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Measurement Report: Methane and NOx emissions from natural gas cooking stoves, the case of Chile and Colombia

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1. Abstract.

Natural gas is widely used for household cooking, with methane (CH_4), its main component, being a potent short-lived greenhouse gas (GHG). While often seen as a cleaner alternative, natural gas combustion and leaks contribute to GHG emissions and indoor air pollution. Yet, fugitive methane emissions from residential appliances, especially cookstoves, are poorly quantified in low- and middle-income countries. In this study, we measured CH_4, carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxides (NOx) emissions from cookstoves in 35 homes in Santiago, Chile, and 23 in Bogotá, Colombia, two countries experiencing rapid growth in natural gas use. We assessed continuous methane leaks, ignition-related emissions, and combustion emissions, using a mass balance approach that accounts for air exchange rates and gas concentrations. Our real-world measurements provide rare data on household cookstove emissions and inform emission factors used in GHG inventories. We found that methane emissions from residential stoves in Bogotá and Santiago are over six times higher than the Tier 1 IPCC emission factors currently used in national inventories. Notably, continuous leaks and ignition-related emissions, which are excluded from official estimates, contribute significantly to total methane emissions. These

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findings suggest that national inventories in Chile and Colombia underestimate methane emissions from household gas use, highlighting the need for more real-world measurements and research across Latin America. Our results have important implications for improving the accuracy of GHG inventories, understanding the role of household energy use in climate change, and guiding effective mitigation strategies.

1 Introduction

Natural gas is widely used for household cooking, with millions of homes globally relying on it for daily meal preparation in developing countries today (Quinn et al., 2018, WHO 2014) and with future use projected to increase further (Stoner et al., 2021). Unlike other gas appliances that vent emissions outdoors, stoves release combustion byproducts directly indoors, which can impact air quality (Barros and Fontes, 2024, Balmes et al., 2023). In recent years, the use of natural gas in residential applications—including cooking, heating, and water heating—has expanded substantially not only in developed countries but also in developing and low-income countries (IEA, 2024), often replacing much dirtier fuels, such as biomass or other solid fuels. This increasing reliance on natural gas raises concerns about both indoor air quality and its contribution to greenhouse gas (GHG) emissions (IPCC, 2021). The GHG emission trajectories that are compatible with decreasing the likelihood of extreme climate change require both, substantial near-term reductions in global GHG emissions and to sustain those emissions at near net-zero. Mitigating methane is one of the fastest ways to reduce warming in the short term (UNEP, 2021). However, atmospheric CO_2 and methane concentrations are still rising rapidly (Nisbet et al., 2019). In addition to mitigating climate change, methane emissions can play a significant role controlling global ozone background concentrations. Some studies estimate that reducing global anthropogenic methane emissions by 20% could prevent >370,000 premature deaths in a 20 year span (West et al., 2006), with other studies suggesting that a hypothetical reduction of anthropogenic methane to zero could lead to significant reductions in ozone exposure globally (Staniaszek et al. 2022). In addition, natural gas combustion generates carbon monoxide (CO), an air toxic, and like any other high-temperature process in the presence of air, it is a source of nitrogen oxides ($NOx = NO + NO_2$). Both, long-term (e.g., Huangfu and Atkinson, 2020), and short- term exposure to NO_2 (Oreallano et al., 2020; Zeng et al., 2021) have been associated with deleterious health effects. NOx is also a key ozone precursor. Therefore, reducing emissions associated with residential natural gas use would reduce emissions of key GHGs and air pollutants, and is likely to lead to improved indoor air quality.

Natural gas is primarily composed of methane (CH_4), with small amounts of other short-chain hydrocarbons such as butane, propane, and benzene (Chang et al., 2000, Rowland et al., 2024). Methane is a significant driver of anthropogenic GHG emissions and plays a crucial role in global warming (e.g., Saunois et al., 2024). Although methane has an atmospheric lifetime of around 11 years, much shorter than that of carbon dioxide (CO_2), its 100-year global warming potential is 28, making it a potent short-lived greenhouse gas whose emissions must be mitigated to avoid overshooting current climate goals (e.g., Schindel et al., 2012). Most studies on methane emissions from the energy sector have focused on fugitive emissions from oil and gas exploitation, as well as leaks from natural gas distribution networks (Staniaszek et al., 2022). However, far less research has been conducted on methane emissions occurring inside buildings, particularly from residential appliances like gas stoves (Lebel et al. 2022). This oversight is important because methane has a significantly higher greenhouse gas potential compared to CO_2, meaning even small leaks can contribute disproportionately to the methane emissions from buildings.

