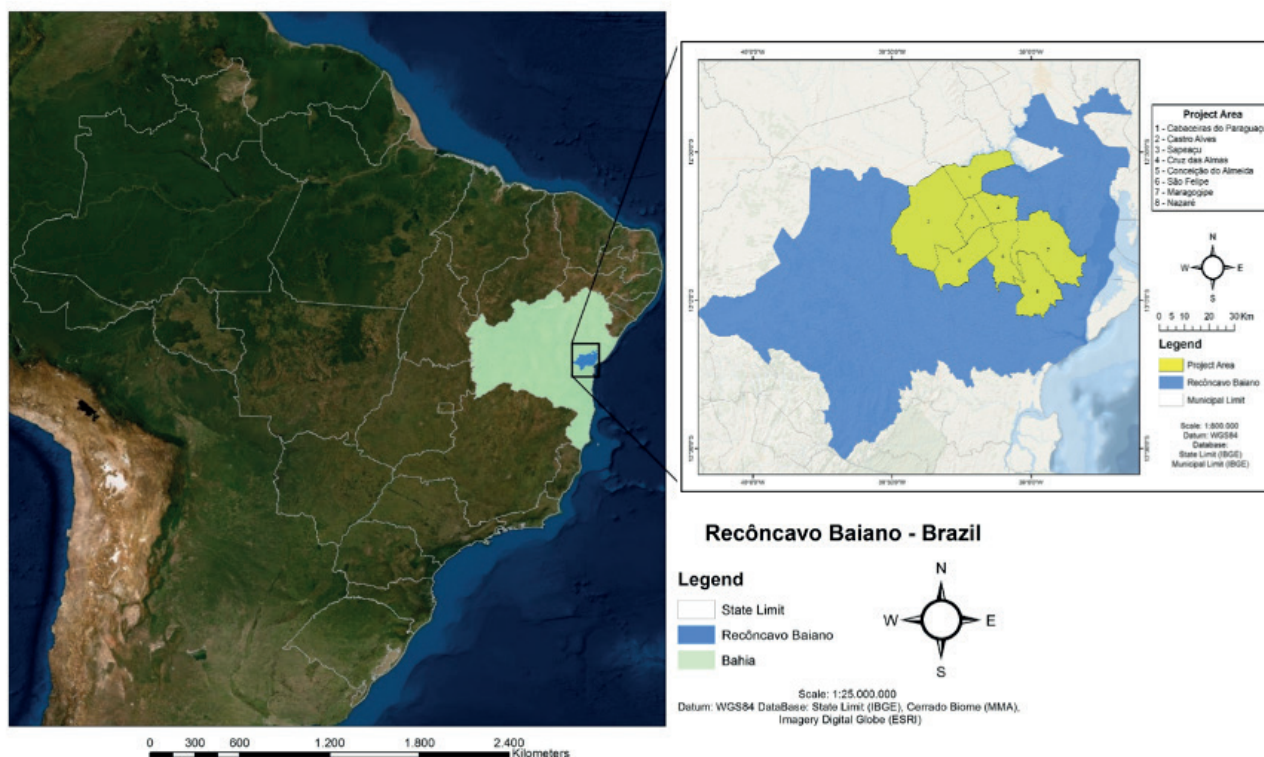
### Firewood consumption

We conducted a field survey through home interviews with a random sample of the target audience to characterize the profile of firewood users and their baseline firewood consumption. All families that receive Instituto Perene support sign a consent form that addresses some issues including data collection in the context of carbon certification. This data collection is carried out by community agents of the project with a strict protocol of protection in handling and storage using a private digital application. The survey questionnaire included such items as: the family member responsible for cooking, number of adults, number of children, type of fuel, type of stove, and amount of firewood used. The questionnaire was created using the Fulcrum App, which is a program for form creation, data collection, and storage that operates on a portable digital device that can operate offline.



**Figure 1.** A. Example of rudimentary stove; B. New ecoefficient model.

## Evaluation of baseline firewood consumption for domestic cooking in low-income rural households in Bahia, Brazil



**Figure 2.** Location of the study area.

The measurement of firewood consumption in the Gold Standard survey template is expressed in kg/month or kg/year (Gold Standard 2013). However, these units are not used by the local population when referring to household firewood consumption. Thus, we recorded the amount of firewood consumed in the traditional units used locally before converting these amounts into the international standard.

