HOUSEHOLD AIR POLLUTION FROM BIOMASS BURNING IN URBAN AND RURAL PARAGUAY

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Table of Contents

List of Tables

List of Figures

Executive Summary

Background

At the national level, about 40% of the energy consumed in Paraguay is obtained from the burning of solid biomass, mainly wood and charcoal[1]. These fuels are fundamental to the country's industries[2], as well as for many low-income families who have difficulty accessing other fuels for cooking. It is estimated that approximately 49% of the Paraguayan population burn biomass for cooking[3]. Although no measurements have yet been made in Paraguay itself, inside households, residents are likely exposed to significant amounts of health-damaging contaminants such as carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$). Exposure to $PM_{2.5}$ has been found in other settings to be responsible for high morbidity and mortality.

Purpose

Household air pollution (HAP) associated with cooking fuels has been well described in various countries, but not in Paraguay. The study presents a description of the current levels of air pollution inside and outside households of two representative populations in the country. Information may be used for designing future clean cooking intervention projects as well for creating national development programs aimed to reduce health-damaging exposure to HAP.

Objective

The main objective was to determine CO and $PM_{2.5}$ concentrations, as measured in the kitchen, and evaluated at personal and community levels. Secondary objectives were to estimate the prevalence of biomass consumption in a rural and sub-urban community; to quantify the $PM_{2.5}$ carbonaceous fraction; as well to determine potential predictors that contribute to $PM_{2.5}$ and CO concentrations observed at kitchen level.

Experimental Design

Air quality was monitored for 24 hours, with measurements of two specific pollutants: CO and $PM_{2.5}$. A cross-sectional measurement campaign was conducted in 113 households. Six households were simultaneously sampled for 24 h, every weekday from July 4th to August 4th, 2016. Samples were obtained in kitchens that used solid biomass, such as firewood and charcoal, and in kitchens using low-emission fuels, such as liquefied petroleum gas (LPG) and electricity.

The study was carried out in two districts of the Central Department: Julián Augusto Saldívar (JAS) and Limpio (LIM). The JAS neighborhood was characterized as a sub-urban community, whereas LIM was identified as a rural village. Both populations were chosen by a team of interviewers from the Pan-American Health Organization (PAHO) and Dirección General de Salud Ambiental (DIGESA).

We monitored $PM_{2.5}$ and CO concentrations in a continuous (1-minute intervals) and integrated manner (one sample every 24 hours). Measurements were made in the kitchen area (n = 113), at personal level (n = 8) and in the outdoor environment (n = 25). Samples of $PM_{2.5}$ were assessed gravimetrically and with FT-IR analysis (Fourier transform infrared spectrometry), the latter for quantification of elemental carbon (EC) and organic carbon (OC). Questionnaires were used to record information on household variables, i.e. construction materials, type of kitchen room (enclosed, semi-enclosed or outdoors), and occurrence of other sources of smoke. Additionally, some quantitative parameters were measured, such as cooking duration, room volume, distance from the household to the external monitoring station, and others. The data obtained were analyzed using multivariate statistical methods in order to determine the degree of association between the different variables and exposure to CO and $PM_{2.5}$. The objective was to develop predictive models of $PM_{2.5}$ and CO that may be useful for future kitchen intervention analyzes.

In parallel, at both communities a campaign was carried out to collect samples of $PM_{2.5}$ in outdoor environment. This with the purpose of being analyzed by gravimetry, FT-IR and X-ray spectroscopy (XRF) for quantification of chemical elements.

Results

The survey conducted by PAHO and DIGESA revealed that in both communities 54% of the population used biomass for as the main fuel for cooking (33% charcoal and 20% firewood). The remaining population uses mostly LPG (40%). Electricity was scarcely used (7%) for cooking, despite finding that 100% of the households were connected to the electrical grid.

In the communities studied, two types of cooking areas were observed: indoors and outdoors. The highest 24-h average $PM_{2.5}$ concentrations (95% confidence intervals) were found in the indoor kitchens as follows: enclosed firewood-burning indoor kitchens; 850 (381 – 1319) $\mu g/m^3$, semi-enclosed firewood kitchen; 681 (440 – 922) $\mu g/m^3$, enclosed charcoal kitchens; 109 (74 – 144) $\mu g/m^3$ and semi-enclosed charcoal kitchens; 104 (65 – 191) $\mu g/m^3$. Lower averages were measured at firewood and charcoal outdoor cooking areas; 112 (71 – 155) and 44 (22 – 66) $\mu g/m^3$, respectively. The lowest levels were observed in kitchens that used LPG and electricity; 52 (44 – 60) and 52 (42 – 62) $\mu g/m^3$, respectively.

The 24-h CO concentration was higher in enclosed kitchens burning firewood; 19 (13 – 25) ppm and charcoal; 9 (5 – 13 ppm), in contrast to that observed in kitchens based on LPG; 0.57 (0.22 – 0.92) ppm and electricity; 0.49 (0.17 – 1.15) ppm.

Personal exposure assessment results indicated that women cooking with firewood in enclosed spaces were exposed to a 233 (92 – 374) μg/m^3 of $PM_{2.5}$ on average. In households where firewood was burned, the bedroom closest to the kitchen recorded an average of 162 (117 – 442) μg/m^3 of $PM_{2.5}$.

24-h average outdoor $PM_{2.5}$ concentration varied from 27 (26 – 28) μg/m^3 in the suburban community to 41 (40 – 42) μg/m^3 in the rural community. About 50% of the outdoor $PM_{2.5}$ mass was contributed by total organic material (EC + OC). Potassium (K), a tracer of biomass burning, was the predominant trace element in the outdoor $PM_{2.5}$ samples.

A multivariate statistical analysis provided two regression models, useful for estimating CO and $PM_{2.5}$ in other Paraguayan kitchens. The models have a predicted R^2 of 0.82 to 0.84, respectively. Statistical analysis revealed that using biomass for cooking, as well as the time spent on cooking, were variables significantly associated with higher concentrations of $PM_{2.5}$ and CO in the kitchen area (p-value < 0.001). Garbage burning was also associated with increased indoor $PM_{2.5}$ levels (p-value = 0.03) and may be one of the most important pollution sources of outdoor pollution in both communities.

Conclusions

The study contributed to present for the first time, the indoor air quality data necessary to establish a baseline in household environments. The $PM_{2.5}$ and CO levels observed in kitchens that consumed firewood and charcoal were well above the WHO IT-1 standards (35 μg/m^3 of $PM_{2.5}$ and 5.7 ppm of CO). High prevalence of biomass consumption was found in both the suburban and rural communities. Although not evaluated in this project, we suggest that one way to reduce dependence on biomass for cooking, as well as exposure to HAP, could explore the introduction of electric cookstoves, preferably the induction type, or alternatively, the "hot plate" type, since they were the most established design among the communities visited. In the long term, we recommend an action plan that considers the identification of new communities with high biomass demand. These would be potential candidates to receive new cookstoves in future programs. We also suggest training in rural communities which do not have a garbage collection service to reduce the practice of burning garbage. It is suggested to hold discussion tables with the Ministry of the Environment, since outdoor $PM_{2.5}$ levels in rural communities are exceeding the national air quality standard, which establishes 30 μg/m^3 as the maximum permissible $PM_{2.5}$ 24-h average concentration.