Natural gas appliances emit methane through incomplete combustion as well as through small but continuous methane leaks, even when the appliance is off (Lebel et al., 2022). Household cookstoves, although small in the quantity of gas burned when compared to gas furnaces, play a crucial role in domestic energy use and contribute to GHG emissions. In developing countries, household fuel consumption represents a significant share of total energy use, yet the emission factors associated with small-scale fuel combustion are often poorly quantified compared to larger-scale sources (Levine, 1996). While some studies have reported emission factors for specific countries and fuel sources (Smith et al., 1993. Lebel et al. 2022), these datasets remain limited, creating uncertainties in global emission inventories. These uncertainties hinder the accuracy of climate models and the development of effective mitigation and adaptation strategies. As research has shown in other natural gas applications,

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underestimating leakage of methane emissions can lead to significant misrepresentations of its full contribution to warming (e.g., Alvarez et al., 2012; Comer et al., 2024)

Furthermore, existing emission inventories primarily account for leaks at gas meters and emissions from incomplete combustion, but they lack detailed data on emissions from stove operation, including continuous leaks and instantaneous releases that occur during ignition and use. Studies suggest that residential gas appliances contribute small but significant amounts of methane to overall household emissions. However, fugitive emissions from residential appliances are often overlooked in the development of national emission inventories. The reliance on generalized or non-local emission factors can lead to inaccurate estimation of emissions, affecting inventory accuracy and leading to misleading projections of future emissions scenarios. It also limits assimilation of research outcomes on the topic, as it is not an imported research initiative, but one that reflects local realities.

As evidence of emissions from natural gas stoves in the global south are scant, building on previous research, this study aims to quantify both GHG emissions as well as other air pollutant emissions, from natural gas cookstoves in Chile and Colombia. The two countries have experienced a rapid expansion in the use of natural gas as household fuel. In Colombia, natural gas currently supplies 17% of residential energy demand, reaching 56.4 PJ per year in 2021, and emissions from its residential use account for 2.44 $MtCO_{2eq}$. Most of it is used in direct-heat applications. Similarly, in Chile, adoption of natural gas has increased in recent years, and currently supplies some 13% of the residential energy demand, and accounts for 1.08 $MtCO_{2eq}$ (MMA, 2018). Both countries, however, have strikingly different residential energy profiles due to climatic differences. In Chile, with a stronger seasonal cycle, residential heating is a significant component of residential energy demand which is supplied mainly by natural gas and wood. In Colombia, for contrast, most of the residential natural gas demand is destined for cooking. Despite its reputation as a cleaner alternative to biomass and other fossil fuels, there is limited data on methane and NOx emissions from gas stoves in these regions. By measuring emissions during different operational phases -including while the stove is off, during ignition, and during combustion- this research seeks to refine household emission estimates, providing evidence to improve GHG inventories, indoor air quality, and inform policy on residential energy use and climate mitigation strategies. These findings will be valuable for national regulators and policymakers, helping to bridge knowledge gaps and enhance the accuracy of emission estimates critical for climate action planning.

2. Methods Subsection

2.1 Data Collection

We measured CH_4, CO_2, CO and NOx (NO and NO_2) emissions from cookstoves in 35 houses in Santiago de Chile and in 23 houses in Bogotá (Colombia). Sampling was carried out in private residences that used natural gas as fuel for cooking, with measurements taking place during June to August of 2024 in Chile, and during September and October of the same year in Colombia. Each sampling unit consisted simply of a kitchen unit equipped with a natural gas stove, and measurements were conducted on one to three burners of each stove. These burners were tested at different heat outputs (high, medium and low flames) to assess emissions and leaks under different operational conditions, following previously established methodologies (Lebel et al., 2022; Kashtan et al., 2023). The sampled residences were selected to represent a variety of socio-economic status and locations within the city. The selected participants were asked to report information on stove characteristics through a short questionnaire. The gas stoves sampled averaged 7-years old in Santiago and 10-years in Bogotá as registered in the self-reporting questionnaire. In some cases, the owner reported not knowing the age of the stove. Ovens were not sampled during this campaign. Users were asked to report the number of times they used the stove on a typical day.