### *Statistical analysis*

There were 686 families in 63 villages that met the criteria and were registered to participate in the study. In our study, approximately 70 families were sufficient to encompass the minimum sample. Random sample selection was performed using the R package (R Development Core Team 2022). The main list consisted of 100 families, with 50 additional families to be used as substitutes if the residents were not at home or could not be located at the time of the visit. A total of 103 field interviews were conducted between January and February, 2019.

The survey was downloaded for the analysis. The first step in the data processing was to standardize the units of measurement used in the survey responses to cubic meters per year ( $\text{m}^3 \text{ year}^{-1}$ ), considering conversion units from other studies (FAO 1947; 1983; Reyes *et al.* 1992; Borges Neto *et al.* 2006). Consumption for each household was determined on a per capita basis by dividing household consumption by the number of household members. Grubb's test was performed to identify and remove extreme values.

The resulting volumetric responses in  $\text{m}^3$  per capita were then converted to weight (kg) per capita using a regional wood density of  $500 \text{ kg m}^{-3}$ , which is characteristic of ombrophilous dense forests. The parametric statistical approach was performed after ensuring data distribution assumptions according to the Shapiro-Wilk test.

## Results and Discussion

### *Firewood consumption in RESEX region*

In this study, four units of measurement were identified:

- i) cubic meter ( $\text{m}^3$  of firewood): this is typically the load-type used when wood is purchased, rather than collected. It constitutes the largest of the four types, and is roughly measured as a pile of logs or branches one meter in length, stacked one meter high, and one meter across;
- ii) animal load (load carried by an animal): this load-type, simply referred to as a "load," is used when the wood is hauled by a pack animal, usually a mule or donkey, equipped with baskets on either side;
- iii) wheelbarrow: this load type is simply the amount of wood that can be stacked and transported in a typical wheelbarrow; and
- iv) headload: as is traditional in many developing regions, wood is still commonly carried in a bundle atop a person's head.

The most widely used load type was headload (45 %), followed by meter (25 %), wheelbarrow (20 %), and animal load (15 %). Figure 3 exemplifies each of the units employed by the population.

The per capita fuel consumption in the region was  $1,297 \pm 952 \text{ kg person}^{-1} \text{ year}^{-1}$  (Fig. 4). As is evident from the large standard deviation, per capita consumption is highly variable, ranging from 150 to  $4,000 \text{ kg person}^{-1} \text{ year}^{-1}$ . This level of variation was expected because of the differences in individual routines. Considering that the average family in this region is composed of 3.7 individuals, the annual household consumption would be approximately 4,800 kg.

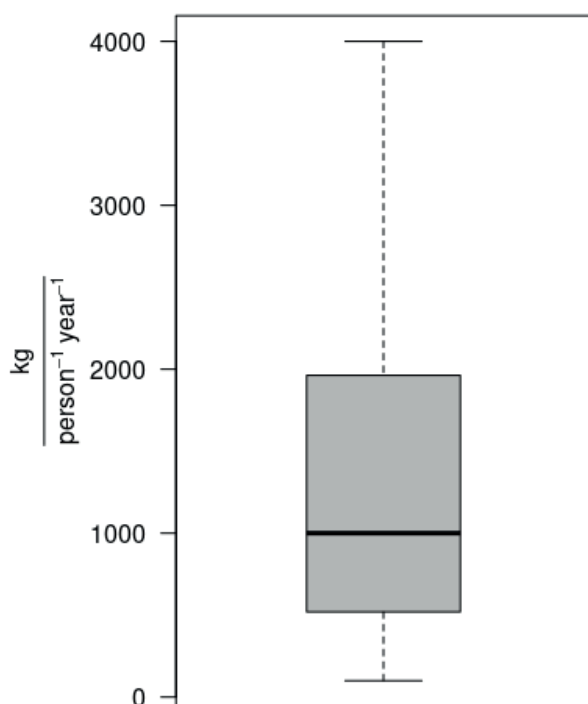
Official government data state that firewood consumption per capita can be calculated using data from the Energy Research Company (EPE 2020) and the Brazilian Institute of Geography and Statistics (IBGE 2019). In 2019, the year of our study,  $22,838 \times 10^6 \text{ kg}$  of firewood and  $628 \times 10^6 \text{ kg}$  of charcoal were consumed in the residential sector. Considering that this biomass was mainly used in cooking activities by 13,989,000 households, composed by 3 members, the annual per capita consumption can be estimated at around 560 kg. The above cited figure considers firewood users along the entire spectrum of fuel stacking behavior. In contrast, the present study focused