Introduction

1.1 Atmospheric pollution

The World Health Organization (WHO) estimates that at least 100 million people in Latin America and the Caribbean are breathing polluted household air, in conditions that far exceed the acceptable limits for health[4]. At present, air pollution is classified as the largest environmental cause of premature death worldwide[5].

Among air pollutants, the most relevant to public health are both CO and $PM_{2.5}$. The first, is a colorless and odorless gas that is released during the incomplete combustion of firewood and charcoal. It has been shown that acute exposure to high concentrations of CO can cause death within minutes, while chronic low-level exposure can lead to detrimental neurological effects[27]. The second, particulate matter (PM), conceptually refers to particles dispersed in air. The most important particles for health are less than 10 microns in size, which are easily inhaled into deep areas of the respiratory system, where they can penetrate the bloodstream and be deposited in different organs of the human body[6]. Depending on their diameter, the particles are categorized into PM_{10} (less than 10 μm), $PM_{2.5}$ (smaller than 2.5 μm), and ultra-fine PM, which corresponds to particles whose size is less than 0.1 μm.

The composition of the PM is relative to the sources that give rise to it. For example, dust from the earth's crust contributes particles rich in elements such as aluminum, iron, and calcium, among others. On the other hand, the combustion of organic matter, such as petroleum or solid biomass, contributes particles formed mainly by carbon (Figure 1). The latter are true agglomerations of carbonaceous nanospheres which are commonly called soot or black carbon. The carbonaceous particles can be decomposed into a fraction of elemental carbon (EC), which corresponds to the spherical aggregate, in addition to a variety of organic compounds with higher molecular weight, called the organic carbon fraction (OC).

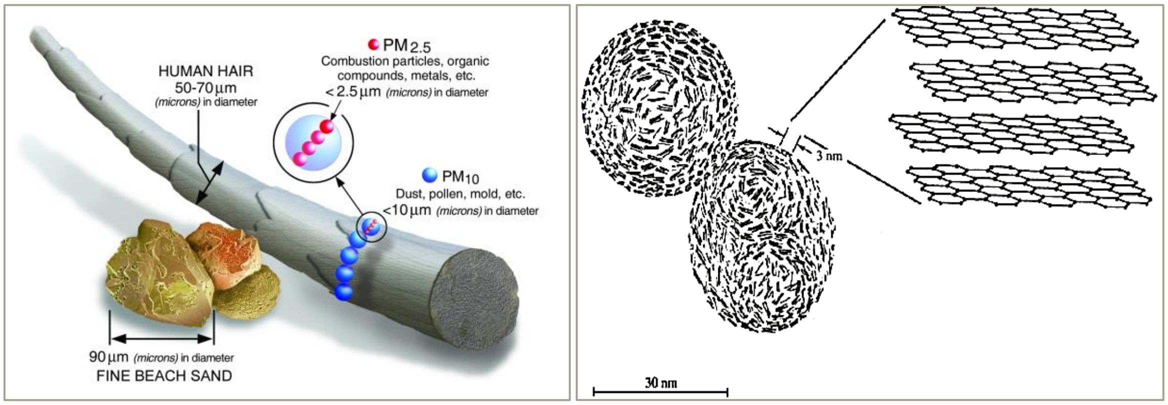

Figure 1. Left: Representation of relative size of PM_{10} and $PM_{2.5}$ (Source: U.S EPA). Right: Representation of particles from the combustion of organic matter (Source: Atmospheric Chemistry and Physics. 2° Edition. Seinfield, Pandis. p: 629)

1.2 Combustion of biomass: impact on health and climate

Black carbon particles are effective in absorbing solar energy, which contributes to increasing global warming and its effects.[7].

Smoke generated by the combustion of plant material, such as fuelwood or charcoal, not only has negative effects on the climate, but also poses a risk to public health[8]. Traditional appliances, such as open fires and braziers, are usually inefficient and do not provide the necessary conditions for complete combustion. As a consequence, high concentrations of harmful byproducts are released. The most relevant for health are particles, especially fine particles ($PM_{2.5}$), and carbon monoxide (CO).

At present, about 40% of the global population depends on solid fuels, including biomass, to perform household functions such as cooking[3]. In poorly ventilated spaces, this activity worsens indoor air quality, producing what is termed "household air pollution". The latest estimates are that this type of pollution causes between 2.8 and 4.3 million deaths annually[9-12].

Women and children in low-income families are the ones who are paying the price of living in contaminated households. This is because they spend most of their time inhabiting spaces where smoke from cookstoves and braziers can easily result in 100 times higher mass concentration of particles than the levels considered acceptable by WHO. Some of the impairment caused by this type of pollution are listed below. These have been described under the most recent evidence compiled the WHO and the literature.

- Women exposed to air pollution derived from firewood combustion inside households, are twice as likely to suffer from chronic obstructive pulmonary disease (COPD) as women who live in clean-air homes[13].

· Smoke from biomass fuels is a risk factor for pneumonia, the leading cause of child death worldwide[14].

· For lung cancer, about 17% of premature deaths in adults are attributable to the exposure of carcinogenic compounds, such as polycyclic aromatic hydrocarbons (PAHs) generated by burning biomass, especially in the kitchen[15].

· A growing number of studies have shown a significant association between household air pollution with birth defects, low birth weight, tuberculosis, cataracts, and nasopharyngeal cancers, among others[16].

To protect health, WHO suggests the permissible levels of air contaminants within environments in which people spend significant time, including indoors[17]. These guidelines suggest that $PM_{2.5}$ levels should be 10 µg/m^3 (final target) but never exceed 35 µg/m^3 (Interim-Target 1) as an annual average. On the other hand, the guidelines recommend that the daily average of indoor CO should be below the threshold of 7 mg/m^3, approximately 5.7 parts per million (ppm).

1.3 Scenario in Paraguay

Air pollution has been an issue that has gained prominence in Paraguay in recent years. The Clean Air Act enacted in 2014, required the Secretariat of the Environment (SEAM) to determine the air quality maximum concentrations for several pollutants considered harmful to public health. In 2015, SEAM presented their first national air quality standards (Res. N°259/15), which established the limit values for $PM_{2.5}$ and CO in the outdoor environment. The maximum daily concentration of $PM_{2.5}$ allowed in the country is equal to 30 µg/m^3, close to that suggested by WHO and the U.S EPA (Table 1). At present, the country does not yet have measuring equipment or monitoring stations, which makes it difficult to determine the degree of compliance with these standards.

Table 1. Standards (concentration limits) of $PM_{2.5}$.