Burner emissions were measured using a static flux chamber method as applied in recent studies (Lebel et al., 2022). In each sampled household, a chamber was created by enclosing the kitchen space using plastic sheets, making a best effort to minimize the air exchange between the enclosed kitchen space (containing the stove) and the surroundings. This approach was used to construct a chamber of known volume and with minimal air exchange with the surroundings. Seals were reinforced with foam

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bars, painter's tape, and sandbags. Fans were deployed to ensure a short mixing timescale inside the chamber, so the conditions of a well-mixed system were fulfilled (see Supplementary Material).

Continuous gas monitors with sensitivity in the ppb range were used in both cities. For Methane (CH_4), concentrations were recorded at 1Hz with a Li1780 Traces Gas Analyzer (LI-COR) and Aeris Mira ULTRA CH_4/C_2H_6 analyzer in Santiago and Picarro G-4301 non-dispersive infrared (NDIR) spectrometer for Bogotá sampling campaign. NO and NO_2 were measured with a Teledyne 200A and Thermo-Fischer 42iQ chemiluminescence analyzers. Carbon monoxide (CO) was measured with an APMA-370 NDIR spectrometer (Horiba Inc.) and Thermo 48i CO analyzer (Thermo Scientific). The temperature in the enclosed kitchen space was monitored with an Onset HOBO Logger (UX100-23A) and HT SensorPush data logger (HT.w Sensor).

2.2 Measurement of Emission Factors (EF)

We determined the emission rates for NOx (=NO+NO_2), CO_2, and CH_4 in (mg/min) for each sampled stove during three different operating settings. These operating settings were designed to determine (1) CH_4 emissions resulting from continuous leaks, (2) instantaneous CH_4 releases from turning on or off each burner, and (3) emissions of NOx, CO, CO_2 and CH_4 during combustion. Continuous leaks were measured during the "Steady-State Off" stage, which consists of measuring gas concentration within the enclosed space and the burners turned off, under constant air circulation. This process lasts approximately 10 minutes. Instantaneous releases of CH_4 were quantified by analyzing the observed *pulse* of CH_4 concentration, i.e., an immediate increase in concentration, after turning on or off a given burner.

After the "Steady-State Off" stage was completed, researchers then accessed the kitchen and proceeded to ignite one of the gas stove burners. To ensure the measurements were representative of everyday cooking conditions, a water-filled cooking pot was placed on the ignited burner during this phase. Immediately after igniting the burner, the kitchen was vacated and sealed to begin the timed measurement phase, termed "Steady-State On" which lasted typically 6 to 10 minutes. During this phase, the concentration of combustion generated species CO_2, CO, and NO_x, quickly increased. At the end of the stage, the burner was turned off, waiting about ten seconds before exiting the kitchen again. Figure 1 shows the evolution of different gas species during these sampling stages.

The determination of the emission rate of a gas "i" was carried out through a mass balance of the species within the kitchen chamber. Provided the gases do not undergo significant chemical reaction during the observation period and that the chamber is well-mixed, the evolution of the concentration $\boldsymbol{C_i}$ (mol/m³) of the gas within the chamber can be expressed as (Cooper & Alley; 2010):

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

where $\frac{\boldsymbol{dC_i}}{\boldsymbol{dt}}$ is the rate of accumulation of gas "i" (mol/m³·min) in the chamber, $\boldsymbol{C_{i,b}}$ (mol/m³) is the background or ambient concentration of gas "i", $\boldsymbol{V_0}$ is the volume of the enclosed space in the kitchen (m³), and $\boldsymbol{\lambda}$ (min⁻¹) is the air exchange rate between the confined kitchen space and the surroundings. By accurately measuring the concentration $\boldsymbol{C_i}$ over time, and by determining $\boldsymbol{\lambda}$ and $\boldsymbol{V_0}$ is possible to estimate the emission rate of gas $\boldsymbol{E_i}$ (mol/min). The room temperature (T) and pressure (p) of the chamber must be known, as the monitoring devices determine mol fractions, $\boldsymbol{\chi_i}$, (mol/mol), and they must be converted to molar concentrations by $\boldsymbol{C_i = \chi_i\, p/RT}$. In this work, we follow closely the methodology of (Kashtan et al. 2023). Details can be found in Supplementary Material. The methodology can be applied for any period in which the stove is operating in

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steady state, and therefore, the emission rate is approximately constant over that period. We aim to determine the average emission rate for a given operation setting, $\overline{E_i}$ (mol/min). The methodology can then be applied over multiple intervals within the same kitchen, modifying the stove's operating mode each time. For example, if a single burner is turned on and the methodology is applied, the emission rate for that burner can be determined. If the process is repeated with other burners, the emission rates of additional burners can also be measured.

