TRANSICIÓN ENERGÉTICA A NIVEL RESIDENCIAL

Cocción y Calefacción en América Latina

# Report of measurements: São Paulo, Brazil

## Towards the electrification of gas appliances in Latin America: A narrative from the Global South

UNA INICIATIVA DE:

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# SUMMARY

# FIGURE

# TABLE

# 1. INTRODUCTION:

## a. Context

According to the World Meteorological Organization (WMO) Greenhouse Gas Bulletin (No. 20 – October 28, 2024), the global average concentration of $CO_2$ reached 420.0 ppm in 2023, representing an increase of 2.3 ppm compared to the previous year. Methane ($CH_4$) levels also saw a marked rise, reaching 1934 ppb, while the global concentration of nitrous oxide ($N_2O$) rose to 336.9 ppb in 2023 and the CO2 reached a concentration of 420 ppm. In 2022, the global average concentration were 417.9 ppm for CO2, 1923 ppb for CH4, and 335.8 ppb for N2O

The WMO reports that this persistent increase reflects the ongoing impact of human activities. Anthropogenic sources contribute approximately 4.7 billion tons of $CO_2$ annually.

## b. Brazilian Context

As a signatory of the United Nations Framework Convention on Climate Change (UNFCCC), Brazil has as one of its commitments to present its National Inventories of Greenhouse Gas Emissions (GHG). In its most recent National Inventory, Brazil has been committed to the implementation of the "2006 IPCC Guidelines for National Inventories of Greenhouse Gas Emissions" (Ministério Ciência e Tecnologia, 2022), being organized into five sectors: Energy; Industrial Processes and Use Of Products (IPPU); Agricultural; Land Use, Land Use Change And Forests (Lulucf) and Waste.

The latest National Inventory contemplated in the Fourth National Communication presents Brazil's GHG emissions from 1990 to 2016. In 2016, Brazil's emissions totaled 1,467 Tg $CO_2e$, with $CO_2$ being the most emitted GHG. Agriculture contributed 33.2% of total emissions, the Energy sector 28.9%, and the LULUCF sector 27.1%. IPPU and Waste contributed smaller portions of emissions, representing 6.4% and 4.5%, respectively.

In 2016, the state of São Paulo's energy sector was responsible for 59% of GHG emissions, around 90 Mt $CO_2e$. These emissions are mainly fed by transport (vehicular emissions) - National Inventory of Greenhouse Gas Emissions, Brazil, 2022. The city of São Paulo follows in the same direction as the state of São Paulo, with the largest emissions from the energy sector, 11 Mt $CO_2e$ in 2023. The biggest emitter in this sector is transport, followed by air and residential sectors (classified as IPCC Category 1A4b in the national inventory), as shown in Figure 1 (SEEG, 2024). According to the Sao Paulo municipality report on GHG emissions (São Paulo, 2021) the transportation sector is responsible for about 60% of emissions (only 55% in 2021), due to the use of fossil fuels (gasoline and diesel).

According to SEEG's estimate (SEEG Brazil), 2,296 Mt of CO2e were emitted in 2023, distributed as follows: Deforestation (46%), Agriculture (28%), Power Generation (18%), Waste (4%) and Industrial Processes (4%). Analyzing only the energy sector, we have the following breakdown: Transportation (53.3%), Industry (16.2%), Fuel Production (13.2%), Residential (6.4%) and Other (11.2%). According to these figures, the impact of the residential sector on greenhouse gas emissions is approximately 1.2%.

The Brazilian Energy Balance summary report for 2020 highlights the diverse sources of energy consumption in residential settings across the country, emphasizing the dominance of electricity at 46% throughout the entirety of the household premises. However, the reliance on other fuels like firewood (26.6%), Liquefied Petroleum Gas (LPG) (24.4%), and Natural Gas (NG) at 1.5% varies significantly by region (EPE, 2020).

In the Southern Region, colder climates and traditional practices lead to higher firewood usage, while the North and Northeast Regions show a tendency towards solid fuels due to economic constraints. LPG, although accounting for a smaller percentage of total energy consumption, plays a crucial role, especially as the primary cooking fuel with over 70% of its use in households. This demonstrates how regional characteristics, and economic factors shape energy preferences in Brazilian households (Gioda, 2019).

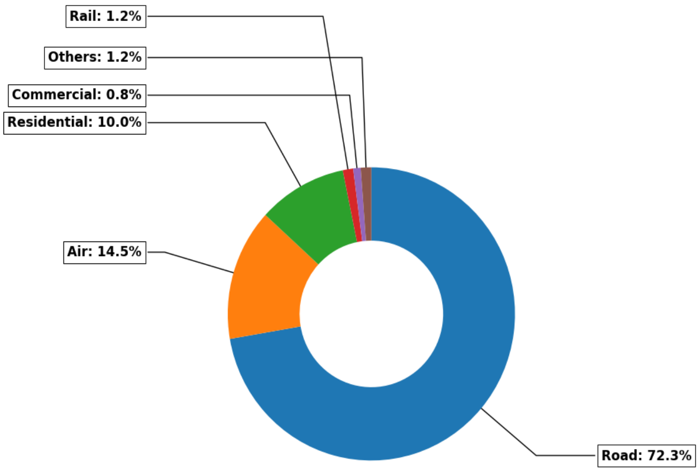



Figure 1. *Sectors with the highest emissions in the city of São Paulo. Elaborated by the authors based on data from Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa (SEEG), 2024.*

Figure 2 illustrates GHG emissions from stationary energy sources, including electricity, LPG, natural gas, diesel oil, fugitive emissions, fuel oil, and kerosene, from 2010 to 2018 (Anthropogenic Emissions and Removals of Greenhouse Gases Inventory in the São Paulo Municipality, 2022). Electricity emerges as the dominant source, with a notable spike in 2014 due to increased reliance on thermal power plants during a drought, significantly impacting residential emissions. LPG and natural gas show stable trends, reflecting their consistent use in cooking and heating, particularly in the residential sector. Diesel, fuel, and kerosene contribute minimally but remain relevant for specific applications in rural or less urbanized areas. Fugitive emissions, primarily from natural gas distribution, add a steady but smaller share. The residential sector significantly contributes to these emissions, driven by its reliance on electricity, LPG, and natural gas.

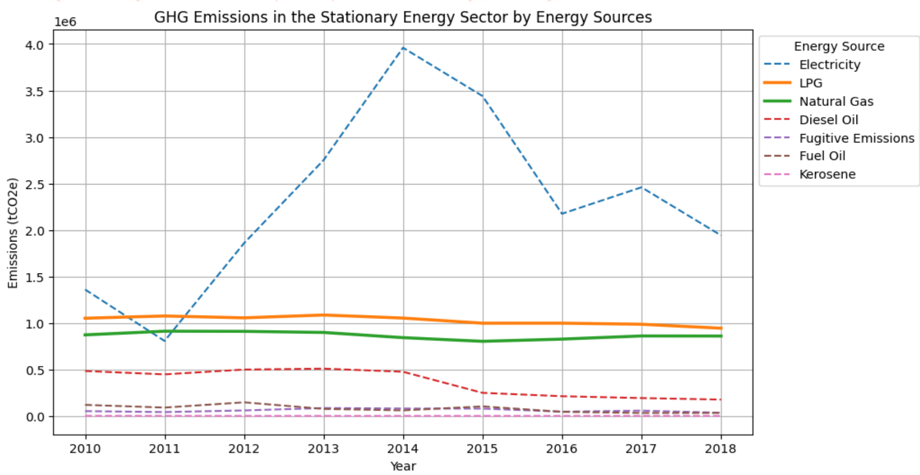



*Figure 2. GHG emissions for energy sources.*

*Elaborated by the authors based on (Anthropogenic Emissions and Removals of Greenhouse Gases Inventory in the São Paulo Municipality 2010 – 2018, 2022).*

The contribution of the residential sector (globally) represents a smaller share of greenhouse gas emissions, which are higher in sectors such as transport and industry. However, it is essential to understand the influence of this sector on national greenhouse gas balances, as well as to know the air pollutants emitted inside homes and how they affect the health of residents. Studies such as that of Cameron et al., 2022 which used the MESSAGE-Access model, emphasize the efficiency of induction stoves, which reduce GHG emissions and improve health outcomes by minimizing indoor air pollution. However, they emphasize that this transition depends on reliable electricity and adequate infrastructure, especially in developing regions with evolving energy systems (Cameron et al., 2022; Climate Science, 2023).
This project aims to gather data on cooking fuel usage in Brazilian kitchens, focusing on the two most used sources: liquefied petroleum gas and natural gas.

## c. Description of project monitoring

This project aims to analyze the CO2, CH4, and NOx emissions emitted by gas stoves in three cities in Latin America: Brazil, Chile, and Colombia. Table 1 describes the towns involved in the project, the number of residences the experiment was performed on, and the gases analyzed.
The study involves a detailed protocol so that if there was a similar standard of measures in all cities, the project had as a basis the study of Lebel et al. (2022), which aims to verify the emissions from using natural gas in the cooking process.

*Table 1: Distribution of measurements by country and gases monitored.*

| Country | City | Number of residences | gases monitored |
|---|---|---|---|
| Brazil | São Paulo | 30 | $CH_4$, $CO_2$, $NO_2$ |
| Chile | Santiago<br>Temuco | 30<br>15 | $CH_4$, $CO_2$, $NO_2$, CO, y $C_6H_6$. |
| Colombia | Bogotá | 20 | $CH_4$, $CO_2$, $NO_2$, CO |

The measurements were carried out in kitchens of volunteer residences in the São Paulo Metropolitan region; the experiment was conducted in 30 properties.

# 2. ACTIVITIES DESCRIPTION

## a. Measurement Protocol

Measurement Protocol for Evaluating Greenhouse Gas (GHG) Emissions in Brazilian Households was developed based on international studies and tailored to local conditions. The methodology applied follows a series of steps to ensure the accuracy and reliability of the data collected. The key stages of the protocol are described below:

### 1. Kitchen Dimensioning and Initial Preparation

To prepare for the sampling process, the kitchen's dimensions (width, height, and length) were measured using a laser measuring device to calculate its volume accurately. During this step, sampling tubes connected to the monitoring equipment were installed on a tripod, which was adjusted to the height of the person cooking and positioned near the stove for optimal data collection.

Initial preparation and ventilation were conducted following the dimensioning process to stabilize gas concentrations. With doors and windows open, two fans - (see Figure 3a) were used to ventilate the kitchen, ensuring that gas concentrations, such as $CO_2$, $CH_4$, and $NO_2$, reached levels close to the external environment. This procedure allowed for accurately measuring baseline gas concentrations, serving as reference points for subsequent stages. Stabilization was continuously monitored until the concentration values remained constant, ensuring reliable baseline measurements.

### 2. Steady-State "Back_Module"

After initial stabilization, the kitchen was sealed or closed to begin the "Steady-State Off" phase (Figure 3b). At this stage, all stove burners were turned off, and the room remained closed to assess possible gas infiltration or residual concentrations. For approximately 2 minutes (a duration determined through preliminary testing), $CO_2$, $CH_4$, and $NO_2$ concentrations were continuously monitored to ensure the space was completely isolated from external sources, providing an accurate baseline for "off" state gas levels.