	$PM_{2.5}$ (µg/m^3)	
	1 year	*24 h*
WHO*	10	25
United States**	12	35
Paraguay***	15	30

* WHO, Air quality guidelines - global update 2005
** EPA, National Ambient Air Quality Standards
***SEAM, Res. N°259/15

Paraguay is characterized by the powerful hydroelectrical resource generated by the Parana river. In 2016, the bi-national *Itaipú* hydroelectric plant, operated jointly with Brazil, generated more than 103 GW/h (gigawatts per hour), making it the largest renewable energy source on the planet. Despite the abundance of electricity, biomass and petroleum byproducts are still the most used fuels in the country. According to the latest National Energy Balance report (NEB)[i], the annual energy consumption in 2016 was dominated by diesel products (41.2%) and biomass (40.6%).

The statistics of the last NEB and the Permanent Survey of Households[ii], show that:

- Approximately 99.1% of households in the country have electricity. In 2016, the percentage of households that used electricity for cooking reached 11.9% nationwide, 2.1 points more than in 2015.

- In 2016, the average annual price of LPG was $1.12 USD/L. Compared to the previous year, the LPG consumption at a national level decreased 2.2%. The percentage of households that use LPG as main fuel for cooking decreased to 54.0% in 2016, which means 3.5% less than in 2015. According to this estimation, 23 thousand new houses opted for another type of cooking fuel.

- The number of households using charcoal in kitchen decreased from 7.9% in 2014 to 7.0% in 2015. The decrease was observed in both the rural and urban populations.

- The firewood consumption increased by 1.5% nationally. Its use at the residential level for cooking increased from 23% in 2015 to 25.4% in 2016.

Regarding the percentage of the population that practices biomass combustion to cook, information varies by data source. For instance, in the last Statistical Yearbook (2014)[iii] it is mentioned that 33% of the total households surveyed declared using biomass for cooking. Of this, 13% belonged to urban populations and 62% to rural populations. These estimation is below the percentage showed by international studies, which establish the percentage between 46% (*Global Alliance for Clean Cookstoves*)[iv] and 49% (Bonjour et al., 2013)[3]. Taking into consideration the latter, Paraguay would rank first in South America, among the countries with the highest percentage of the national population dependent on biomass. At the Latin American level, it would occupy the fifth place, after Haiti (91%), Guatemala (57%), Nicaragua (54%) and Honduras (51%), as estimated by Bonjour et al., (2013)[3]

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[i] http://www.ssme.gov.py/vmme/pdf/balance2016/BEN%202016.pdf
[ii] http://www.stp.gov.py/v1/wp-content/uploads/2016/08/0.Triptico-EPH-2015-total-pais1.pdf
[iii] http://www.dgeec.gov.py/Publicaciones/Biblioteca/anuario2014/Anuario%20Estadistico%202014.pdf
[iv] http://cleancookstoves.org/country-profiles/108-paraguay.html

The problems associated with the residential use of biomass have been recognized in the public agenda thanks to two institutions, the General Directorate of Environmental Health (DIGESA, Dirección General de Salud Ambiental) and the Pan American Health Organization (PAHO). Both agencies jointly organized the international seminar "WHO-2014 Guidelines on indoor air quality and its impact on health", which was held in Asunción in August, 2015. The study presented below is the result of these efforts, as well as the growing need to have a baseline on air quality at household level, especially in rural areas where firewood and charcoal are used by the majority of households.

Methodology

2.1 Study Sites

The research was conducted during the month of July of 2016, in two districts of the Central Department, Republic of Paraguay. A suburban community was visited in the district of Julián Augusto Saldívar (JAS), while in the district of Limpio (LIM) a rural village was visited. Figure 2 illustrates the location of both communities, which are approximately 20 km from Asuncion, the capital district. The specific location of the monitored households is available in Annex 1 of this document.

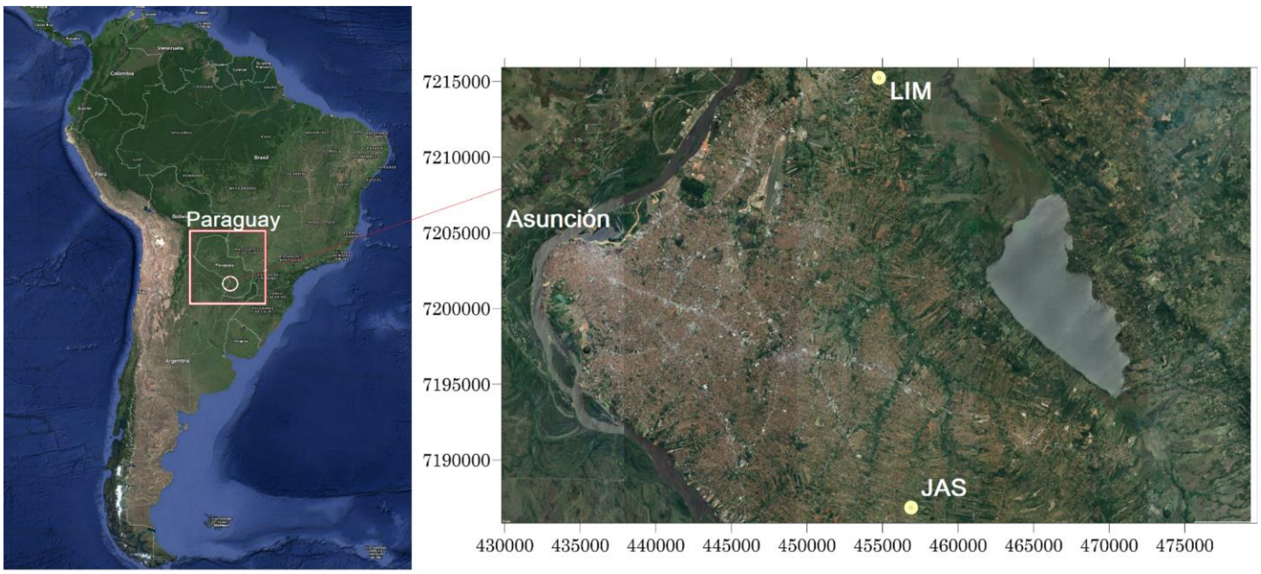

Figure 2. Study sites: *JAS (456884, 7186852), LIM (454773, 7215205). WGS 84 (UTM zone 21S)*

2.2 Energy survey and household selection

These districts were chosen by PAHO for the purposes of this research. In June 2016, survey data was collected in JAS and LIM, on the type of energy used in residences. The Energy survey, designed by PAHO, was administered in 238 households by interviewers (DIGESA employees), who were previously trained by PAHO. The questionnaire used was modeled on WHO's World Health Survey.

Once the survey process was completed, a database was created without personal identifiers. This database excluded names or personal data but contained household information, such as location and the type of fuel used for cooking. As exclusion criteria were considered the presence of pregnant women or smokers in the household, as was asked during the survey application.

The final database was disaggregated according to the type of fuel used for cooking; LPG, electricity, firewood and charcoal. In each subset, a random number of households was selected to be visited and invited to participate in the monitoring campaign. Subsequently, in July 2016, the field team[v] visited the house, introduced the subject of the study and its measurements to the head of family and invited him or her to participate at the end of the recruitment script. Following the recruitment process, a total of 113 households agreed to participate in the study.