The absolute emission rates, either in a molar (mol/min) or mass basis (mg/min), can be used to estimate total emissions if typical operating times and intensities are known. For some applications, however, it is useful to express these emission rates as an emission factor, i.e., normalized by the amount of natural gas burned during the operation. Since most of the carbon emitted during combustion is likely contained in the species that were measured, namely CO_2, CO, and CH_4, it is possible to precisely determine the amount of natural gas used during operation, provided its composition (C_xH_y) is known. In this way, the combined molar flows of these major carbonaceous species are a good estimate of the molar flow of natural gas $\overline{q}_{GN}$ (mol/min). The latter can be computed as $\overline{q}_{GN} = \overline{E}_{CO_2}(1 + \overline{y}_{CO} + \overline{y}_{CH_4})/x$, where $\overline{y}_{CO}$ and $\overline{y}_{CH_4}$ are the molar flow ratios of CO to CO_2 and CH_4 to CO_2 respectively. In normal operation conditions, both $\overline{y}_{CO} \ll 1$ and $\overline{y}_{CH_4} \ll 1$. Furthermore, using the lower heating value (LHV) of natural gas (MJ/mol) and the molar weight of species Mi (kg/mol), an energy-based emission factor, EF_i (kg/TJ), for each species can be estimated as $EF_i = M_i\overline{E}_i/(\overline{q}_{GN}\,LHV)$. Expressing emissions in terms of the emission factor facilitates the comparison of the observed values to those used in local air quality inventories or those for GHG emission inventories. The city of Bogotá is supplied with a natural gas mixture with 82.2% CH_4, 10.2% ethane, with the remaining being propane, butane, pentane, hexane and CO_2 (UPME, 2016). The mean number of carbon atoms in the Natural Gas supplied to Bogotá is $x = 1.14$, and the LHV is 45.05 MJ/kg. For the case of Santiago, natural gas is richer in methane, with 90.0% CH_4, 6.38% ethane, 0.22% propane, with the remaining fraction corresponding to higher-carbon content gases and CO_2. For Santiago, we used $x = 1.05$ and LHV of 43.7 MJ/kg (CNE, 2009).

The volume V_0 of the confined space was determined geometrically by carefully measuring all the relevant dimensions of the confined space, and subtracting the volume occupied by other kitchen appliances and shelves. This method has been shown to differ by only 3% from volume determinations using trace gas measurement methods (Lebel et al., 2022). The air exchange rate λ (min^{-1}), a key parameter to be determined in this methodology, was measured using the concentration decay method. This is, by measuring CO_2 concentration as it decreases in the enclosed space in the absence of sources and determining the logarithmic slope of the time series, i.e., applying Equation 1 for CO_2 when $E_i = 0$. In our study, a specific period was devoted for this analysis in each kitchen, typically immediately after the "steady state on" stage. At that moment, CO_2 concentration inside the chamber was significantly higher than background levels. After turning the burners off, the kitchen was sealed again, and the decay constant of CO_2 concentration was determined with a least-squares method.

3 Results

Figure 1 shows the typical evolution of CH_4, CO_2 and NOx concentration during a combination of "pulse-on", which corresponds to the initial pulse of gas emitted when the burner is ignited, and "steady state on" stages, which reflects steady-state emissions while the burner remains on. The variations in the concentration of each species reflects the process by which it is released to the atmosphere. The pulse of methane released immediately before ignition is visible, while the combustion generated species (CO_2 and NOx) accumulate in the chamber while the stove is on.

The methane emission rates found for each house and each burner sampled during the campaign are shown in Figure 2. As it is often the case, the distribution of emissions is highly skewed, approaching a lognormal distribution, with a small subset of the sample (the highest emitters) accounting for a significant fraction of the sample's total emissions. The datasets in Bogotá

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and Santiago share similar characteristics and are comparable to what has been reported in previous studies elsewhere (Lebel et al., 2022, Merrin & Francisco, 2019). The mean (median and C.I. for the median) "steady-state on" CH_4 emissions, which are those that occur during the combustion process, were 445.2 (79.4 C.I. 41.1 – 110.8) mg/h in Bogotá (n=51 burners), and 422.1 (43.1 C.I. 26.5 – 100.5) mg/h in Santiago (n=65 burners). However, because of the highly skewed distribution, the mean in both cases was sensitive to the outliers visible in Figure 2. When the two extreme outliers observed in each city are removed, the mean methane emission rate decreases to 108 mg/h and 184 mg/h for Bogotá and Santiago, respectively. Expressed as energy-based emission factors, these emissions rate are remarkably similar, equivalent to 31.75 kg CH_4/TJ for Bogotá and 31.91 kgCH_4/TJ for Santiago, and are likely a lower bound estimate of the true value Our results show that the true variability in emission rates, which spans several orders of magnitude, is much larger than the method accuracy (see Supplementary Material).