### 3. Gas Injection ("Inject Gas_Module")

Immediately after the "Back" period, the gas injection phase, referred to as "Inject Gas," was performed. During this stage, 450 mL of $CO_2$ was injected into the kitchen using a syringe connected to a $CO_2$ cylinder. This standardized injection allows the calibration of measurement instruments and helps determine the air exchange rate within the room. $CO_2$ concentrations were monitored over time until stabilization and subsequent decay, enabling the calculation of correction factors and assessing the room's insulation efficiency.

### 4. ST_OFF_Module

After the Inject Gas phase, the Stated OFF phase was conducted to allow gas concentrations ($CO_2$, $CH_4$, and $NO_2$) to return to baseline levels. This phase lasted approximately 2 minutes.

### 5. ST_ON_Module

Following the "Off" phase, one of the stove burners was lit to initiate the "Steady-State On" phase. To simulate the typical use of equipment, a pot with water was placed on the burner to recreate real cooking conditions. During this phase, $CO_2$, $CH_4$, and $NO_2$ concentrations were monitored while the burner remained lit until stabilization was reached. This stage lasted approximately 5 minutes, capturing maximum emission levels associated with burner use.

### 6. OFF_Module

In the OFF phase, the previously lit burner was turned off for about 2 minutes. This phase was repeated three times in each cycle.

### 7. ON_Module

After 2 minutes, the burner previously lit during the Steady ON phase was relit for 1 minute. This phase was also repeated three times in each cycle.

### 8. Background Period ("Back")

After the "On" phase, a new ventilation period, referred to as "Back," was carried out to reduce environmental gas concentrations. This step ensures that the measurement space returns to conditions similar to the external environment before proceeding with the following gas injection. This stabilization is crucial to ensure that subsequent measurements are based on a new baseline.

### 9. Cycle Repetition

The entire measurement cycle was repeated for each stove burner, ensuring representative data collection under varying usage intensities. This structured process ensures standardization and consistency of the data, enabling future comparisons and reliable inferences about GHG emissions associated with cooking gas use in Brazilian households.


Figure 3. *SP_CASA01: Example of kitchen preparation for sampling: a-) Kitchen Dimensioning and Initial Preparation; b-) Sealed or closed to begin the "Steady-State Off".*

The cycles and durations of each module used in the experiments are detailed in Table 2, along with the specific modules assigned to each cycle. The cycle durations were adapted from the study conducted by Label et al. (2022) and tailored to the context of Brazilian residences—preliminary tests conducted before the measurements identified patterns that influenced the timing of each module. For example, the "Inject Gas" module was performed for 4 minutes at the beginning of the measurements. This duration was selected based on observations that $CO_2$ concentration values stabilized within this timeframe, allowing for accurate calibration and air exchange rate assessment.

In the "State ON" module, it was determined that a 5-minute duration was sufficient for the concentrations of $CO_2$ and $CH_4$ to stabilize while the burner was active. For the "ON" and "OFF" modules, distinct patterns of gas behavior were observed: a noticeable increase in gas concentrations during the "ON" phase, followed by a decay during the "OFF" phase. These changes were effectively captured within 1 minute for the "ON" module and 2 minutes for the "OFF" module. The modules were distributed across four cycles to capture emissions from different sources and scenarios. Cycle 1 focused on the larger burner, Cycle 2 on the smaller burner, Cycle 3 on the oven, and Cycle 4 on the general kitchen environment. These cycles are demonstrated in Figure 4 and highlights the modules used in each cycle. This division ensured a comprehensive evaluation of emissions under various cooking conditions and equipment use cases, further enhancing the representativeness and reliability of the data collected.

Table 2. *Module, cycles, and time of each module performed in the residences.*

| Module | Cycle | Time | Module | Cycle | Time | Module | Cycle | Time | Module | Cycle | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Back | 1 | 2 min | Back | 2 | 2 min | Back | 3 | 2 min | Back | 4 | 2 min |
| Inj_gas | 1 | 4 min | St_OFF | 2 | 2 min | St_OFF | 3 | 2 min | St_ON | 4 | 5 min |
| St_OFF | 1 | 2 min | St_ON | 2 | 5 min | St_ON | 3 | 5 min | | | |
| St_ON | 1 | 5 min | Off | 2 | 2 min | Off | 3 | 2 min | | | |
| Off | 1 | 2 min | On | 2 | 1 min | On | 3 | 1 min | | | |
| On | 1 | 1 min | Off | 2 | 2 min | Off | 3 | 2 min | | | |
| Off | 1 | 2 min | On | 2 | 1 min | On | 3 | 1 min | | | |
| On | 1 | 1 min | Off | 2 | 2 min | | | | | | |
| Off | 1 | 2 min | On | 2 | 1 min | | | | | | |
| On | 1 | 1 min | | | | | | | | | |

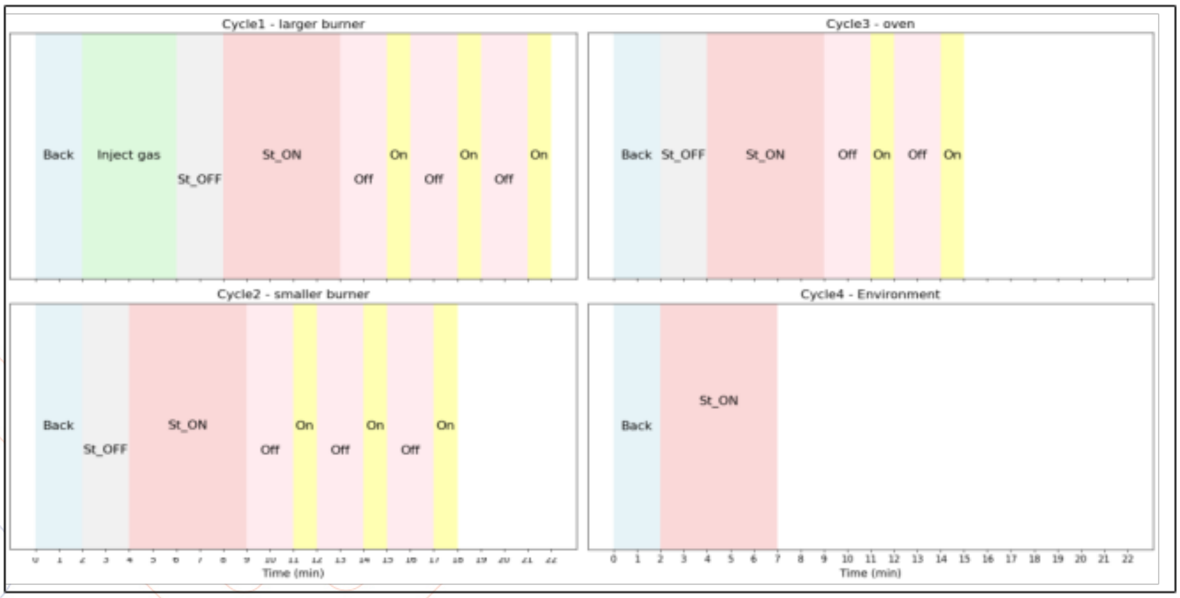



Figure 4. *Each cycle was adjusted, ranging from ~10 to ~20 minutes.*

## d. Materials & Equipment

This section delineates the materials and equipment employed in the measurements, providing a brief explanation of their functionality and purpose. This step is crucial to establish the reliability of the results, facilitating a thorough understanding of the technical and operational specifications of the materials, instruments, and technologies utilized.
The materials and equipments used were (Figure 5):

1 - Fans;

2 - Plastic for sealing (in case of open kitchens);

3 - Tripod for fixing the equipment tubes;

4 - Gas analyzer - ABB;

5 - NO, $NO_2$ and $NO_x$ analyzer;

6 - $CO_2$ cylinder;

7 - Auxiliary Pump.

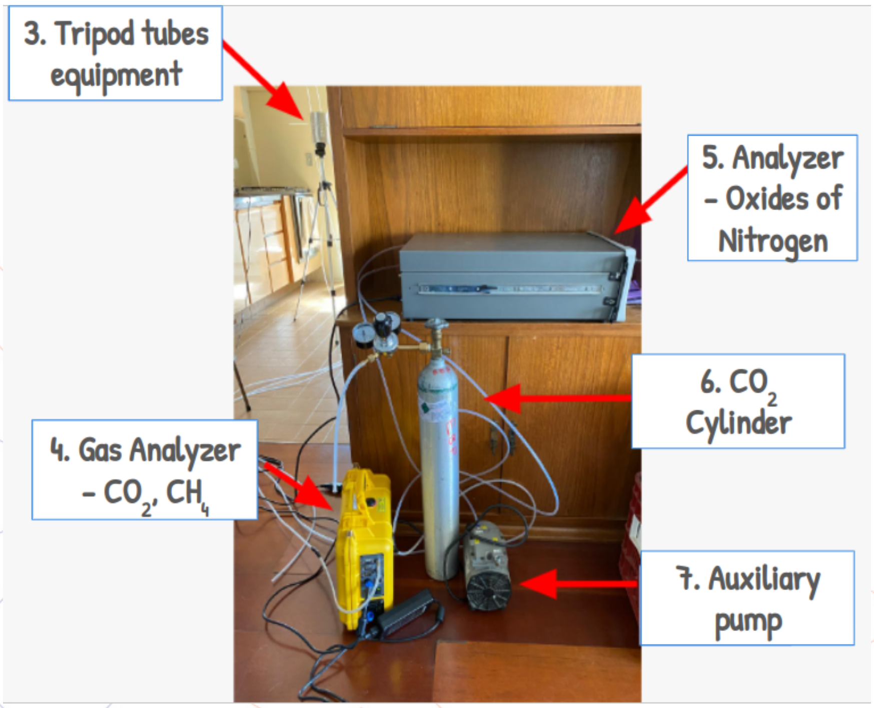



Figure 5. *Equipments and Materials used during the campaign.*

Two types of analyzers were used for the experiment: one for CO2 and CH4 measurements and another for NO, NO2, and NOx measurements. Both equipment are described below (Table 3).

*Table 3. Description of equipment used for monitoring $CH_4$, $CO_2$, and $NO_x$ emissions.*

| GAS | MANUFACTURER | MODEL | SENSING PRINCIPLE | ACCURACY |
|---|---|---|---|---|
| $CH_4$ | ABB | Micro portable Greenhouse Gas Analyzer - MGGA (LGR-ICOS ™ GLA Series) | Integrated Cavity Output Spectroscopy (OA-ICOS) | ± 0.01 - 100 ppm. |
| $CO_2$ | | | | ± 10 ppm - 20000 |
| $NO_x$ | Ecotech | Serinus 40 | Chemiluminescence | ± 0 to 20 ppm |

## Serinus 40 Oxides of Nitrogen

The Serinus 40 (Ecotech) nitric oxide analyzer uses gas-phase chemiluminescence detection for continuous analysis of nitric oxide (NO), total nitrogen oxides ($NO_x$), and nitrogen dioxide ($NO_2$). Approved by the US EPA as a reference method and certified by the TUV (Technischer Überwachungsverein) according to EN (European Norms), the instrument consists of a pneumatic system, a converter from $NO_2$ to NO, a reaction cell, a measuring cell (PMT), an ozone generator and a PCA controller. Chemiluminescence occurs by the emission of light from an activated species of $NO_2^*$, formed by the reaction between NO and $O_3$ in an evacuated chamber, following the mechanism:

$$NO + O_3 \rightarrow NO_2^* + O_2.$$


The Serinus 40 analyzer has a measuring range ranging from 0 to 20 ppm, with automatic auto-ranging, being the range designated by USEPA from 0 to 0.5 ppm and the TUV EN certification establishing the ranges from 0 to 1000 ppb for NO and from 0 to 260 ppb for $NO_2$. The instrument detection limit is 0.4 ppb when the Kalman filter is active. The accuracy is 0.4 ppb or 0.5% of the reading, whichever is greater, while the linearity is 1% of the total scale. The response time of the instrument is 15 seconds to reach 90% of the reading, and the sample flow rate is 0.3 slpm, 0.6 slpm in the flow path for NO and $NO_X$.