2.3 Study population

Table 2 shows the fuel use in universe of participating households during the sampling. Of the total, 35% cooked with emissions-free fuels (LPG or electricity), 34% made it with firewood and 31% with charcoal. Occasionally, about two-thirds of households used a secondary fuel, most of this being charcoal (See Table 6). During the monitoring period, those responsible for cooking were asked not to use any secondary fuel.

Table 2. Size and proportion of participating households.

Fuel used for cooking	N (%)
LPG	27 (24%)
Electricity	12 (11%)
Firewood	38 (34%)
Charcoal	36 (31%)

2.4 Air quality monitoring in the kitchen area

The air quality in the kitchen area was monitored for 24 hours through the equipment described in Table 3. The equipment was located approximately 1.5 meters from the appliance used for cooking, at an approximate height of 1.6 meters above the ground, which corresponds to the approximate adult breathing zone closest to the combustion source (Figure 3). Monitoring was done during working days and started between 8-10 am. During this event only one type of fuel was used for cooking.

The equipment was composed of a CO monitor (EL-USB-CO, Lascar Electronics), a $PM_{2.5}$ monitor (UCB-PATS, Berkeley Air Monitoring Group)[18], a $PM_{2.5}$ sampler (BGI Triplex cyclone, Pall Teflon filter), and an air temperature monitor (HOBO, Onset).

[v] Composed of Matias Tagle, Alice Bergottini and Claudia Acosta.

Table 3. Instrumentation used for the monitoring of the cooking area environment.

Parameter	Principle	Interval	Instrument
$PM_{2.5}$	Gravimetric	24 hours	Teflon filter, Triplex cyclone, SKC air pump XR-5000
	Photoelectric	1 minute	UCB-PATS
CO	Electrochemical	1 minute	EL-USB-CO
T_{air}	Temperature sensor	1 minute	HOBO

Figure 3. Monitoring equipment co-located in the kitchen area.
(1): EL-USB-CO for CO monitoring. (2): System for $PM_{2.5}$ collection composed of the Teflon filter, triplex cyclone and the air pump (inside the bag). (3): HOBO used to monitor indoor air temperature.

$PM_{2.5}$ was collected on a Teflon filter (37 mm, 2.0 µm pore) with the purpose of being chemically analyzed. For this, the filter was weighed using an analytical micro-balance (Mettler Toledo XP2U, SN B251650436[vi]), inserted into a 3-piece cassette (23370-U, Sigma-Aldrich) together with a Whatman paper disc (36 mm, Sigma-Aldrich). The cassette, in turn, was connected to a cyclone (Triplex SCC1.062, Mesa Labs) and to an air pump (AirChek XR5000, SKC Inc.) using a Tygon® hose and Luer connectors (Sigma-Aldrich).

[vi] Located at the Kirk R Smith Laboratory, UC Berkeley, in Richmond, California.

Using a digital flowmeter (The Challenger CH100, Mesa Labs), the airflow was initially set at 1.5 l/min, a value specified as the cyclone cutoff point for particles smaller than 2.5 μm. Once the monitoring was completed, a second measurement of flow was performed. The average between the two airflow rates was multiplied by the total minutes of pump operation in order to estimate the volume of air sampled (m^3).

As quality assurance and quality control measures, the following procedures were performed: Triplex cyclones were cleaned with an ethanol solution (70%) before each sampling, the cassettes were kept sealed before and after sampling, and samples were transported in hermetic bags (Ziploc®) until the final storage (-20 ° C). Some households were randomly selected (n = 3) to locate blank filters, in addition to the effectively collected $PM_{2.5}$ filter. Blank filters were deployed in cassettes that were not connected to an air flow, but were subjected to the same protocol as the sample filters.

Once the monitoring campaign was finished, a gravimetric analysis was carried out on $PM_{2.5}$ samples. For this, the filters were weighed again on the same micro-balance. Both for pre-weights and post-weights, filters were conditioned prior to both weighing for 24 hours in temperature- and humidity-controlled room (23 ° C, 40% RH) and were passed between polonium-210 metal strips with anti-static function, and weighted a minimum of 3 times, or until a stable value was reached, i.e. the last two masses differed by 5 μg or less.

The mass concentration of $PM_{2.5}$ (μg/m^3) was estimated by dividing the difference between the weight of the filter before and after the monitoring by the corresponding volume of air sampled. An average increase in weight of 8.3 μg was obtained for the field blank filters after the sampling period; this value was subtracted from the mass of the actual samples.

Variables remained close to the target value. The mean monitoring time was 22.9 hours (± 0.6), the distance between the monitors to the cookstove was 1.54 meters (± 0.37) and the airflow at the end of sampling was 1.49 L / min (± 0.05).

For subsequent statistical analyses, 7 $PM_{2.5}$ samples were discarded, 3 of them due to premature air pump stop, and 4 due to inconsistencies between the values obtained by the FT-IR and the gravimetric analysis (the mass determined by FT-IR was higher than the gravimetric value).

2.5 Monitoring of personal exposure to $PM_{2.5}$

A smaller subset of households that cooked with firewood (n = 4) and charcoal (n = 4) were randomly selected for personal exposure assessment. This measurement was carried out in parallel to the monitoring in the kitchen area. For this, the person in charge of preparing the food was asked to wear a bag containing the gravimetric monitoring system for 24 hours (Figure 4).

Figure 4. Monitoring of personal exposure to $PM_{2.5}$

2.6 Air quality monitoring in bedrooms

A group of households that cooked with biomass (n = 14) was randomly selected to perform air monitoring in a room other than the kitchen (24-h). For this, the bedroom closest to the kitchen was chosen. The instrument used was the UCB-PATS, whose measurements were calibrated against gravimetric results.

All the procedures involved were approved by the Ethics Committee of Research in Paraguay (CEI-LCSP No. 42); UC Berkeley (No. 2016-02-8451) and the Ministry of Public Health and Social Welfare (No.73/310516).

2.7 Monitoring of air quality in the community environment

In order to determine the $PM_{2.5}$ concentration outdoors, a central location in each village was selected for installing a fixed monitoring station. The equipment was placed on the roof of households that used electricity for cooking (Figure 5), away from direct emissions of smoke or sources of combustion. Time-integrated (24 h) $PM_{2.5}$ samples were collected approximately 2.5 m above the ground, on Pall Teflon filters (37 mm), using a two-stage impactor[19]. This system operated at 4 l/min specified as the cut-off point for $PM_{2.5}$.

Figure 5. Outdoor air monitoring station.

Filters were subjected to gravimetric analysis using the same protocol described in section 2.4. In addition, 1-minute average $PM_{2.5}$ concentrations were recorded using a light-scattering laser photometer (DustTrak II Aerosol Monitor 8530, TSI). The average 24-h concentrations obtained by laser photometry were calibrated against the concentrations estimated by reference instrument (Annex 2).