**Figure 3.** Examples of types of fuelwood amounts: **A.** Metro; **B.** Carga animal; **C.** Carrinho de mão; **D.** Feixe.



on the heaviest fuelwood users, which constitute the target population for the improved cookstove program. For this population, firewood is the predominant fuel for cooking, with LPG used in a limited supplementary form.



**Figure 4.** Firewood consumption per capita ( $\text{kg person}^{-1} \text{ year}^{-1}$ ) in the RESEX region, Bahia, Brazil. Consumption: minimum ( $100 \text{ kg person}^{-1} \text{ year}^{-1}$ ); 1st. quartile ( $520 \text{ kg person}^{-1} \text{ year}^{-1}$ ); median ( $1,000 \text{ kg person}^{-1} \text{ year}^{-1}$ ); mean and standard deviation ( $1,297 \pm 952 \text{ kg person}^{-1} \text{ year}^{-1}$ ); 3rd. quartile ( $1,963 \text{ kg person}^{-1} \text{ year}^{-1}$ ); maximum ( $4,000 \text{ kg person}^{-1} \text{ year}^{-1}$ ). The confidence interval was 95 %, after removing the four outliers.

### Characteristics of the RESEX population

Families in the sample population consisted of 1 to 11 members, with an average of  $3.7 (\pm 1.0)$  people per household. According to the Continuous National Household Sample Survey (PNAD continua) carried out by the IBGE in 2019, the average number of people per household is 2.9. For families below the poverty line, it can reach 5.7. However, these numbers are lower than in the 1960s, when the vast majority of Brazilian families had 8 members.

In most households (84 %), women are responsible for cooking, as reported by WHO (WHO 2021). In 100 % of the households, there was a wood stove, and 92 % of households also had a gas unit. The firewood stove was the primary stove used in 100 % of households. These results are expected, as other studies in rural regions also show this preference (Démurger & Fournier 2011; Win 2018; Gioda 2019). In most homes (68 %) a 13 kg LPG cylinder lasts between 1 and 2 months, while a significant portion (32 %) had cylinders that lasted for more than 3 months and up to one year.

These results indicate that LPG is only used for a few days in each month. According to the gas companies, a 13 kg gas cylinder (LPG) corresponds to  $16.38 \text{ m}^3$  and a 4-burner stove consumes  $0.29 \text{ m}^3 \text{ h}^{-1}$ . Considering an average stove use of 3 hours per day, the monthly consumption should be  $0.29 \text{ m}^3 \times 3 \text{ h} \times 30 \text{ days} = 26.12 \text{ m}^3$ ; therefore, one and a half cylinders per month (21 kg) are needed. For low-income families, the price of LPG was determinant for its use. The price of LPG cylinders reported in 2019 by survey participants ranged from 58 to 85 Brazilian real (about 13 to 19 US dollars). The government's financial aid (*Bolsa Familia*) was approximately 89 Brazilian real per month (20 US dollars). This aid allows the purchase of a single gas cylinder, with no funds remaining for the purchase of food, resulting in the use of firewood/solid fuels, which are cost-free.

It was also predictable that only 15 % of the wood stoves had chimneys. Burning firewood in stoves without chimneys results in high levels of gases and particles in kitchens and other rooms of the house, which causes increased health problems. Through the interviews, it was possible to observe the effects that this pollution (smoke) had on the occupants. Complaints included a foul smell on clothes and hair, blackened cookware, coughing, eye irritation, burns, and dirty walls. Other health problems were also identified such as back pain from cooking over a low stove or carrying firewood. Therefore, the replacement of rustic stoves with improved units will improve the quality of life of these families.