*Figure 6. Analyzer Serinus 40 (Ecotech) for measurements NO, $NO_2$ and $NO_x$.*

### Microportable Greenhouse Gas Analyzer - (LGR-ICOS ™ GLA Series)


The Microportable Greenhouse Gas Analyzer - MGGA (LGR-ICOS TM GLA Series) employs the Integrated Cavity Output Spectroscopy (OA-ICOS) technique, configured to acquire samples of methane ($CH_4$), carbon dioxide concentrations ($CO_2$), and water vapor ($CH_4$), reaching an accuracy of <0.9 ppb (1 second) for $CH_4$ and <350 ppb for $CO_2$ (1 second). The MGGA has measurement rates ranging from 0.01 to 10 Hz and supports $CH_4$ concentrations of 0.01 to 100 ppm and $CO_2$ concentrations of 10 to 20,000 ppm, respectively. The analyzer's optical system consists of two lasers with specific wavelengths for detecting $CH_4$ and H20v (Laser A) and $CO_2$ (Laser B), respectively. (ABB Inc., 2020).

*Figure 7. Microportable Greenhouse Gas Analyzer (LGR-ICOS TM GLA Series).*

## e. Definition of Sample Object Components

Measurements were conducted in kitchens, essential spaces in a home specifically designed for food preparation and storage. According to the Oxford English Dictionary (OED), a kitchen is "a room or area equipped for preparing food, usually containing a stove, oven, sink, and other necessary appliances." In many Brazilian households, kitchens also serve as spaces for social interaction, where meals are often prepared and consumed, reinforcing their role as a central area of domestic life.

This study focused on different types of stoves, defined as devices used to cook food by applying heat generated from sources such as gas, electricity, or firewood. According to the Cambridge Dictionary, a stove is "an appliance that uses a heat source, typically divided into burners or heating zones, to cook food". Specifically, this study analyzed stoves powered by natural gas or LPG, most featuring 2 to 6 individual cooking elements (burners). These burners were the primary objects of analysis due to their direct impact on energy consumption and the emissions associated with their use in Figure 8 shows the example of the stove and your burners, respectively.

Additionally, two types of kitchens were evaluated during the sampling process: open and closed. Open kitchens, commonly referred to in Brazil as "American-style kitchens," are integrated with other areas of the house, such as living or dining rooms, without physical dividers between the spaces (see Figure 8 - SP_CASA01 for an example). In contrast, closed kitchens are fully separated from other areas by walls or doors, providing a more enclosed environment (see Figure 9 - SP_CASA23 for an example of this kitchen style). The top image in Figure 9 shows an example of an open kitchen (SP_CASA01), which necessitates putting a seal, and the bottom image in Figure 9 shows the kitchen's example closed (SP_CASA23), which didn't necessitate putting a seal. This differentiation allowed the evaluation of how structural conditions and airflow within the kitchens influence emission measurements, highlighting the characteristics that most affect the environmental performance of these spaces.


*Figure 8. The stove example (SP_CASA01). For measurements, it was chosen to use a larger burner (1) and a smaller burner of the stove (2), as highlighted in the figure.*


Figure 9. *Kitchen house A, example of open kitchen with plastic use for sealing.*

## f. Housing selection and characterization

### Dissemination and volunteer selection campaign

First, a dissemination campaign was conducted, which involved sharing information about the project via email to recruit volunteers. The emails were sent to contacts in the University of São Paulo databases. Additionally, the information was shared in WhatsApp groups associated with USP and EBP Brazil. The promotion began in June 2024, initially registering 25 houses in São Paulo. Below are the promotional materials and the registration form's cover page.


*Figure 10. Form volunteer selection campaign.*

### Region of study

The city of São Paulo is known as the most populous in the state of São Paulo and Brazil. According to the 2022 census, the population of São Paulo is 11,451,999. The metropolitan region of São Paulo has around 20 million inhabitants.

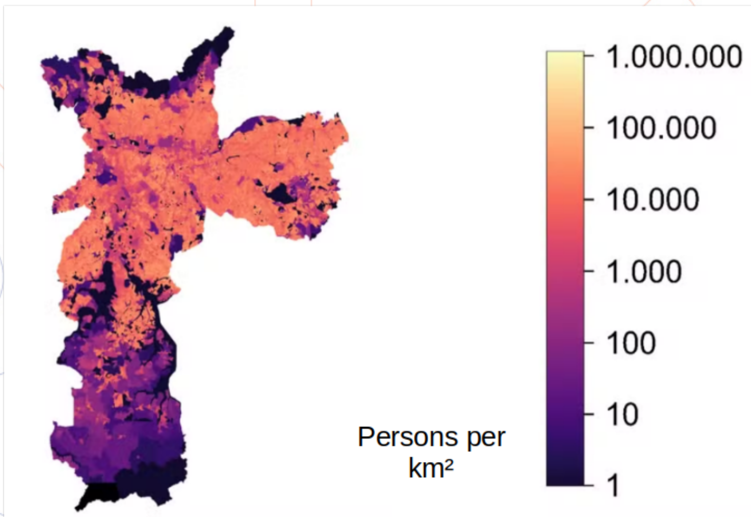



*Figure 11. Map of population density in the city of São Paulo (SP) - CENSUS 2022/IBGE.*

### Distribution of Residences

Most of the volunteer residences for the study were located in the city of São Paulo, with additional samples from neighboring towns in the metropolitan region, as shown in the map of participant residences (Figure 12). The map highlights the Metropolitan Area of São Paulo (MASP), with the city of São Paulo marked in red. The triangles represent the distribution of volunteer residences, indicating that most data collection occurred in São Paulo.

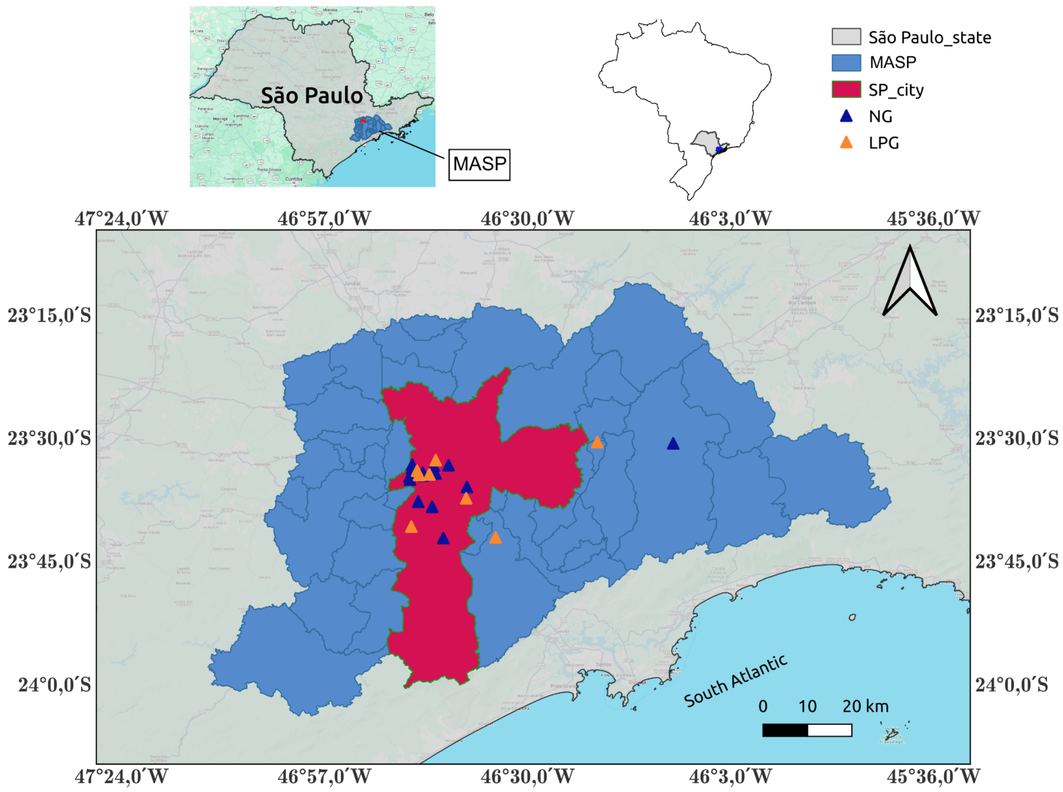
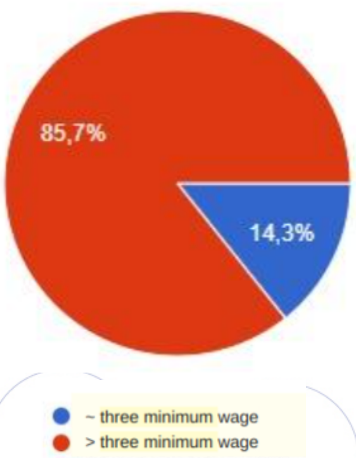



Figure 12. *Spatial distribution of residences.*

## São Paulo: Household Income of Participants




86% of households had an income of more than three minimum wages, and 14% had a lower income. Considering the project participants, no relevant structural factors in these two groups of homes could have influenced the study's results. The differences are concentrated in the quality of the finishes used and the size and location of the properties.

*Figure 13. Salary range of participants.*

## Statistics of the residences

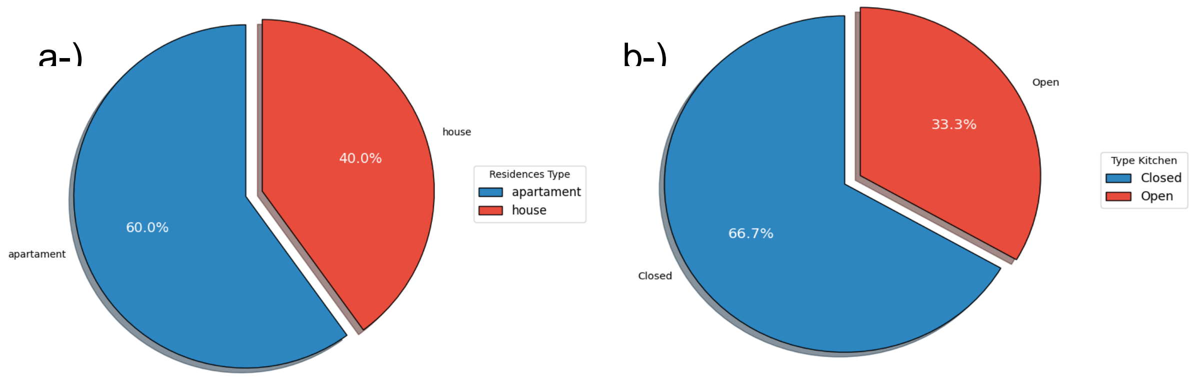



*Figure 14. a-) Distribution of housing types among participating residences; b-): Distribution of kitchen layouts among the sampled residences.*

The participating residences included apartments and houses, reflecting the variety of housing in São Paulo. 60% of the samples were collected in apartments, while 40% were in houses (Figure 14a), which usually had larger kitchens. Approximately 67% of the kitchens were closed, while 33% were open (Figure 14b), requiring sealing.