Meteorological parameters, such as wind speed and wind direction, rainfall, temperature and relative air humidity, were obtained from the Faculty of Agrarian Sciences of the National University of Asunción. The faculty operates a weather station on the campus of San Lorenzo (448000 E, 7190060 S, 21 J), distant 13 km from JAS and 18 km from LIM.

2.8 Chemical analysis of PM2.5: Fourier Transform Infrared Spectrometry and X-Ray Fluorescence Spectroscopy.

The carbonaceous fraction of $PM_{2.5}$ (EC and OC) was quantified through a Fourier Transform Infrared Spectrometry (FT-IR). The analysis was conducted at the Air Quality Research Center (AQRC), University of California at Davis[vii].

[vii] Analysis performed by Andrew T. Weakley, Benjamin Croze, and Ann Dillner

The analysis was carried out on the Teflon filters after the gravimetric procedure. The research team at the AQRC determined the mass of EC and OC present in the $PM_{2.5}$ samples through the spectrometer Bruker Tensor 27 FT-IR (Bruker Optics Inc). Technical description of this methodology has been documented elsewhere[19-22].

An X-ray fluorescence spectroscopy (XRF) was performed on the outdoor $PM_{2.5}$ samples. The analysis was carried out to determine the concentration of 68 chemical elements. The analysis was conducted at the Department of Environmental Health, Harvard School of Public Health using the Epsilon 5 XRF spectrometer[viii] (PANalytical, The Netherlands). The elements measured were those ranging in atomic number from 11 (Na) to 82 (Pb). Further description of this technique, as well as the quality control and quality assurance of the XRF analyzes are presented elsewhere[23].

2.9 Predictor variables at household level

During the monitoring campaign, potential predictors of CO and $PM_{2.5}$ indoor concentrations were recorded. A questionnaire applied by the field team, which is shown in Annex 3, captured information concerning categorical variables, such as the construction materials of floor, walls and roof, kitchen structure, the occurrence of sweeping, heating, cigarette smoking, incense, mosquito repellent and outdoor garbage burning (Table 4).

Table 5 shows the parameters recorded as continuous variables. These included the time that the cookstove usage, room volume, total monitoring time, distance between the sampling instruments and the cooking appliance, as well as the distance between the household and the outdoor station.

[viii] Analysis performed by Choong-Min Kang.

Table 4. Categorical variables recorded through questionnaires.

Variable	N	Categories
Community	2	JAS LIM
Fuel	4	LPG Electricity Firewood Charcoal
Kitchen structure	3	Open (outdoors) Enclosed (4 walls and roof) Semi-enclosed (3 walls and roof)
Roof material	4	Ceramic (tiles) Fibrocement Metal/Zinc Thatch
Wall material	4	Concrete/bricks Metal Nylon Wood
Floor material	4	Ceramic Concrete Soil Wood
Sweeping	2	Yes/No
Heating	2	Yes/No
Smoking	2	Yes/No
Mosquito coil burning	2	Yes/No
Garbage burning (outside)	2	Yes/No

Table 5. Continuous variables recorded through measurements.

Variable	Unit
Cookstove usage	minutes
Sampler-to-cookstove distance	m
Kitchen room volume	m^3
Monitoring duration	minutes
Household-station distance	m

Cookstove usage was recorded for 24 hours using small temperature sensors (iButton DS-1922T, Maxim Integrated), also known as SUMs (Stove Use Monitors)[24-26]. These sensors were adhered to the base of cooking appliances, i.e. fireplaces, braziers, or LPG / electric cookstoves. The SUMs recorded the appliance's temperature ($T_{cookstove}$) every 1 minute, while at the same time the air temperature in the kitchen area (T_{air}) was recorded by HOBO sensors (Onset Inc, CA, USA), co-located with the air monitors (Fig. 3). The total time of cookstove usage was quantified by the sum of minutes in which the $T_{cookstove}$ was at least 10 ° C above the T_{air}.

A laser length meter (GLM 40, Bosch) was used to measure the volume of the kitchen, as well as the distance between the monitors and the appliance used for cooking. The distance between each home and the fixed monitoring station was calculated through the GPS coordinates of households (Oregon 700, Garmin) using QGIS 2.12 Lyon software.

2.10 Statistical analysis

As descriptive statistics, arithmetic mean, standard deviation and 95% confidence intervals in the mean (95% CI) were used. For inferential statistics, Multiple Linear Regressions (MLR) were performed.

The normal distribution of the continuous variables was examined through the Shapiro-Wilks test and the visual inspection of the distribution of the data. In case of deviation from the normal distribution, the measurements were transformed into their logarithmic value.

A statistical approach was performed to create predictive models from the observed indoor concentrations and potential explanatory variables shown in Table 4 and Table 5. The method was developed for the set of observations obtained in households with enclosed and semi-enclosed kitchens (n = 81), as well as for the set of observations obtained in households that used LPG or electricity for cooking (n = 35). In the latter, the concentration of outdoor $PM_{2.5}$ and the distance between the household and the monitoring station were additionally included as potential predictors variables.

To determine the best sub-set of predictor variables, a combined multiple regression method was developed. For this, all variables shown in Table 4 and Table 5 were incorporated at the same time into a MLR which was subjected to eliminations and progressive introductions (stepwise regressions). The MLR that provided the lowest Akaike information criterion (AIC) value was selected as the regression model containing the most appropriate subset of predictor variables. Once the best subset of variables was selected, the final models were examined for multicollinearity (variance inflation factor), atypical data-points (Bonferroni-adjusted *p*-values) and influential observations (Cook's distance).

After excluding outliers, the final MLR model was constructed on the basis of the previously identified best subset of predictor variables. The general assumptions of linear regression analysis (normality, linearity and homogeneity of variance) were evaluated by visual inspection of residuals on the appropriate diagnostic plots. The architecture of the analysis performed is illustrated in Figure 6.