The "steady-state off" emission rates, which quantify continuous methane releases from imperfect seals in the ductwork and/or in the stove itself, are several times lower than those measured during combustion (i.e., the "steady-state on" stage). Over half the stoves in Bogota leaked methane at a rate higher than 10 mg/h. The mean (median) steady-state leak emission rate was 32.5 (12.4 C.I. 8.8 – 20.0) mg/h in Bogotá, and 13.3 (3.8 C.I. 2.3 – 5.0) mg/h in Chile. Because these emissions are generated from the fittings and ductwork, they do not belong to a specific burner but to a stove and kitchen installation. The difference in leaks observed between the two cities might be partially explained by the higher mean age of stoves sampled in Bogotá compared to Santiago. Despite the emission rate from leaks being lower than those during combustion, the former occurs continuously, while the latter occur only during cooking. Although detailed stove use data is missing in both countries, stoves are likely idle many times longer than it is in operation. Therefore, our measurements suggest that for Bogotá, emissions from continuous leaks are likely on par with total combustion emissions, while they account for a smaller fraction of total emissions in Chile.

Instantaneous releases of CH_4 during the operation of turning on and off the burners were in average 25.5 mg per event for Bogota, and 48.8 mg per event for Santiago. These instantaneous releases, which are expected to occur, on average, twice during each use of a given burner, are equivalent to between 1 to 4 hours of continuous leaks. This suggests that these episodic methane releases contribute a non-negligible amount to total emissions.

Emission from NOx, which is formed during high-temperature processes in the presence of air, were measured during the "steady-state on" stage, because it is not expected to be generated in any other stove operation setting. Figure 3 displays the measured emission rates from each individual burner sampled in both cities, as a function of the measured flow of CO_2 and CH_4, a quantity proportional to the molar flow of natural gas. The mean emission rates found in both cities were similar, with 91.4 mg/h for Bogota and 94.4 mg/h for Santiago. The NO_X emission rate (NO_2+NO) was found to increase linearly with the amount of gas burned, with a slope of 0.36 mmol/mol (C.I., 0.32-0.40) and R^2=0.87 for Bogota, and 0.24 mmol/mol (C.I., 0.18-0.31) with R^2=0.64 in the Santiago samples. This proportionality is consistent with the expected dependance of NOx generation on flame intensity and combustion temperature. When expressed as energy-based emission factors, these results imply 21.4 gNOx/GJ gas burned (C.I., 19.1 – 23.8) and 15.1 gNOx/GJ (C.I., 11.4 – 19.6) for Bogota and Santiago, respectively. In Bogota, where a log was kept regarding the intensity the sampled burners were operating at, revealed mean emission rates of 30.7 mg/h, 74.1 mg/h and 139.0 mg/h for those burners labeled as operating in low, medium and high flame intensities respectively. In Santiago all burners were operated in a high flame intensity setting.

4. Discussion

The emission rates measured in this work imply emissions several times higher than those resulting from using the Tier 1 emission factors suggested by the IPPC guidelines for countries with no available local data (IPCC, 2006). For methane, the

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emission factor during combustion of natural gas for residential cooking were very similar between both locations examined, and on average equal to 31.75 kg CH_4/TJ for Bogotá and 31.91 kgCH_4/TJ and Santiago. These values are over 6 times higher than those used in the construction of national inventories (i.e., the IPCC Tier 1 emission factor for natural gas combustion is 5.0 kg CH_4/TJ) for Colombia and Chile respectively. Over 42% of the samples in Santiago were above this Tier 1 emission factor, with a similar percentage observed in Colombia. We consider these estimates as conservative, as we decided to leave out two extreme out layers from the reported estimate of mean emissions. Furthermore, this first-of-its-kind study in Latin America, supports the idea that continuous methane leaks might be larger and more commonplace than previously thought, and are likely to emit significant amounts of methane. These types of continuous releases were only recently incorporated into IPPC GHG emission guidelines, but further evidence to constrain its true value is still needed. Despite the potential limitation from the sample size, the findings of this work suggest that the contribution to national methane emissions from residential use of natural gas are significantly underestimated in both countries. The findings for both cities are consistent with recent methane and NOx emission estimates carried out in the U.S. (Lebel et al., 2022).