## Stoves and Gas

In Brazil, the two primary cooking fuel types are Liquefied Petroleum Gas (LPG) and Natural Gas (NG). Among these, the use of natural gas represents a significant portion of completed tasks in the surveyed kitchens, which shows Figure 15a.

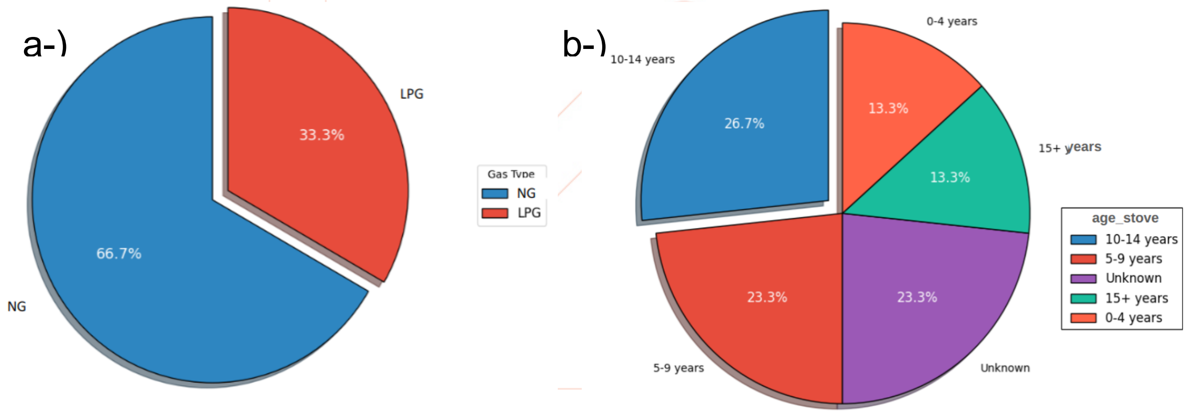



*Figure 15. a-) Distribution of cooking fuel usage in São Paulo kitchens - Natural Gas (NG) and Liquefied Petroleum Gas (LPG); b-) Age distribution of stoves in the surveyed kitchens.*

The kitchens where samples were collected revealed a diverse range of stove ages, from 1 to 40 years of use. The most common age group was 10–14 years, accounting for approximately 27% of all stoves recorded. This was closely followed by stoves aged 5–9 years and those whose age was unknown, which were reported in equal proportions. Stoves at the extremes of the age spectrum—ranging from 0–4 years and more than 15 years—comprised the smallest share of the surveyed units (Figure 15b).

## g. Contact with post-selection volunteers

After registering the volunteers, the researcher contacted those interested to confirm their participation, provide additional details, and address any questions they might have. Once the interest was confirmed, further information about the kitchen was requested to prepare for the measurements. Another topic discussed and agreed upon was the date and time of the volunteer's availability to schedule the sampling.

During these discussions, the sampling duration was always emphasized—ranging from 2 hours and 30 minutes to 3 hours. Information about the equipment and the noise it might produce was also shared.

On the day of the visit, upon arriving at the residence, each homeowner was asked to sign the Informed Consent Form (Appendix b. informed consent forms), which explains the project details and requests authorization for all activities conducted during the sampling, including photographing the residence. After the measurements were completed, a copy of the Informed Consent Form was sent to each volunteer.

## h. Emission rate estimation methodology

To accurately determine gas emissions in residential kitchens, methodologies combining the calculation of the environment's volume, the air exchange rate (ACH), and the mass balance of monitored gas concentrations were adopted. These approaches ensure reliable estimation, enabling the evaluation of emission behavior under different operational conditions.

### Mass Balance and Emission Rate

The emission rate of a gas "i" was estimated using a mass balance approach within the control domain, represented by the kitchen space isolated from the rest of the residence using plastic barriers. Assuming that gases do not undergo significant chemical reactions after being emitted, the evolution of the concentration $C_{i,b}$ (mol/m³) over time is described by the equation:

$$V_0 \frac{dC_i}{dt} = E_i - \lambda V_0 (C_i - C_{i,b})$$

**Where:**

- $C_{i,b}$ é a concentração basal do gás;

- $V_0$ é o volume da cozinha (m³);

- $\lambda$ é a taxa de troca de ar (ACH), em min$^{-1}$.

Accurate measurement of gas concentrations over time enables determining the instantaneous emission rate of gas "i". This methodology was applied to different operational modes of stoves, such as the use of individual burners, and the average emission rate was calculated as follows:

$$\underline{E_i} = V_0\left(\frac{\Delta C_i}{\Delta t} + \lambda\,(\underline{C_i} - C_{i,b})\right)\frac{p}{RT}$$

This method accounts for the environment's volume, baseline and measured concentrations, and the air exchange rate, providing detailed insights into emissions.

### Volume Estimation

The formula for calculating the environment's volume (in liters) is based on the physical dimensions of the space being measured, like a kitchen:

$$Measured\ (L){:}\ V\ =\ (Height\ x\ Width\ x\ Depth)\ x\ 1000$$

A tracer gas ($CO_2$) controlled release was also performed to validate the volume estimates, assuming homogeneous gas dispersion. This combined approach reduced uncertainties, ensuring greater accuracy in the calculations.

### Determination of Air Exchange Rate (ACH)

The air exchange rate $\lambda$ was determined after ventilating the kitchen and ensuring concentrations similar to those of the external environment. A controlled release of $CO_2$ was then carried out, and the decay rate of the concentration was monitored, enabling the precise calculation of the ACH. This step was essential to validate the measurements and assess the degree of isolation in the environment.

### Emission Factor Calculation

Once the emission rate $\underline{E_i}$ was determined, emissions could be expressed per unit of natural gas consumed $\underline{q_{GN}}$, based on the average composition of natural gas $(C_xH_y)$. Assuming that most of the carbon is emitted as $CO_2$, CO, and $CH_4$, the consumption rate is given by:

$$\underline{q_{GN}} \approx (\underline{E_{CO_2}} + \underline{E_{CO}} + \underline{E_{CH_4}})/x$$

The emission factor $FE_i$ for gas "i" was calculated using:

$$FE_i = M_i\underline{E_i}/(\underline{q_{GN}}\,.\,LHV)$$

**Where:**

- $M_i$ is the molecular weight of gas "i";

- $LHV$ is the lower heating value of natural gas.

## i. Characteristics of natural gas and LPG in Brazil

Liquefied petroleum gas (LPG) and natural gas (NG) are the primary fuels used in residential settings in Brazil, playing a critical role in meeting household energy needs. LPG, regulated by the National Agency of Petroleum, Natural Gas, and Biofuels (ANP), is predominantly composed of propane ($C_3H_8$) and butane ($C_4H_{10}$), with minor amounts of other hydrocarbons such as ethane ($C_2H_6$). To enhance safety, a sulfur-based odorant, typically ethyl mercaptan ($C_2H_6S$), is added to make leaks easily detectable by smell. LPG is widely distributed in 13 kg (P13) cylinders commonly used for home cooking. The residential sector accounts for 78% of the final consumption of LPG in the country (EPE, 2023). Its importance in this sector is highlighted because, in 2020, LPG was the primary cooking fuel used in 94% of households across Brazil (EPE, 2022b). This further underscores the widespread reliance on LPG for cooking in Brazilian homes.

*Table 4. Technical characteristics of LPG.*

| CHARACTERISTIC | UNIT | PROPANE/BUTANE MIXTURE |
|---|---|---|
| Higher Heating Value (4) | MJ/kg | 46 |
| Maximum Vapor Pressure at 37.8°C (1) | kPa | 1430 |
| Butanes and heavier, max. (2) | % vol. | - |
| Pentanes and heavier, max. (2) | % vol. | 2,0 |
| Propane, min. | % vol. | - |
| Propene, max. | % vol. | - |
| Residue, 100 mL evaporated, max. | ml | 0,05 (3) |

| | | |
|---|---|---|
| Evaporation Residue, max. (4) | mg/kg | 350 |
| Total Sulfur, max. | mg/kg | 140 |

(referred to in articles 1, 2, 4, 6, and 9 of ANP Resolution Nº 825, of August 2020)

Natural gas (NG) is primarily composed of methane ($CH_4$), making up over 70% of its composition, followed by smaller proportions of ethane ($C_2H_6$) and propane ($C_3H_8$). Its gaseous state under normal atmospheric conditions makes it suitable for direct pipeline distribution. In São Paulo, LPG remains the dominant fuel for residential kitchens, particularly in areas lacking the infrastructure for NG distribution. It is widely utilized in both urban and rural regions. However, the use of NG is gradually expanding, especially in urban centers and metropolitan areas where pipeline networks enable its direct delivery to homes (Associação Brasileira das Empresas Distribuidoras de Gás Canalizado - Abegás). The primary component of the natural gas supplied by Comgás in São Paulo is methane, which accounts for more than 90% to 95% of the total, with its quality ensured by ANP specifications, as shown in the table below:

Table 5. *Technical characteristics of natural gas (As amended by ANP Resolution Nº. 7/2010) *São Paulo - Southeast*

| CHARACTERISTIC | UNIT | LIMIT (2) (3) |
|---|---|---|
| | | North, Central-West, Southeast* and South |
| Higher Heating Value (4) | kJ/ m³ | 35,000 to 43,000 |
| | MJ/kg | 45 |
| | kWh/m³ | 9.72 to 11.94 |
| Wobbe Index (5) | kJ/m³ | 46,500 to 53,500 |
| Methane Number, min. (6) | | 65 |
| Methane, min. | % mol. | 85.0 |
| Ethane, max. | % mol. | 12.0 |
| Propane, max.. | % mol. | 6.0 |
| Butanes and heavier, max. | % mol. | 3.0 |

| | | |
|---|---|---|
| Oxygen, max. (7) | % mol. | 0.5 |
| Inerts ($N_2$+$CO_2$), max. | % mol. | 6.0 |
| $CO_2$, max. | % mol. | 3.0 |

# 3. RESULTS

This chapter presents the campaign's results conducted in São Paulo, which involved 30 houses. The measurements were carried out between August 21, 2024, and September 24, 2024. Table 6 provides detailed information about the homes included in the study, including the number of houses, the study dates, house types, the use of plastic sealing, the type of gas used for cooking, and other relevant data**.**