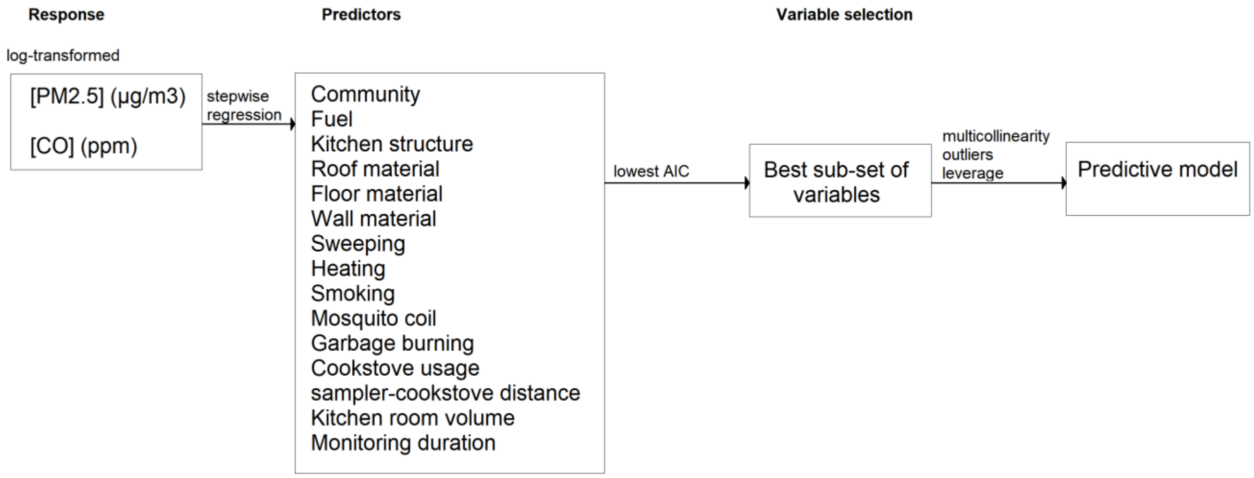

Figure 6. Plan of data analysis used to generate the predictive models for indoor $PM_{2.5}$ and CO concentrations.

RStudio software (R Foundation for Statistical Computing, Vienna, Austria, R version 3.3.1) was used for all statistical computing. The 'olsrr' package was used to estimate the predicted R^2 in the final model. Variables related to building materials were subjected to a multiple correspondence analysis (MCA), performed through the 'FactoMineR' package. A principal component analysis (PCA) was performed on the chemical elements detected in outdoor $PM_{2.5}$ samples ('factoextra' package), in order to determine the relative contribution of likely sources.

Results

3.1 Analysis of the energy survey in suburban and rural communities

Table 6 summarizes the results of the survey conducted by PAHO and DIGESA on the type of fuel used for different household needs (cooking, heating and lighting). The survey found that about 54% of the households in both villages used firewood and charcoal as the main fuel for cooking. At the community level, the rural community (LIM) showed a higher prevalence of firewood consumption as the main fuel used for cooking (30%) compared to the JAS suburban community (6%). In the latter, LPG was the most demanded fuel, reaching a 46% share in the universe of households surveyed.

In both JAS and LIM, electricity was used least for cooking (7%). However, 100% of the houses interviewed had connection to the electrical system and used electricity as the main energy for lighting.

In terms of the secondary fuel used for cooking, charcoal was the predominant in both villages (more than 40%) and around 30% of households in each community declared not using another type of fuel.

Table 6. Main results of the PAHO-DIGESA survey.
Fuel used for different household needs.
(%: proportion of the total number of households surveyed)

	JAS	LIM
N	127	111
Kitchen (primary fuel)		
LPG	48%	32%
Electricity	8%	9%
Firewood	6%	30%
Charcoal	38%	29%
Kitchen (secondary fuel)		
LPG	9%	7%
Electricity	9%	9%
Firewood	9%	11%
Charcoal	41%	45%
None	32%	28%
Heating		
Electricity/LPG/other	7%	6%
Firewood	1%	4%
Charcoal	12%	10%
None	73%	79%
No answer	7%	1%
Lighting		
Electricity	100%	100%

About one-third of the population claimed to use charcoal as the main fuel for cooking. As shown in Table 7, the survey revealed that most of firewood and charcoal consumers make combustion in open spaces. Nevertheless, between 20 and 30% said they use to burn biomass in enclosed environment (indoors). The preference of burning biomass fuels outdoor, especially charcoal, may be conditioned to days without precipitation. The burning of charcoal is commonly done in metal braziers, which are small in size, facilitating their portability (Fig. 9B).

Table 7. Place where combustion is carried out for cooking.
(%: Proportion relative to each fuel group).

	Enclosed (indoor)		**Semi-enclosed (outdoor)**		**Open space (outdoor)**	
	JAS	LIM	JAS	LIM	JAS	LIM
LPG	100%	100%	0%	0%	0%	0%
Electricity	99%	94%	0%	0%	1%	6%
Firewood	8%	16%	15%	10%	77%	74%
Charcoal	23%	10%	14%	11%	63%	79%

Concerning the practice of heating, 76% of the respondents indicated that they did not heat their home, while a smaller percentage indicated doing so by burning charcoal (11%), firewood (2.5%) or by electrical/LPG appliances (6.5%). From the observational data regarding the structure of the kitchen, none of the surveyed households which used biomass as the main cooking fuel had ventilation systems, such as a chimney or ducts for releasing smoke outdoors

The survey also inquired about the role of gender in labor related to cooking. It was pointed out that the women in the communities were primarily responsible for the purchase of fuel and the preparation of food.

3.2 Characteristics of the studied households

In households monitored for $PM_{2.5}$ and CO, three types of kitchen structures were observed: an enclosed room, semi-enclosed room and outdoor cooking area (Figure 7). These last two structures were observed exclusively in homes that cooked with firewood or charcoal. The enclosed kitchen structure was represented as a room inside or outside the household, with four walls and a roof. The semi-enclosed structure was defined as a room located at the side of the home, with a roof, but only three walls. As was observed in the preliminary survey, none of these structures had chimneys to move emissions out of the room.

Figure 7. Examples of structures in the cooking area.
A: Enclosed. B: Semi-enclosed. C: Outdoor.

Table 8 shows the universe of monitored kitchens, grouped by the fuel and the place where the combustion was carried out. Of the monitored kitchens that used firewood, 28% did it in enclosed spaces, 49% in semi-enclosed spaces and 23% in open spaces. In the case of those who used charcoal, most of them did so outdoors (49%).

Table 8. Universe of cooking areas monitored in JAS and LIM, by type of structure

	LPG	Electricity	Firewood	Charcoal
N	27	12	39	35
Structure				
Enclosed	27 (100%)	12 (100%)	11 (28%)	12 (34%)
Semi-enclosed			19 (49%)	6 (17%)
Outdoor			9 (23%)	17 (49%)

The volume of the cooking room was higher, on average, in households that used LPG (40.1 m^3). Table 9 shows the average volume (in m^3) of the enclosed and semi-enclosed kitchens that used electricity (28.0), firewood (20.9) and charcoal (26.5).

Additionally, Table 9 shows the average hours per day (h/d) which the cookstove was on, as reported by SUMs (cookstove usage). The shortest time belonged to kitchens that used clean fuels, namely LPG and electricity (3.4 and 3.9 h/d, respectively). Increasing in time, 5.0 h/d were used in kitchens burning charcoal and 7 h/d in those using firewood.

Table 9. Cookstove usage and kitchen room volume. Mean and (SD).

	LPG	Electricity	Firewood	Charcoal
Cookstove usage (hours/day)	3.4 (1.3)	3.9 (1.6)	7.4 (3.1)	5.0 (2.7)
Kitchen volume (m^3)	40.1 (17.1)	28.0 (9.4)	20.9 (15.3)	26.5 (17.1)

The results of the multiple correspondence analysis (ACM) performed for building variables is shown in Figure 8. The analysis indicated that roofs of kitchens using firewood were constructed mostly by asbestos cement, besides wood or nylon walls and uncoated floors. In contrast, those kitchens using LPG or electricity were associated with materials of higher purchasing power, such as ceramic, concrete and bricks. In case of kitchens that used charcoal, they were constructed of materials of intermediate quality, such as metal and wood.