The findings of this work reveal the relevance of conducting real-world emission measurements, as these can provide a more realistic picture of the actual emissions from any given sector. The specific potential for GHG emission reductions attainable by switching to other energy sources for residential cooking are highly dependent on the local conditions, i.e., the carbon intensity of the power generation in each country, together with the efficiencies of the available electric cooking technologies.

4. Conclusions

This study constitutes the first direct measurement of the emission rates of NOx, CO, and CH_4 from the use of natural gas in residential kitchens in Latin America. The findings of this effort to determine real-world emission rates reveal that methane releases, both episodic during the action of turning on/off the burners, as well as continues leaks into the kitchen space, constitute most of the total methane emissions from natural gas stoves, both in Chile and in Colombia. Those type of fugitive emissions, are not accounted for in the emission estimates reported by countries to the UNFCCC. Furthermore, in our sample we found that CH_4 emissions during combustion, expressed as energy-based emission factors, were between 6 to 19 times higher than those typically assumed in absence of local emission datasets.

In addition, we quantified the emissions of air pollutants NOx and CO, finding values consistent with other studies. In the case of Bogotá, a city located at 2600 m above sea level, the results indicate higher CO emissions, likely from less efficient or oxygen deficient combustion, which in turn could lead to lower flame temperatures, and lower NOx emissions. Further research could increase sample sizes (involving other cities in the region) and include the measurement of hazardous species released by combustion of natural gas stoves.

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Figures

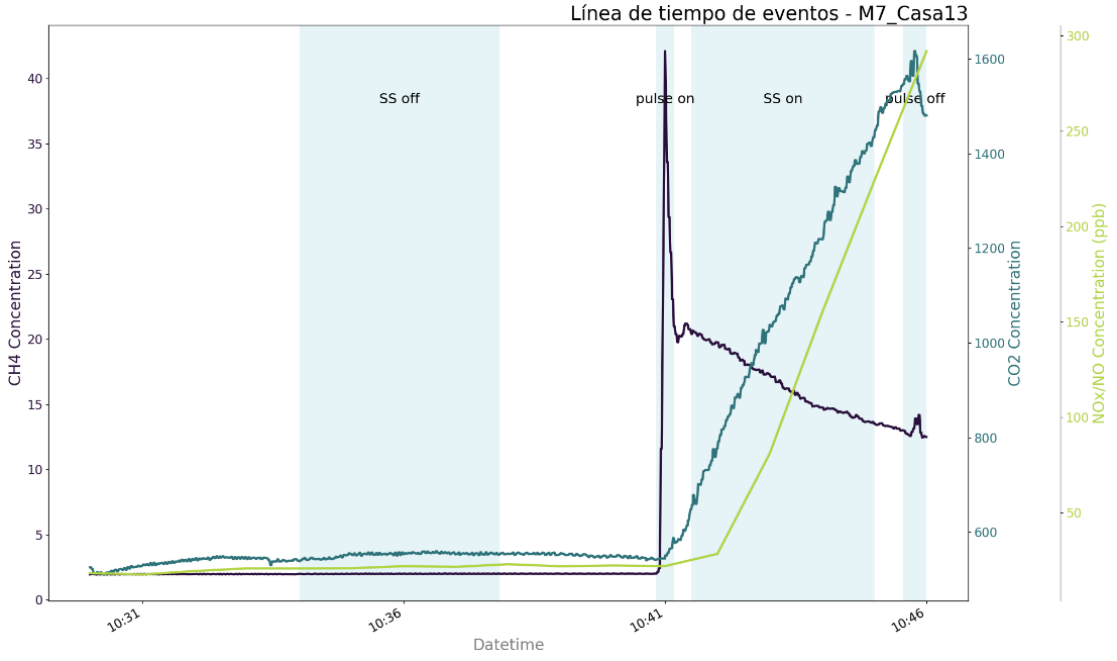

Figure 1 Variation in the concentrations of the gases analyzed during the sampling campaign. The sharp increase in CH4 associated with burner ignition (pulse-On) is clearly visible. Also, the linear increase in combustion generated gases (NOx, and CO2) can be observed.