Table 6. *Information Measurements houses.*

| City | Region | Nomenclature | Date | Type Kitchen | Plastic to seal * | Age Stove | Residences Type | Gas Type |
|---|---|---|---|---|---|---|---|---|
| SÃO PAULO/SP | Western zone | SP_CASA01 | 08-21-24 | open | Y | 6 | house | GN |
| SÃO PAULO/SP | Western zone | SP_CASA02 | 08-22-24 | closed | N | 10 | house | LPG |
| SÃO PAULO/SP | Western zone | SP_CASA03 | 08-22-24 | closed | N | 11 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA04 | 08-23-24 | closed | N | 15 | house | LPG |
| SÃO PAULO/SP | Southern zone | SP_CASA05 | 08-23-24 | closed | N | 10 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA06 | 08-23-24 | closed | N | 3 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA07 | 08-27-24 | closed | N | 20 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA08 | 08-27-24 | closed | N | 10 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA09 | 08-27-24 | closed | Y | 10 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA10 | 08-28-24 | open | Y | 25 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA11 | 08-29-24 | closed | Y | 40 | house | LPG |
| SÃO PAULO/SP | Western zone | SP_CASA12 | 08-29-24 | closed | N | 7 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA13 | 08-29-24 | closed | Y | 3,5 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA14 | 09-02-24 | closed | N | 7 | house | LPG |
| SÃO PAULO/SP | Western zone | SP_CASA15 | 09-02-24 | closed | N | 10 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA16 | 09-04-24 | closed | N | 10 | apartament | GN |
| SÃO BERNARDO DO CAMPO/SP | MASP ** | SP_CASA17 | 09-05-24 | closed | N | 5 | house | LPG |
| SÃO BERNARDO DO CAMPO/SP | MASP ** | SP_CASA18 | 09-05-24 | closed | Y | 10 | house | LPG |
| SÃO PAULO/SP | Southern zone | SP_CASA19 | 09-05-24 | closed | N | 1 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA20 | 09-06-24 | closed | N | 14 | house | GN |
| SÃO PAULO/SP | Western zone | SP_CASA21 | 09-10-24 | open | Y | 10 | house | LPG |
| SÃO PAULO/SP | Western zone | SP_CASA22 | 09-10-24 | open | Y | 4 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA23 | 09-10-24 | closed | N | 10 | house | LPG |
| MOGI DAS CRUZES/SP | MASP ** | SP_CASA24 | 09-11-24 | open | Y | 5 | apartament | GN |
| POÁ/SP | MASP ** | SP_CASA25 | 09-11-24 | closed | N | 11 | apartament | LPG |
| SÃO PAULO/SP | Western zone | SP_CASA26 | 09-12-24 | open | Y | 5 | house | GN |
| SÃO PAULO/SP | Western zone | SP_CASA27 | 09-12-24 | open | Y | 6 | apartament | GN |
| SÃO PAULO/SP | Western zone | SP_CASA28 | 09-12-24 | open | Y | 10 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA29 | 09-13-24 | open | Y | 3 | apartament | GN |
| SÃO PAULO/SP | Southern zone | SP_CASA30 | 09-13-24 | open | Y | 10 | house | LPG |

* Y: yes / N: no
** MASP - Metropolitan Area of São Paulo

## a. Normalized Concentration

The normalized concentration profiles illustrate the temporal variability differences between two household examples: SP_CASA02, which uses liquefied petroleum gas (LPG), and SP_CASA03, which uses natural gas (NG) for $CH_4$, $CO_2$, and $NO_x$. In the LPG case, $CO_2$ and $NO_x$ concentrations increase upon stove ignition (St_ON), except during Cycle 4 (ambient conditions).
Methane ($CH_4$) concentrations remained stable for most of the period in SP_CASA02 but showed variability from Cycle 3 onwards, suggesting an external influence unrelated to the LPG source.

Cycles 1 and 2 (large and small burners) elicited immediate responses in all compounds. Figures 16 and 17 present time series examples from House SP_CASA02, which utilizes LPG for cooking, and House SP_CASA03, which uses NG.

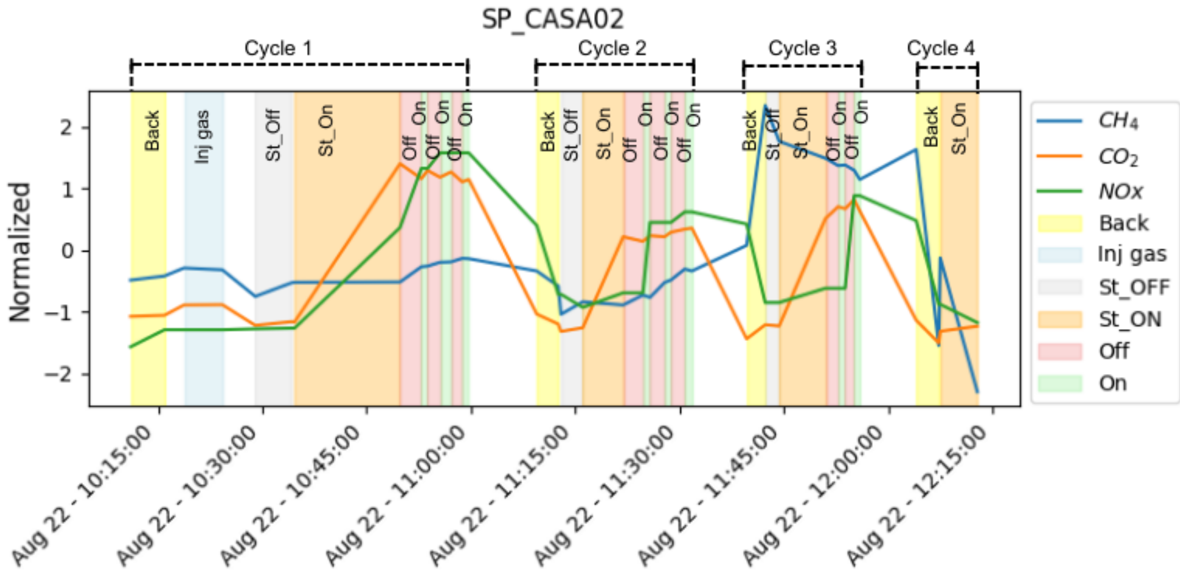



*Figure 16. GLP: House 02 (SP_CASA02) – House (dimension (m): 3.2x4.86x2.54)*

In the case of NG (SP_CASA03), all gases displayed an increase upon stove ignition (St_ON), except in Cycle 4. In Cycle 3 (oven use), the response appeared delayed but resulted in higher $CH_4$ concentrations. This behavior was observed in other households using NG, although no consistent pattern was identified across all samples, meaning it did not occur universally. Such delays, particularly in ovens, may be associated with leaks, which warrants further investigation.

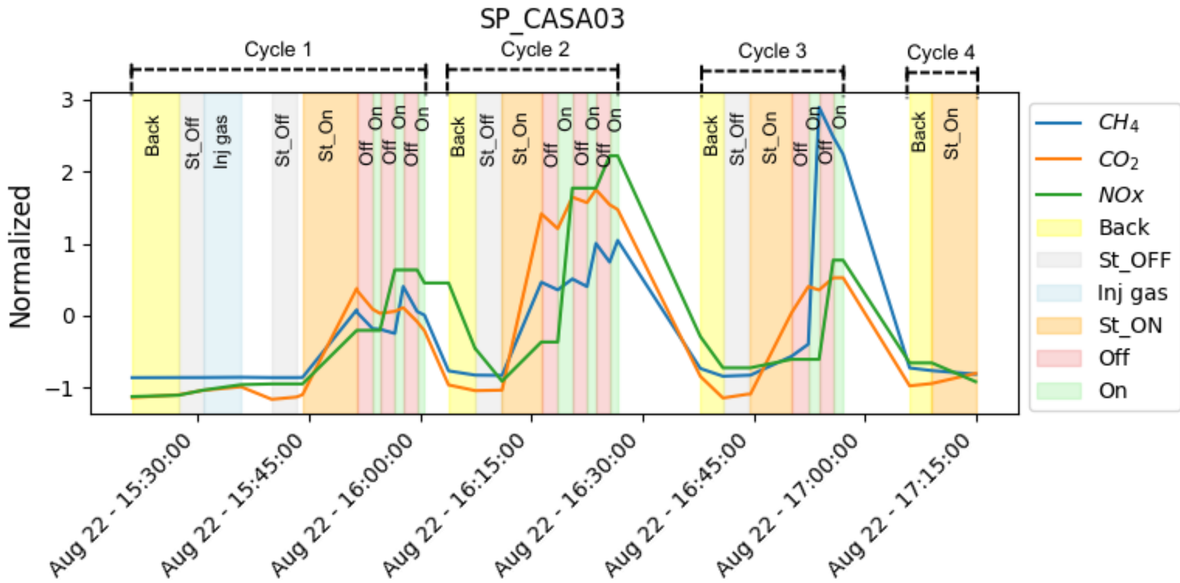



*Figure 17. GN: House 03 (SP_CASA03) – Apartment (dimension (m): 2.53x3.57x2.05)*

Note: In both houses, the kitchens are closed and do not need plastic for sealing.

## b. Consolidated results of Gas Concentration Variability: Cycles and Steady-State Events

The variations in gas concentrations across the monitored houses are depicted by operational cycles and steady-state events (St_Off and St_On) for $CH_4$, $CO_2$, and $NO_2$.

### Methane (CH4):

Generally, the observed methane concentration levels within the houses, such as in the background or steady-off event, approach ambient values (1.9 – 2.0 ppm). However, in some periods, an external source influence is apparent, with concentrations reaching up to 10 ppm even when all appliances are off and doors and windows closed (St_Off). Upon burner activation (St_On), concentration increases are observed explicitly in houses utilizing natural gas (NG) across both cycles.

In Cycle 1, concentrations rise but generally remain low, except for Houses 07 and 20 (Figure 18). Conversely, Cycle 2 (smaller burner) exhibits the highest concentration values among the houses alongside the most significant inter-house variability, see Figure 19.