Even though the socioeconomic status was not formally determined, this analysis can be interpreted as an approximation to the likely income of each household. According to the ACM, those kitchens that cooked with firewood were built with low-cost materials, and thus can likely be associated with a lower purchasing power.

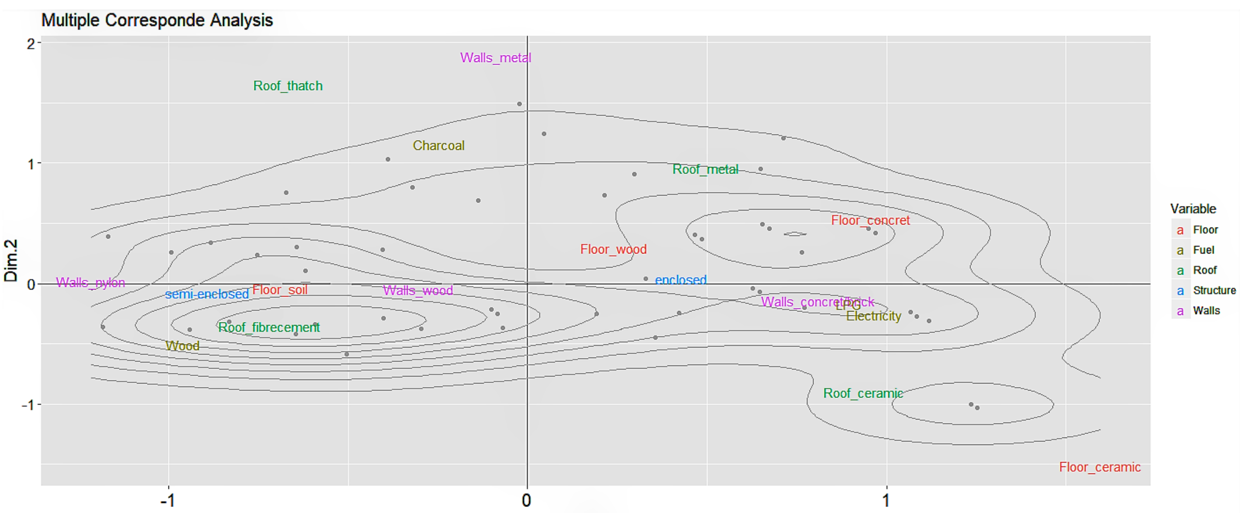

Figure 8. ACM result that illustrates the relationship between kitchen building materials with the fuel used for cooking. It is shown the degree of correlation between the two-dimensional solution (Dim.1 and Dim.2) with the different categories of the fuel type, kitchen type, roof, floor and wall construction materials (shown in Table 4). Individual observations are shown as points.

The monitored households used one of four different cooking appliances: three-stone open fires for burning firewood, metallic braziers for burning charcoal, regular LPG cookstoves or electric hot-plate cookers. The designs commonly found are depicted in Figure 9.

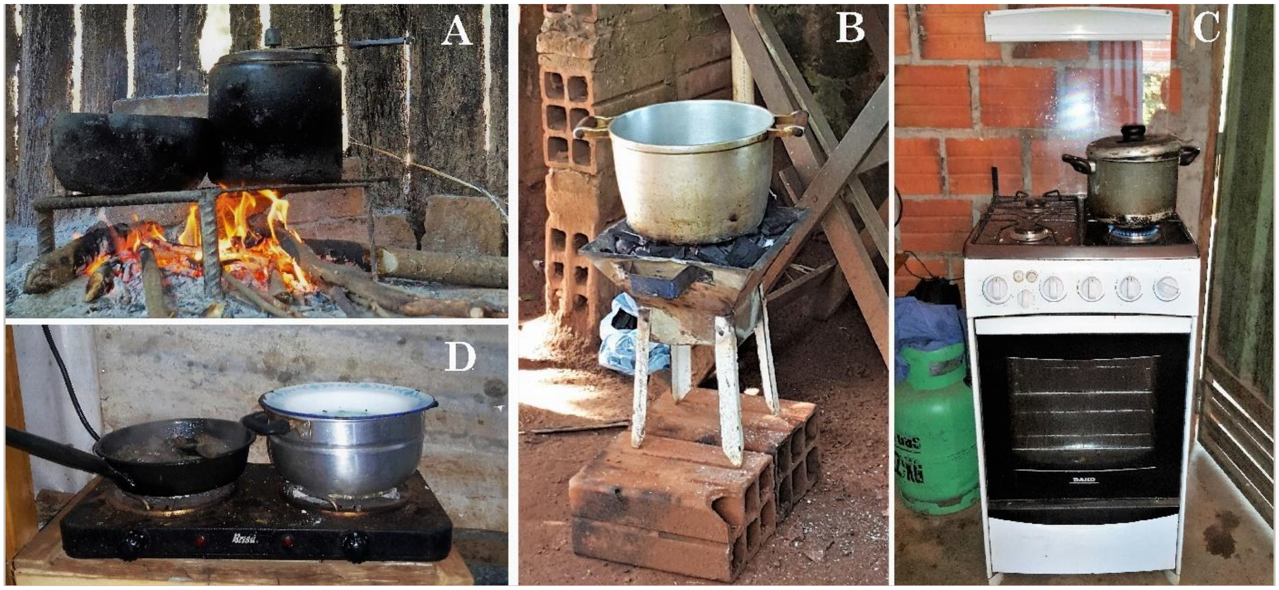

Figure 9. Cookstoves commonly found in the sub-urban and rural village.
A: Open fire (firewood). B: Brazier (charcoal). C: LPG Cookstove. D: Hot plate (electric).

3.3 Exposure to CO and $PM_{2.5}$ in the kitchen area

Table 10 below shows the average CO concentration recorded for 24 hours in the kitchen area.

In studied kitchens, this compound was observed at higher concentrations for those that used firewood, especially those with enclosed (17.8 ppm) and semi-enclosed kitchens (20.4 ppm). These average concentrations were about three-fold higher than the daily WHO recommendation (~ 5.7 ppm).

Kitchens that used charcoal had an average concentration of 8.8 ppm (enclosed) and 5.6 ppm (semi-closed). In those kitchens, the average CO concentration was 1.7 times higher than the WHO recommendation.

Outdoor kitchens, maybe due to their greater natural ventilation, had the lowest concentrations of CO; 0.68 and 1.1 ppm for firewood and charcoal, respectively.