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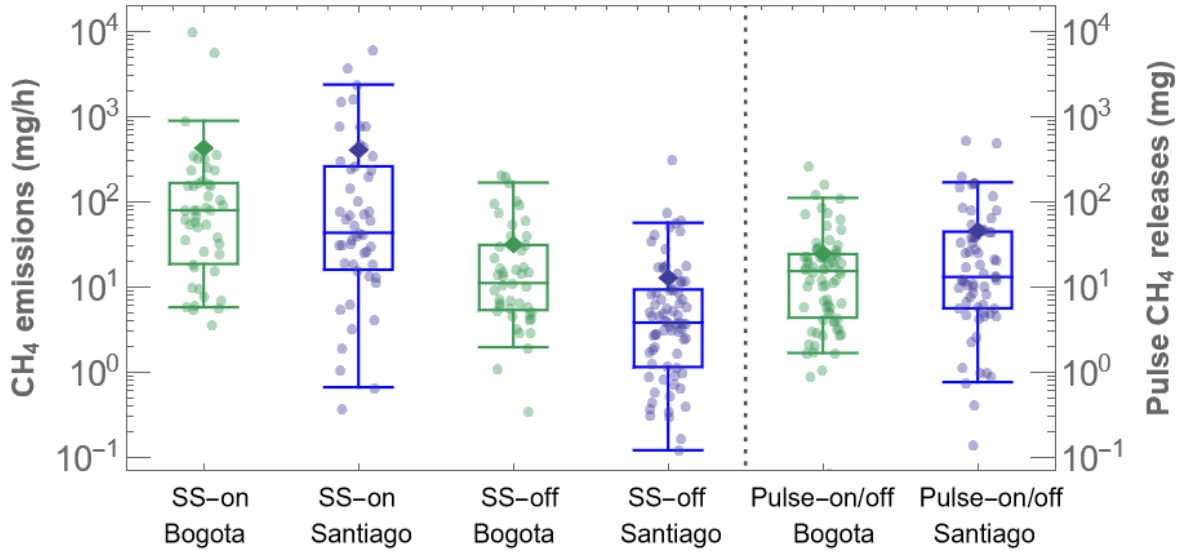

Figure 2: Methane emission rates for "steady-state on" (SS-On) and "steady-state off" (SS-Off) measured during the sampling campaign in Bogota (Colombia) and Santiago (Chile). Filled circles represent emission rates for individual burners (for SS-On). For SS-Off, the circles are repetitions of continuous methane release rates in each kitchen (i.e., are not associated with a specific burner).

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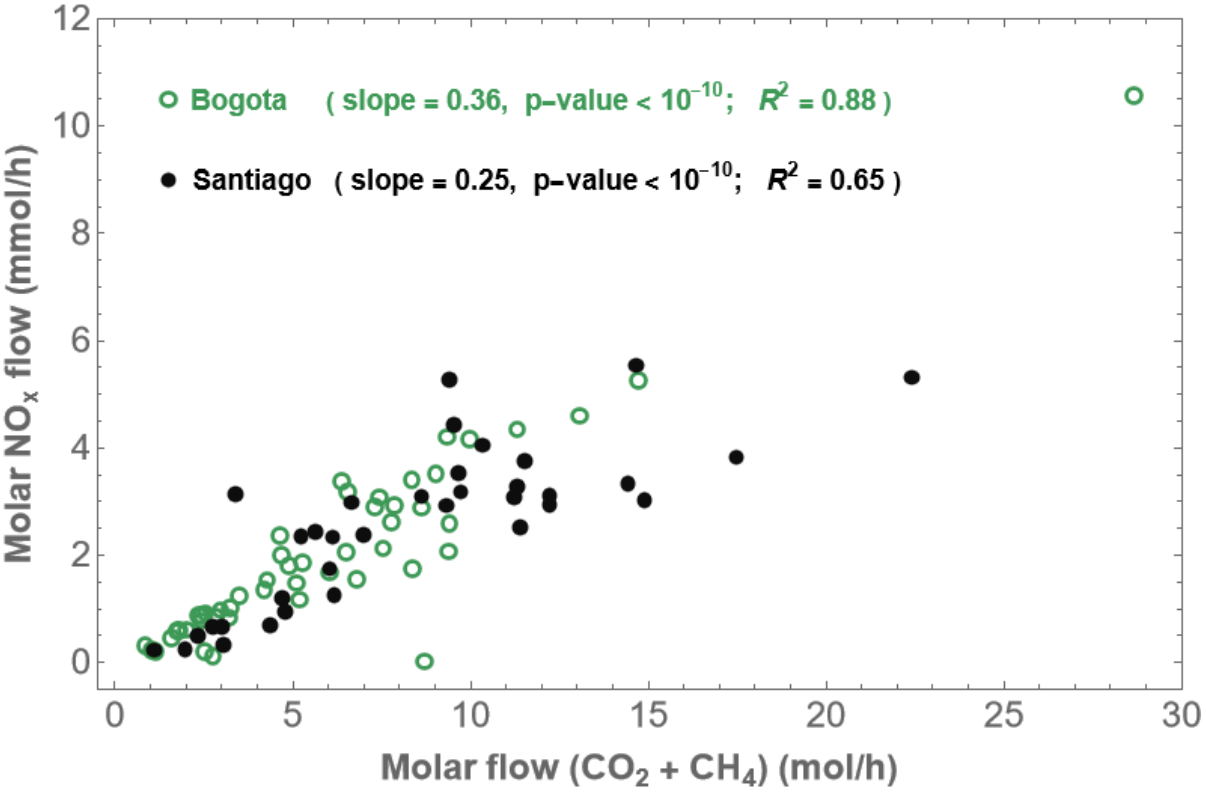