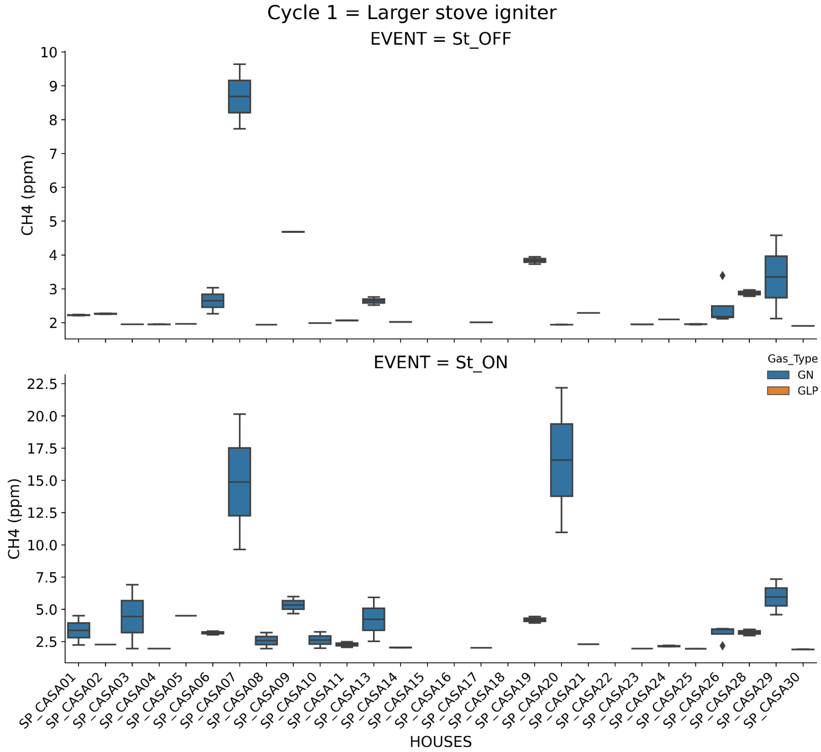



*Figure 18. Variabilities of methane concentrations in the 30 residences, in Cycle 1, separated by steady state events (St_Off and St_On).*

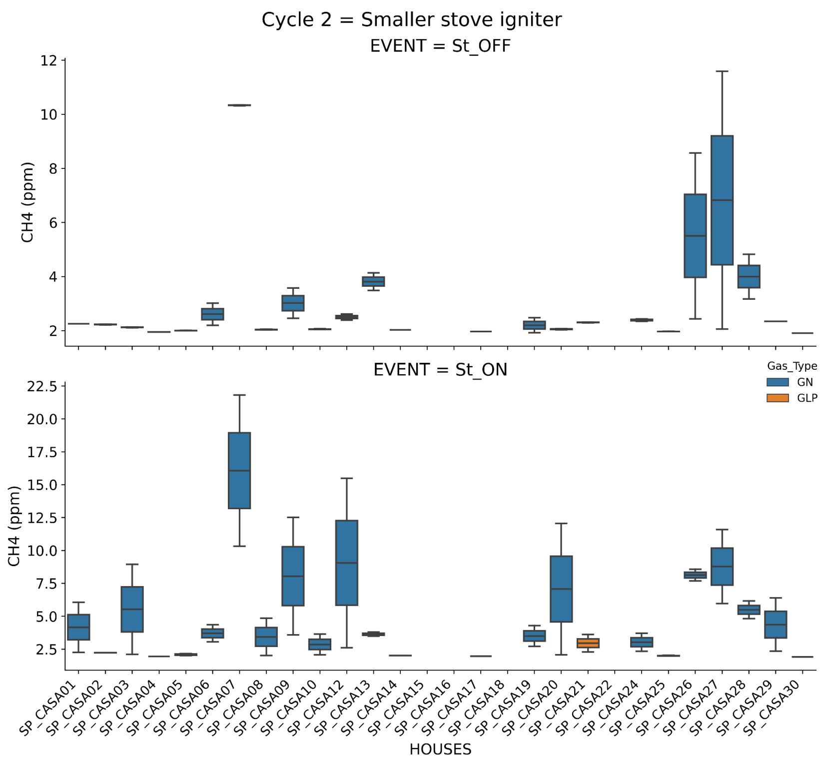



*Figure 19. Variabilities of methane concentrations in the 30 residences, in Cycle 2, separated by steady state events (St_Off and St_On).*

## Carbon Dioxide (CO2):

For $CO_2$, concentrations with all systems off (St_Off) range from 500 to 1000 ppm. In Cycle 1 (Figure 20), St_On levels are between 500 and 1800 ppm. During Cycle 2 (Figure 21), some cases exceed the health effect threshold (NIOSH), reaching levels where minimal health effects could occur. While there is considerable variability between houses, concentrations for both NG and LPG remain similar.

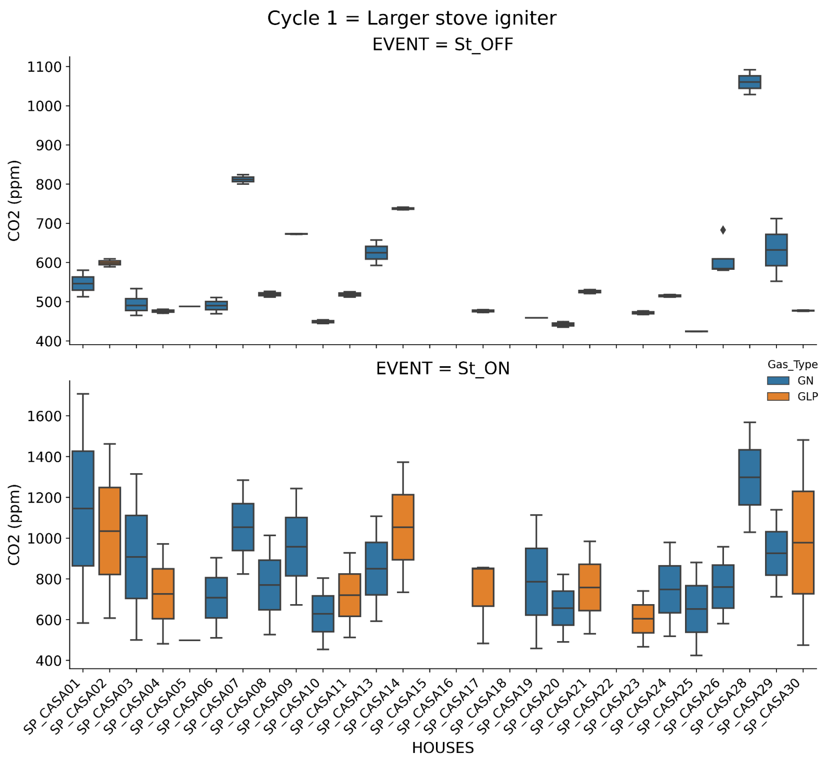



*Figure 20. Variabilities of carbon dioxide concentrations in the 30 residences, in Cycle 1, separated by steady state events (St_Off and St_On).*

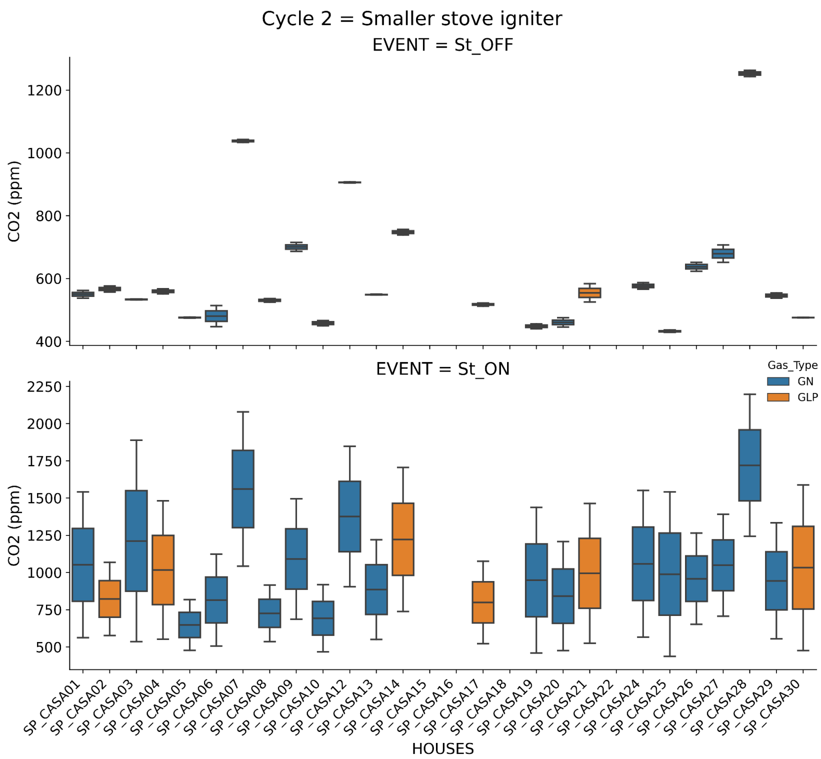



*Figure 21. Variabilities of carbon dioxide concentrations in the 30 residences, in Cycle 2, separated by steady state events (St_Off and St_On).*

## Nitrogen dioxide ($NO_2$)

Figure 22 and Figure 23 highlight the high variability in $NO_2$ concentrations between homes, observed in both St_On and St_Off states. There appears to be no significant difference between natural gas (NG) and liquefied petroleum gas (LPG) sources. Cycle 2 shows elevated $NO_2$ concentrations across homes.

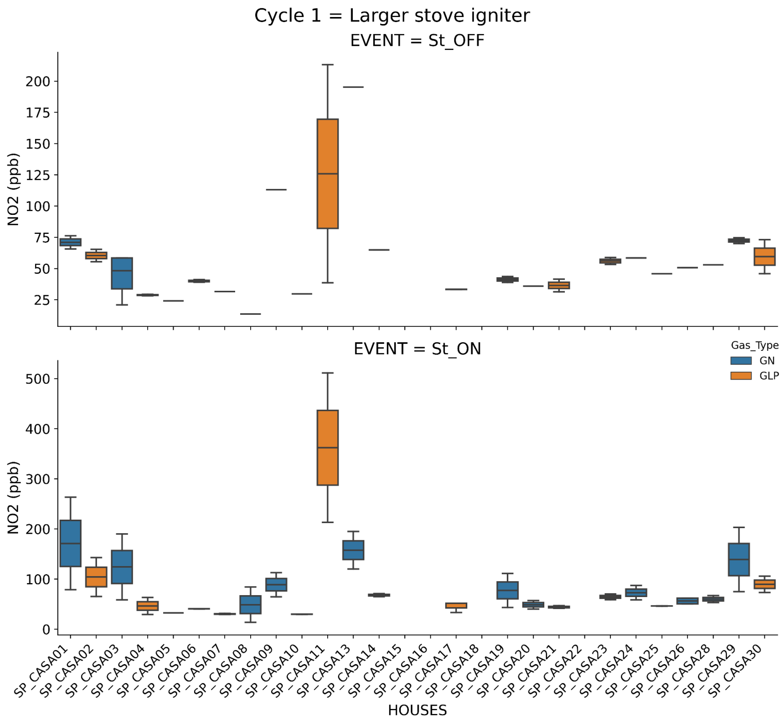



*Figure 22. Variabilities of nitrogen dioxide concentrations in the 30 residences, in Cycle 1, separated by steady state events (St_Off and St_On).*

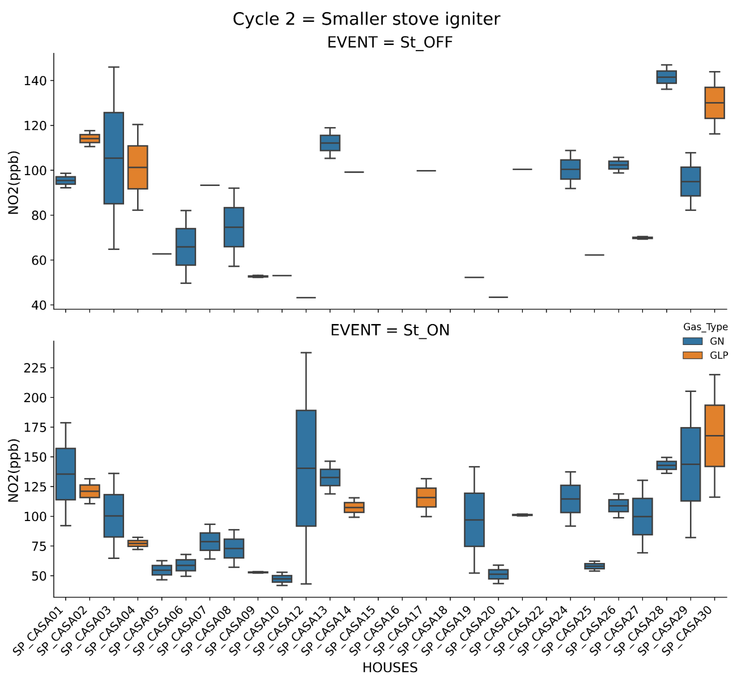



*Figure 23. Variabilities of nitrogen dioxide concentrations in the 30 residences, in Cycle 2, separated by steady state events (St_Off and St_On).*

## c. Concentrations by cycles: $CH_4$, $CO_2$, NO and $NO_2$

Figure 24 shows the variability in $CH_4$ and $CO_2$ concentrations across the monitored homes. $CH_4$ shows the highest values in natural gas (NG) homes, with considerable variability and several outliers, while homes using liquefied petroleum gas (LPG) display relatively stable $CH_4$ levels. The $CO_2$ concentration exhibits the most significant variability, particularly in Cycle 2, in some cases where concentrations often exceed health effect limits. LPG homes show elevated $CO_2$ levels in both burner cycles (Cycle 1 and Cycle 2).