The use of firewood has reduced over time in Brazil; however, in periods of greater economic crises, consumption rises. In 2018, the number of users increased by approximately 20 % compared to that of 2016 due to the devastating effect of Brazil's economic recession on the poorest sector of the population, compounded by a sharp increase in the price of LPG. In contrast, firewood/charcoal consumption increased by only 2 %, although the lack of primary data underestimates the consumption of firewood in the country. In surveys conducted by the IBGE in 2020 and 2021, no questions were asked about the use of fuel for cooking; therefore, in the past year, there has been no official data on firewood consumption. Nonetheless, since the beginning of the COVID-19 pandemic in March 2020, the media has consistently reported an increase in the number of families who have abandoned LPG to cook with firewood due to job losses and the rise in the price of LPG. Between July 2020 and July 2021, the price of LPG rose by 30 % or three times more than inflation (9.85 %).

### Comparison of firewood consumption obtained in other Brazil regions and worldwide

Few studies have been carried out *in-situ* to determine the consumption of firewood in Brazil. The works found in the country are briefly described below, together with others from around the world. In Limeirinha, a rural community in



the interior of the state of Pernambuco, northeast region, in an area of Atlantic Forest, an annual consumption of firewood of 292 kg per capita was measured. The number of residents ranged from 1 to 13, with an average of 3.2. Firewood consumption in this region was influenced by income, education, and the number of residents (Arruda *et al.* 2019). In Lages, Santa Catarina, one of the coldest places in Brazil, firewood is consumed in 38.2 % of the households interviewed, with up to 264 kg per capita per year used in those households (Passos *et al.* 2016). In the community of Muquem (Alagoas), a Quilombola community in northeastern Brazil, the Atlantic Forest is sparse, but firewood from private properties or gardens is still predominantly used (Silva *et al.* 2018). Other studies have shown consumption similar (1,168 to 1,220 kg per capita per year) (Vale *et al.* 2003; Lopez *et al.* 2000) or higher (1,825 kg per capita per year) (Cunha *et al.* 2008) than the present work (Tab. S1). It is important to consider that most of these studies are from past decades and that changes in habits and socioeconomic conditions have changed since then.

The global use of firewood for cooking, heating, and protection is related to different factors such as income, availability, customs, altitude, climate, level of education, and family size (Tab. S1). The requirement for energy is critical in certain areas. In Latin America, the use of firewood is still predominant in many households, and in Mexico, approximately 16 million people use firewood for cooking and heating (Marquez-Reynoso *et al.* 2017). In a protected area in the northwest part of Chiapas, Mexico, which is near important rainforests, the lowest firewood consumption was recorded in large families. The annual consumption per capita ranged from  $475 \pm 260$  for families with 7 members to  $1,205 \pm 570$  for families of 4 (Marquez-Reynoso *et al.* 2017). Biomass consumption in Costa del Lepá, Patagonia, Argentina, varied greatly depending on season (Morales *et al.* 2018). The lowest per capita consumption was recorded in the spring ( $9.10 \pm 1.75$  kg) and the highest in the winter period ( $32.94 \pm 7.5$  kg) (Morales *et al.* 2018), showing a significant difference between seasons, with winter consumption approximately 4 times higher than that in spring. Studies in Peru have shown that there is a difference in the consumption of firewood in lowlands (723 kg per capita) and highlands (1,080 kg per capita) for a similar sized family (4.59 and 4.78, respectively) (Ektvedt 2011).

Some mountainous regions, such as the rural region of Tajikistan, where there are limited energy sources and long winters with very low temperatures, people depend on firewood (Mislimshoeva *et al.* 2014). Similar to this study, the families of the villages in this region have low-income levels and use rudimentary stoves; however, each household is composed of an average of 6 people (Mislimshoeva *et al.* 2014). The level of education had an inverse correlation to the use of firewood. In these regions, the average annual consumption of firewood per household was  $1,840$  kg ( $307$  kg person<sup>-1</sup> year<sup>-1</sup>), which is approximately 4 times less than