300 **Figure 3: NO_X (NO_2 + NO) molar flow (mmol/h) as function of the molar flow of CO_2 + CH_4 (mol/h), the latter of which is proportional to the molar flow of natural gas used in the combustion process. A linear relationship between both variables is observed in the measurements carried out in both cities. The slope of this linear relationship is proportional to the NOx emission factor.**

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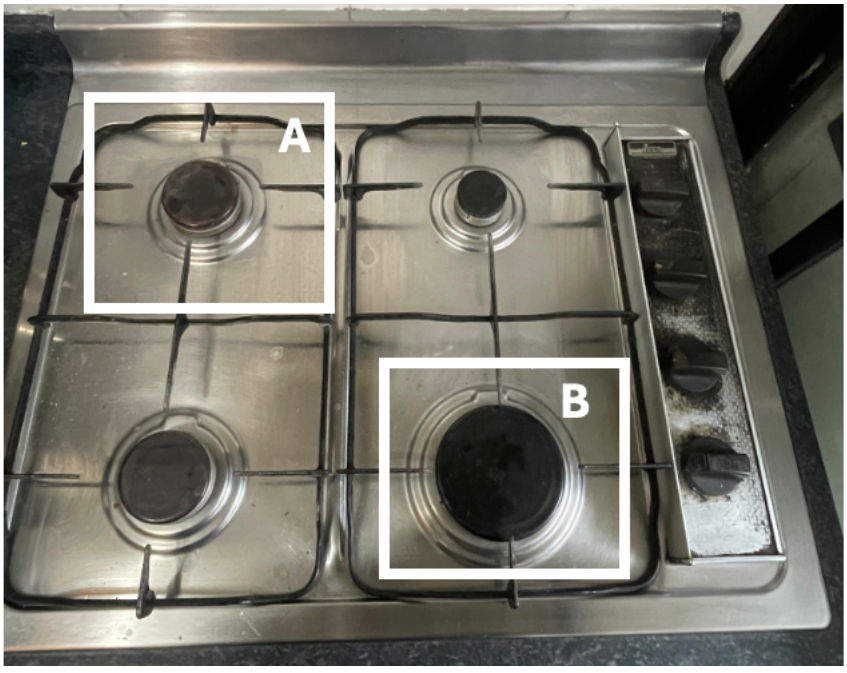

Figure 4: A smaller burner (A) and a large burner (B) from one of the stoves used for sample collection in Santiago, Chile. (Photo taken by Abenezer Shankute)

Data availability

Processed steady-state data used in this study are openly available in the Zenodo repository under the DOI **0.5281/zenodo.17641450 ,** and are distributed under a Creative Commons Attribution 4.0 International (CC BY 4.0) license.Conflict of Interest.

The authors declare no conflict of interest.

Author contributions

RM-B and CG-M conceived the study, acquired funding, conducted data curation, formal analysis, investigation, methodology, project administration, resources, supervision, validation, visualization, and wrote the original draft. TM-B, EB, PT-P, RV, CC, CF, AS, NH, SH-S, and PV contributed to data curation and investigation. CF and AS provided software, supervision, validation, visualization, and methodology. NH and PV contributed resources. SH-S contributed formal analysis. MM-C and

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