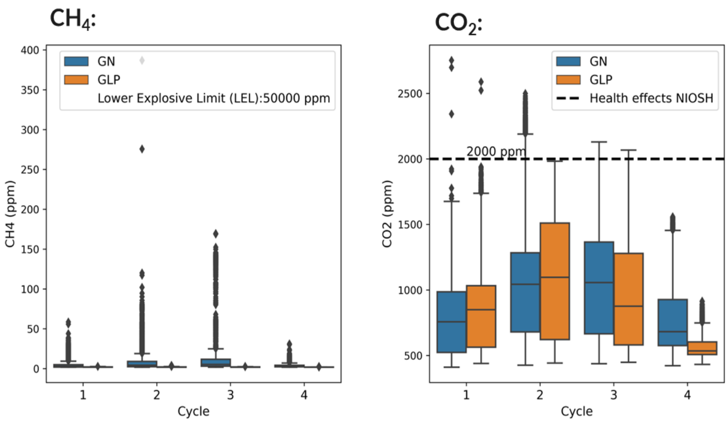



*Figure 24. Variability in $CH_4$ and $CO_2$ concentrations across monitored homes.*

Figure 25 presents the NO and $NO_2$ concentration data for households using natural gas (NG) and liquefied petroleum gas (LPG). NO concentrations show significant variability in both distribution and median values. Although the medians for NG are generally higher than those for LPG in most cycles, along with the presence of outliers, it was impossible to precisely quantify the difference between the two fuels due to the broad data distribution. For $NO_2$, the concentrations of LPG and NG during the cycles exceeded the WHO recommendation of 106 ppb for 1-hour exposure. Additionally, a significant increase in concentrations from Cycle 1 to Cycle 2 was observed for both NO and $NO_2$.

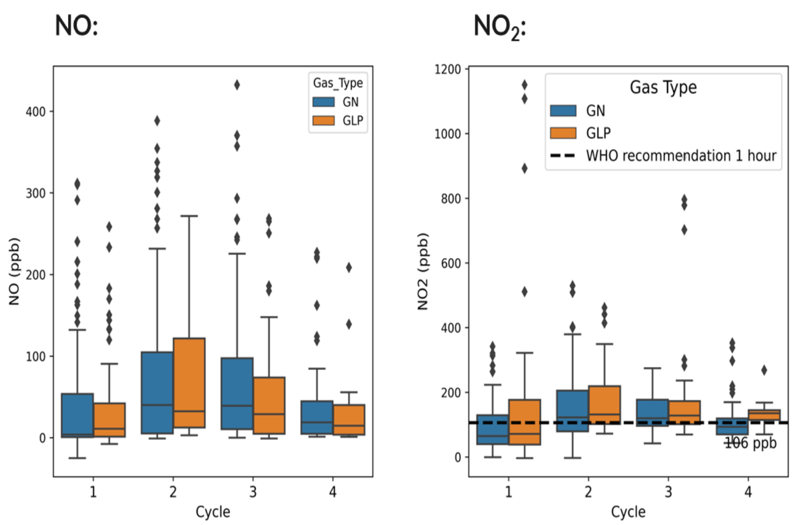



*Figure 25. Variability in NO and $NO_2$ concentrations across monitored homes.*

## d. Emission Rates:

### Emission rate

The emission rate refers to the amount of pollutant released per unit of time and is commonly used to assess emissions in specific operations or direct measurements at sources. On the other hand, the emission factor relates the quantity of pollutants emitted to the activity that generates them, such as fuel combustion.

Table 7 and Table 8 contains the average emission rates and factors, respectively. These values were calculated during the combustion process (steady state ON) for each natural gas and liquefied petroleum gas. The emission rate and factor are the average results of all individual measurements. The table shows the averages without the extreme points (outliers) and in parentheses with the outliers. The $CO_2$ emission rates for NG were 207 g/h, and for LPG, 256 g/h without outliers; while including all data, the average was 270 g/h. For methane ($CH_4$), there was a significant difference between the averages with and without outliers, at 147 mg/h and 495 mg/h, respectively. For LPG, the $CH_4$ average was 16 mg/h. Regarding $NO_2$, the emission rate was low, around 2.99 mg/h for NG and between 4.86 mg/h and 13.65 mg/h for LPG.

Table 7*. Emission rate for $CO_2$, $CH_4$ and $NO_2$*

| Compound | Natural Gas (NG) | Liquefied petroleum gas (LPG) |
|---|---|---|
| **$CO_2$** | 207.02 (212.08) g/h | 256.33 (270.66) g/h |
| **$CH_4$** | 147.68 (495.34) mg/h | 16.57 (16.57) mg/h |
| **$NO_2$** | 2.99 (7.75) mg/h | 4.86 (13.65) mg/h |

### Emission Factor

According to the national greenhouse inventory, Brazil could use IPCC data to estimate household methane emission values. However, the factor adopted in Brazil (LPG = 1.1 $gCH_4/TJ$ and NG = 1 $gCH_4/TJ$) appears to be based on Brazilian emissions data, diverging from IPCC emission factors (NG = LPG = 5 $gCH_4/TJ$).

Considering the values used in the Brazilian inventory and the average gas consumption by stoves of 0.225 kg/h (Petrobras, 2024). The average methane emission factor obtained from the measurements by NG was 14.58 kg/TJ without the outliers and with one hundred percent of the data was 48.92 kg/TJ, 49 times higher than the national factor and 9.8 times higher than the IPCC value and by LPG, the average was 1.60 kg/TJ (?) 1.45 times higher than the Brazilian inventory value and 0.32 times lower than the IPCC value in general for methane.

The emission factor for $CO_2$ obtained was around 20,000 kg/TJ for NG and 14,000 kg/TJ for LPG. For $NO_2$, the emission was 0.29 kg/TJ for NG, an 0.46 kdg/TJ without outliers and 1.3 kg/TJ with all data for LPG.

*Table 8. Emission factor for $CO_2$, $CH_4$ and $NO_2$*

| Compound | Natural Gas (NG) | Liquefied petroleum gas (LPG) |
|---|---|---|
| **$CO_2$** | 20.44 (20.94) g/MJ | 14.58 (20.94) g/MJ |
| **$CH_4$** | 14.58 (48.92) mg/MJ | 1.60 (1.60) mg/MJ |
| **$NO_2$** | 0.29 (0.76) mg/MJ | 0.46 (1.31) mg/MJ |

## Carbon dioxide emission rate

Although the average emission rates and factors for $CO_2$ are similar for NG and LPG, the distribution of the rates shows notable differences. For NG, Figure 26 illustrates a range of values from 0 to 600 g/h, while for LPG, the values are more consistently positive, ranging from 180 to 700 g/h.

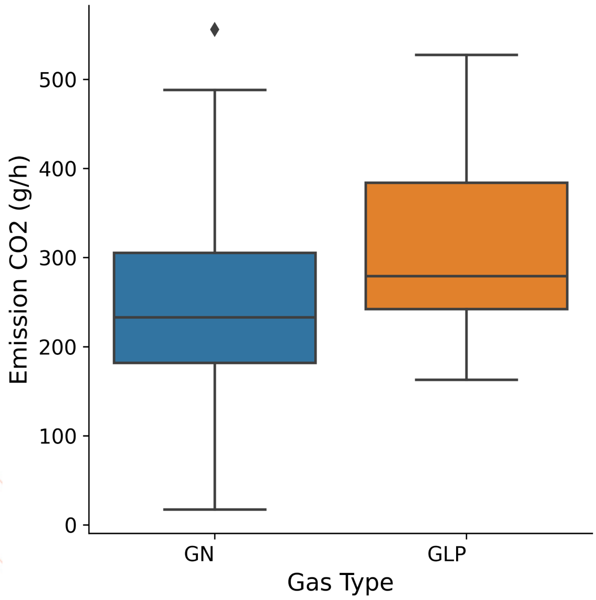



*Figure 26. Emission rate for $CO_2$ in grams per hour (g/h)*

## Methane Emission rate

The methane emission rates clearly highlight the difference between NG and LPG (Figure 27). For LPG, emissions are almost non-existent, resulting in no distribution. In contrast, NG shows a wide data distribution, with extreme values, including negative emissions and rates exceeding 2000 mg/h, and an even eight more extreme outlier above 8000 mg/h. It is worth noting that the average emission rate, including outliers, was 406 mg/h.

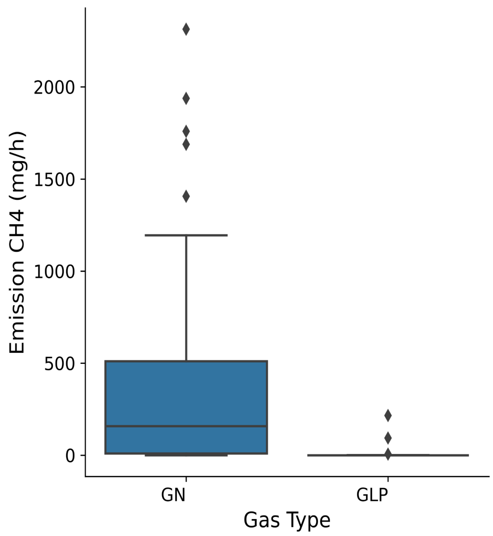



*Figure 27. Emission rate for $CH_4$ in grams per hour (g/h)*

## Nitrogen dioxide Emission rate

Figure 28 shows that $NO_2$ emission rates are similar for NG and LPG. There are no significant differences between these gases in this dataset. However, a greater range of values and outliers is observed for LPG, reaching levels above 150 mg/h. One hypothesis raised is that LPG is more commonly used in houses rather than apartments. In the sampled houses, close to the street was noted, which may contribute to increased $NO_2$ levels indoors.