that in our study. The firewood used by families in that study was obtained from a household's private garden, which is the largest source of firewood in the study area and cost-free (Mislimshoeva *et al.* 2014). Many developing countries in Asia use large amounts of firewood. Nepal is an example of a country where approximately 70 % of the energy source for the rural population is derived from wood (Kandel *et al.* 2016). In the Dolakha district of Nepal, the average daily fuelwood consumption was estimated to be 8.4 kg per household or 1.7 kg per capita, while the annual average corresponds to 3,060 kg per household per year (Kandel *et al.* 2016). Total fuelwood consumption was positively correlated with household size, and varied significantly between seasons, with greater levels in winter. The main sources were community forests (23 %) and trees on private farmland (12 %) (Kandel *et al.* 2016). In this region, the households consisted of 5 persons on average (Kandel *et al.* 2016). In India, 70 % of the population lives in rural areas and uses mainly forest biomass for cooking and heating (Negi *et al.* 2018). However, in rural areas such as the Indian Himalayas, forests are the primary energy source (90 %). The firewood consumption varied from 803 ( $\pm 146$ ) kg/per capita/year at 3,000 masl to 1,970 ( $\pm 110$ ) kg/per capita/year at 3,800 masl (Negi *et al.* 2018). The family size ranged from 1.2 to 5.0 members. Firewood consumption was greater at higher altitudes (Negi *et al.* 2018). In Cambodia, most of the population lives in rural areas (80 %), and fuelwood is the most used source of energy for the majority of the population (San *et al.* 2012). In this region, larger family sizes (8-9) consume less fuelwood ( $335 \pm 18$  kg per capita) to cook than smaller families (3-4;  $664 \pm 40$  kg per capita) (San *et al.* 2012). In Myanmar, a Southeast Asian country, firewood is also used by a large part of the population (~70 %) (Win *et al.* 2018). In urban areas, most firewood is commercial (69 %), but is derived from natural forests. In urban households that exclusively use firewood, the per capita consumption averaged 362 ( $\pm 107$ ) kg per year, whereas the average for multi-fuel and single-fuel users was  $217 \pm 139$  kg per year (Win *et al.* 2018).

In Africa, households mainly use solid fuels (charcoal, firewood, agricultural residues, and animal dung) for cooking and heating. In Ethiopia, despite the government's incentive to use biogas, firewood still predominates in many regions (Seboka 2019). The annual firewood consumption per capita of biogas users was estimated to be 202 kg, while families without biogas usage consumed 314 kg (Seboka 2019). In Ghana, the annual average per capita consumption of firewood was higher in the coastal savanna zone (~1,010 kg) than in the forest zone (~590 kg), although the family sizes were similar (7.33 and 7.25) (Amoah *et al.* 2015). In a rural agricultural region in Mali, the firewood consumption was 375 kg for an average family of 12.8 individuals. Here, there is seasonal influence with higher consumption per capita in the cold season ( $2.41$  kg day<sup>-1</sup>) than in the hot season ( $0.79$  kg day<sup>-1</sup>) (Johnson & Bryden 2012).



According to the WHO, the use of firewood and other solid fuels is directly associated with the socioeconomic level of families, with poorer countries having a greater consumption. The use of firewood in communities with less government assistance, mainly in rural areas, relates to the lower purchasing power for more modern fuels and stoves, the low or lack of cost of firewood, the low educational level, the proximity of forests, and other factors. Consumption is also related to climate, where places with a cold climate induce greater consumption. The type of food to be prepared and the family size are directly related to the amount of firewood used, as are family customs. The plant species used were varied and generally consisted of local species. These families rarely use reforestation wood. In Brazil, wood is not only used as firewood for cooking, but also for industry (ceramics, bricks, lime, etc.), timber, and charcoal production.

### *Methodologies used to estimate firewood consumption*

The region with potential for a study has to be defined. Some authors develop a pilot project or initial visit to understand the region and practices, and choose the households to participate, or apply questionnaires to a few families and make the necessary adjustments (Lopez *et al.* 2000; Mata & Souza 2000; Johnson & Bryden 2012; San *et al.* 2012; Amoah *et al.* 2015; Kandel *et al.* 2016; Passos *et al.* 2016). For our study, we used the RESEX region, as it was part of other socioenvironmental programs of the Perene Institute. Similar to our research, other studies have used different statistical tools to determine the sample number of households with 90-95 % confidence for a given region (Mata & Souza 2000; Passos *et al.* 2016). Some have used simple random sampling, systematic sampling, or stratified random sampling techniques (Mata & Souza 2000; San *et al.* 2012; Kandel *et al.* 2016; Win *et al.* 2018; Seboka 2019).