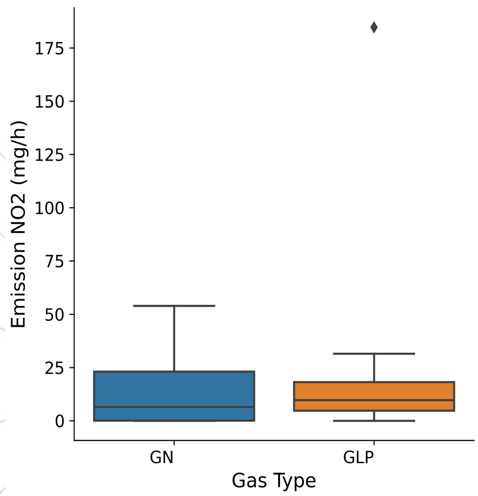



*Figure 28. Emission rate for $NO_2$ in grams per hour (g/h)*

# 4. CONCLUSIONS

## a. General Perceptions

### Overview of Time Series Observations

The time series analysis highlights distinct response behaviors of gases $NO_2$ $NO_x$, $CH_4$, and $CO_2$ under closed ambient conditions. For natural gas (NG) and liquefied petroleum gas (LPG), concentrations of gases such as $CH_4$ and $CO_2$ show significant responses under closed environments, whereas their presence under ambient conditions is very low. When comparing NG and LPG, $CH_4$ concentrations exhibit substantial differences. NG homes consistently show higher $CH_4$ levels, but the concentrations remain far below the lower explosive limit of 50,000 ppm established by the National Fire Protection Association (NFPA). On the other hand, $CO_2$ concentrations vary among homes but display similar trends between NG and LPG, likely influenced by uncontrolled factors such as device types and operational conditions. Meanwhile, $NO_2$ values sometimes exceed WHO's recommended 1-hour limit of 106 ppb even before the stoves are turned on (St_OFF), which may be associated with the main pollution issue in São Paulo: vehicular emissions.

### Variability in Concentrations Across Cycles

The study further dissects gas concentration behavior across different operational cycles:

- **$CH_4$**: Homes using NG display a clear increase in $CH_4$ levels during operation cycles, whereas LPG homes maintain concentrations close to ambient levels, reflecting a minimal response.
- **$CO_2$**: Variability is observed across cycles and within each cycle, primarily linked to stove burner activity. Elevated $CO_2$ levels in certain cases during Cycle 2 highlight the influence of cooking on air quality.
- **NO**: NG homes exhibit higher NO concentrations than LPG homes, but the difference is not mirrored for $NO_2$, which remains consistently elevated for both fuels.
- **$NO_2$**: Across all cycles, $NO_2$ concentrations exceed WHO recommendations, underscoring the potential risk associated with residential fuel combustion.

In general, Cycle 4 (ambient conditions) recorded the lowest gas concentrations for all compounds and fuels, reaffirming the importance of adequate ventilation in reducing indoor pollutant exposure.

## b. Implications on the GHG emissions

### Methane Emission Factor Insights

The study provides important insights into methane emissions associated with residential cooking practices, particularly the differences between homes using Natural Gas (NG) and Liquefied Petroleum Gas (LPG) as a fuel source. Residences relying on NG demonstrated higher methane emissions compared to those using LPG. This finding underscores the importance of considering fuel type when evaluating residential sector greenhouse gas (GHG) emissions.

Although NG usage for cooking remains limited in São Paulo, its adoption is steadily increasing, driven by the expansion of pipeline infrastructure in urban areas. This trend positions NG as an emerging component of Brazil's energy matrix, though the country still lags behind other Latin American nations in NG penetration. LPG, however, continues to dominate as the primary cooking fuel, reflecting its widespread availability and affordability across urban and rural regions.

Transitioning to cleaner cooking technologies, like electric stoves, offers opportunities and challenges. The IPCC highlights that these transitions could significantly reduce methane emissions, a major natural gas (NG) component, and a potent greenhouse gas (GHG). However, adopting electric stoves in Brazil may unintentionally lead to higher residential emissions because of the country's electricity generation mix. Additionally, the financial feasibility of making this transition is uncertain for low-income households due to the high upfront costs and ongoing expenses associated with electric stoves.

The findings also highlight the scarcity of robust statistical data on residential emissions in Brazil, as noted by SEEG (Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa). This lack of data presents a significant barrier to fully understanding and addressing the impact of residential energy use on GHG emissions. Addressing this gap through targeted research and data collection is essential for developing effective policies and strategies to mitigate residential emissions, particularly as the use of NG continues to expand.

Brazil's greenhouse gas inventory uses methane emission factors (LPG = 1.1 kgCH4/TJ, NG = 1 kgCH4/TJ) lower than IPCC values (5 kgCH4/TJ for both). Measurements showed NG emissions of 14.58 kg/TJ (excluding outliers) and 48.92 kg/TJ (with all data), far exceeding national (49x) and IPCC (9.8x) factors. LPG emissions averaged 1.6 kg/TJ, 1.45x higher than national values and 0.32x higher than IPCC estimates.

The emission factor for $CO_2$ obtained was around 20,000 kg/TJ for NG and 14,000 kg/TJ for LPG. For $NO_2$ the emission was 0.29 kg/TJ for NG, and 0.46 kg/TJ without outliers and 1.3 kg/TJ with all data for LPG.

## c. Implications in the Health Air Quality

### Health Air Quality

From a health perspective, the findings indicate that pollutant concentrations generally remain within safety thresholds under standard operational conditions:

- **$CO_2$**: Typically, below the National Institute for Occupational Safety and Health (NIOSH) limit of 2,000 ppm, with some exceptions during Cycle 2.
- **NO**: Concentrations stay within the NIOSH recommended exposure limits (RELs), as time-weighted average ( TWA) of 25 ppm during normal operations.
- **$NO_2$**: Despite exceeding WHO's recommended values, $NO_2$ concentrations remain under the NIOSH REL, as a short-term ( ST) limit of 1 ppm for occupational exposure.

However, the lack of legislation setting standards for indoor air quality prevents an objective analysis of the potential impact of the concentrations found on the health of people living in homes. In addition, São Paulo's urban air quality is heavily influenced by traffic-related $NO_x$ emissions, exacerbating the baseline exposure to these pollutants.

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# 6. APPENDIX

## a. Volunteer registration form

EBP Stanford University USP Universidad Mayor Universidad de los Andes 30 futuro

**FORMULÁRIO DE INSCRIÇÃO**

O projeto "Transformação energética a nível residencial: eletrificação de fogões e fornos na América Latina" procura compreender como os dispositivos domésticos de cozinha e aquecimento afetam a qualidade do ar interior, bem como potenciais repercussões na saúde e, com base nestes dados, propor regulamentos e programas públicos que favoreçam as condições de habitabilidade a nível residencial.

Importantes instituições juntaram-se a esta causa: Stanford University, Universidad Mayor de Chile, Universidad de los Andes de Colombia, EBP Chile, EBP Brasil, Universidade de São Paulo, Fundación Futuro Latinoamericano e o Global Methane Hub e, entre as primeiras ações a desenvolver, serão realizadas medições em casas no Brasil.

Com esse histórico, escrevemos para convidá-lo a participar da convocatória, por meio da qual serão selecionadas 30 residências em São Paulo nas quais serão monitorados os gases emitidos pelo uso de aparelhos a gás, como fogões e fornos. Os escolhidos receberão os resultados da pesquisa em sua casa e o reconhecimento pela sua contribuição.

Nome e sobrenome *

Sua resposta

Correio eletrônico (email) *

Sua resposta

Telefone de contato *

Sua resposta

Região *

- São Paulo
- Região Metropolitana

Próxima    Limpar formulário

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## b. informed consent forms

Global Methane Hub

USP

TERMO DE CONSENTIMENTO

**Obrigado por participar desta Pesquisa sobre qualidade do ar.**

**Preencha este termo depois de ler a Folha de Informações e/ou ouvir uma explicação sobre a pesquisa.**

**Título do estudo:** "Transformação energética a nível residencial: eletrificação de fogões e fornos na América Latina"

**EBP Brasil e Universidade de São Paulo:** Ofício No.202406241025EVF

Antes de você concordar em participar deste projeto, o pesquisador que está pedindo seu consentimento deve explicá-lo. Se você tiver alguma dúvida sobre a Folha de Informações ou a explicação, pergunte ao pesquisador antes de tomar sua decisão. Você receberá uma cópia deste Termo de Consentimento e da Folha de Informações para guardar e consultar a qualquer momento.

Ao **rubricar** cada caixa, você concorda com esta parte do estudo. Quaisquer caixas não rubricadas significarão que você NÃO concorda com essa parte do estudo e isso pode significar que você não é elegível para o estudo.

| Participando do estudo | | |
|---|---|---|
| | Afirmação | Por favor, rubrique cada caixa |
| 1 | Confirmo que li e compreendi a Ofício No.202406241025EVF para o estudo acima. Tive a oportunidade de considerar as informações e fazer perguntas que foram respondidas de forma satisfatória. | |
| 2 | Eu entendo que minha participação é voluntária. Além disso, entendo que uma vez iniciado o monitoramento em minha casa, os dados já coletados não poderão ser retirados do estudo. | |
| 3 | Eu entendo que as informações que eu forneci podem estar sujeitas a revisão por indivíduos responsáveis da Universidade de São Paulo para fins de monitoramento e auditoria. | |
| 4 | Eu concordo em participar deste estudo. | |
| 5 | Eu entendo que as informações que eu forneci serão usadas de forma anônima, incluindo relatórios, publicações, apresentações, sítios eletrônicos, etc. | |
| 6 | Eu entendo que meus dados pessoais (estilo de vida diário), incluindo este termo de consentimento, vinculando-me aos dados da pesquisa, serão mantidos em segurança de acordo com as diretrizes de proteção de dados e só estarão acessíveis para a equipe de pesquisa imediata ou pessoas responsáveis na Universidade de São Paulo. | |

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| | | |
|---|---|---|
| 7 | Autorizo o processamento dos dados da localização da minha casa e estilo de vida diário durante a amostragem (pratos feitos, tempo de preparo, etc.) para os fins indicados na Folha de Informações. | |
| 8 | Eu concordo em compartilhar uma foto da minha cozinha com os instrumentos instalados para os fins indicados na Folha de Informações. | |
| 9 | Autorizo a instalação de dois monitores de poluição do ar na minha cozinha. | |
| 10 | Eu concordo com a realização do estudo em nome de todos os ocupantes da minha casa. | |

| Uso futuro das informações no estudo | | |
|---|---|---|
| | Afirmação | Por favor, rubrique cada caixa |
| 1x | Permito que meus dados não identificados sejam arquivados [em um arquivo de dados externo (por exemplo, UK Data Archive)] e compartilhados anonimamente com outros pesquisadores, a fim de realizar pesquisas futuras [especificar quaisquer restrições de uso, por exemplo, não para uso comercial ou apenas acesso protegido]. | |

| Assinaturas | | |
|---|---|---|
| Nome do participante | Assinatura | Data ___/___/___ |
| Nome do pesquisador | Assinatura | Data ___/___/___ |

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