The use of questionnaires is important to understand the demographic and socioeconomic characteristics of families, which influences firewood consumption. Interviews were conducted face-to-face by trained personnel. The questionnaires were applied preferentially to the head or older member of the family. In the RESEX region, women are primarily responsible for cooking and gathering firewood; therefore, they were interviewed in most homes. Questionnaires were specifically prepared to meet the research objectives. However, some basic information was present in all surveys, including location (urban or rural), characteristics of the dwelling, firewood consumption patterns (*e.g.*, purpose, amount consumed, types of stove, cooking frequency, how firewood is obtained, type of firewood, and other types of energy for cooking), and socioeconomic and demographic characteristics (number of residents, age, gender, education level, income, and occupation) (Mata & Souza 2000; Vale *et al.* 2003; Borges Neto *et al.* 2006; Bezerra & Aguiar 2011; Ektvedt 2011; Johnson & Bryden 2012; San *et al.* 2012; Mislímshoeva *et al.* 2014; Amoah *et al.* 2015; Specht *et al.* 2015; Kandel *et al.* 2016;

Passos *et al.* 2016; Marquez-Reynoso *et al.* 2017; Morales *et al.* 2018; Negi *et al.* 2018; Win *et al.* 2018; Seboka 2019).

The methods employed for firewood consumption were either directly determined or estimated. Some studies have directly weighed the amount of firewood using a mobile scale (Lopez *et al.* 2000; Mata & Souza 2000; Amoah *et al.* 2015; Specht *et al.* 2015; Morales *et al.* 2018; Win *et al.* 2018; ). Other studies estimated daily consumption using the same container for all residences (*e.g.*, bags) or asked the respondents for the exact quantity of fuelwood used (San *et al.* 2012; Mislímshoeva *et al.* 2014; Negi *et al.* 2018). In some studies, a certain amount of firewood was weighed before and after 24 h or a certain number of days, and the difference between the two weights was the daily consumption of the family (Ektvedt 2011; Kandel *et al.* 2016; Marquez-Reynoso *et al.* 2017; Negi *et al.* 2018; Win *et al.* 2018; Arruda *et al.* 2019;). Overall, per capita consumption was calculated by dividing firewood consumption per day by the number of members per household. These results can also be extrapolated to the annual consumption. A brief description of the methods adopted in each cited study is presented in Table S1.

To check the relationship between socioeconomic, demographic, and other characteristics and the basic linear model of firewood consumption, several statistical tests were applied (Lopez *et al.* 2000; Mislímshoeva *et al.* 2014; Win *et al.* 2018; Arruda *et al.* 2019; ), Statistical Package for Social Sciences (SPSS 17.0) (Kandel *et al.* 2016), SPSS for Windows version 16.0 (SPSS Inc., Chicago) (Amoah *et al.* 2015). In our study, we used R software, and Grubbs and Shapiro-Wilk tests. Descriptive statistics, such as the mean, standard error, confidence interval coefficient of variation, and percentage participation, as well as the simple linear correlation between variables, were applied (Passos *et al.* 2016). Probability and non-probability sampling techniques were adopted (Amoah *et al.* 2015). Overall, the data and interviews were checked and validated for all studies.

## Conclusions

In this study, the average firewood consumption was  $1,297 \pm 952$  kg person<sup>-1</sup>year<sup>-1</sup>, which is substantially higher than the national average estimated by using governmental data (560 kg person<sup>-1</sup>year<sup>-1</sup>). These results show that on-site measurements differ from those estimated by official agencies, and those studies such as this are essential to accurately assess local firewood use. National averages do not consider the particularities of each region, including tree species, stove type, cultural aspects, preparation and type of food, family size, climate, and access to other fuels. Studies such as this help bring attention to the widespread problems associated with cooking over open fires, which affects millions of families in Brazil, contributing to forest degradation, climate change and health problems.



Public policies that enable a transition away from inefficient stoves are required, since they can improve the quality of life of disadvantaged people. Further studies are needed to explore the health impacts of open-air fires used for domestic cooking on low-income families, as well as the resulting financial costs to the national healthcare system.

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## Conflict of interest

The authors declare no conflict of interest.

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