Table 10. CO concentration in the kitchen area (24 h). Mean and (95% CI)

Fuel	N	CO (ppm)
LPG	25	0.51 (0.19–0.83)
Electricity	10	0.42 (0.14–0.98)
Firewood		
enclosed	10	17.8 (5.4–30.3)
semi-enclosed	18	20.4 (12.4–28.3)
outdoor	6	0.68 (0.40–1.76)
Charcoal		
enclosed	11	8.8 (4.0–13.7)
semi-enclosed	7	5.6 (0.8–11.9)
outdoor	18	1.12 (0.42–1.82)

Regarding kitchens based on clean energy sources, i.e. LPG and electricity, the average concentration of CO was below 1 ppm. Despite this, the $PM_{2.5}$ average concentration in the same kitchens was 52 µg/m^3, higher than the values expected for an emission-free environment (Table 10). In the same table, it is shown $PM_{2.5}$ concentrations and its carbon fraction measured in different types of kitchens.

Table 11. Cooking area $PM_{2.5}$ and its carbon fraction (OC and EC) concentrations (24 h). Mean and (95% CI)

Fuel	$PM_{2.5}$ µg/m3	OC µg/m^3	EC µg/m^3
LPG	52.3 (44.3–60.3)	17.6 (13.6–21.6)	2.6 (0.85–4.5)
Electricity	52.0 (41.8–62.6)	16.5 (12.3–20.8)	4.1 (2.8–5.5)
Firewood			
enclosed	850.5 (381.2–1319.9)	498.1 (148.8–847.3)	166.3 (37.7–294.9)
semi-enclosed	681.2 (439.9–922.5)	362.8 (212.5–513.1)	134.9 (69.0–200.8)
outdoor	112.7 (70.8–154.7)	55.1 (30.6–79.5)	9.8 (4.2–15.5)
Charcoal			
enclosed	109.1 (74.0–144.1)	43.7 (32.3–55.1)	19.8 (10.0–29.7)
semi-enclosed	104.0 (65.3–191.5)	52.8 (1.0–106.6)	9.9 (0.34–20.1)
outdoor	44.1 (22.4–65.8)	21.0 (8.0–33.9)	8.0 (1.9–18.0)

Of all fuel groups, kitchens that burned firewood and charcoal showed the highest levels of $PM_{2.5}$, OC and EC, when compared with the LPG and electrical kitchens averages.

In enclosed spaces, the firewood-based kitchens averaged 850 µg/m^3 of $PM_{2.5}$. In semi-enclosed kitchens, 681 µg/m^3 were averaged. The cooking area near open fires in outdoor spaces presented 112 µg/m^3, a concentration above the level that is suggested by WHO (35 µg/m^3). Similarly, the enclosed charcoal-burning kitchens also presented an average $PM_{2.5}$ concentration above the level that is suggested as safe for health (109 µg/m^3).

For the OC and EC, higher average concentrations were measured in enclosed kitchens, followed by semi-closed and outdoor cooking areas. In enclosed firewood kitchens, the

OC mass accounted 58% of the $PM_{2.5}$ mass, while the EC accounted 19%. In enclosed kitchens using charcoal, these values were 40% and 18%, respectively. The difference in contribution of the OC to the mass of the particle can be explained by the fact that charcoal has already released organic material during the previous carbonization process to which it has been subjected.

In LPG and electrical kitchens, the elemental carbon (EC) contributed with a quite similar percentage to the mass of $PM_{2.5}$ (5-7%, respectively). These proportions were close to that found in outdoor samples (Table 15), allowing to suggest a possible infiltration of $PM_{2.5}$ from outdoors to indoors.

3.4 Personal exposure to $PM_{2.5}$

The $PM_{2.5}$ exposures for the women in charge of cooking was evaluated for eight cases. Three participants were women who burned firewood in semi-enclosed areas, while one women cooked in an enclosed space. The other four monitored women cooked with charcoal in braziers, but outside the household. After 24 hours, the mean $PM_{2.5}$ concentration observed in women who burned firewood was 5 times higher than the mean concentration observed in women who used charcoal outdoors.

In the case of women who cooked with charcoal, personal exposure to $PM_{2.5}$ was slightly higher than the concentration suggested by the WHO, averaging 41 µg/m^3. In contrast, women who cooked with firewood had an exposure of 233 µg/m^3. Table 12 shows the average concentration of $PM_{2.5}$, measured both on a personal level and in the kitchen area. In general, the exposure to $PM_{2.5}$ of a woman cooking with biomass was half the concentration observed in the kitchen area.

Table 12. $PM_{2.5}$ concentration measured at personal level and cooking area. Mean and (SD)

	Personal	**Kitchen**	**Kitchen/Personal (ratio)**
Firewood	232.9	408.0	1.97
N=4	(88.6)	(106.9)	(1.04)
Charcoal	41.1	85.8	1.97
N=4	(20.8)	(59.8)	(0.45)

Similar values of personal exposure were found in a study conducted in rural communities in Ghana, Africa[28]. In this country, women who were studied had cooking areas and practices comparable to those configurations found in Paraguay. That is to say, the studied Ghanaian women cooked on charcoal in open spaces and on firewood in enclosed or semi-enclosed kitchens. Personal exposure to $PM_{2.5}$ found in Ghana was reported as 44 μg/m^3 for those women who used charcoal, while was reported as 142 μg/m^3 for those who burned firewood.

Table 13 shows the concentrations of the OC and EC present in $PM_{2.5}$ samples collected in the women who wore the personal monitors. The total carbon concentration (TC), that is, the sum of EC and OC, was higher in samples from women using firewood (70 μg/m^3) compared to samples from women who cooked with charcoal (18 μg/m^3).

In Ghana, women who burned firewood (in open and enclosed spaces) were exposed to an average concentration of 9.7 μg/m^3 of black carbon, which is an approach to the concentration of EC. This concentration is lower than the value estimated for women who cooked with the same fuel in Paraguay (15 μg/m^3). Nevertheless, measurements in Paraguay were performed only in enclosed or semi-enclosed conditions. In the case of women using charcoal, a concentration of 3.2 μg/m^3 (black carbon) was measured in Ghana, which is closer to the measurement obtained in Paraguay, where a personal exposure of 4.4 μg/m^3 of EC was estimated.

Table 13. OC, EC and TC concentration (μg/m^3) in $PM_{2.5}$ measured at personal level. Mean + (SD)

Personal	Firewood	Charcoal
OC	55.3 (22.9)	14.4 (2.3)
EC	15.0 (8.2)	4.4 (1.0)
TC	70.3 (31.1)	18.7 (3.4)

3.5 $PM_{2.5}$ and CO concentration in sleeping areas

The average concentration of PM2.5 and CO monitored in the bedroom closest to the cooking area is shown in Table 13. The $PM_{2.5}$ recorded in bedrooms close to kitchens that used firewood averaged 162 μg/m^3. This value was higher than that observed for bedrooms in households that cooked with charcoal (28 μg/m^3), and above the concentration of $PM_{2.5}$ that is suggested as safe by WHO.

There was a marked difference in CO concentrations in households that cooked with firewood. In these households, an average concentration of 19.5 ppm was recorded in kitchens, whereas in the dormitories the level reached 0.88 ppm, considerably lower.

1-minute concentrations of CO recorded in the kitchen area and in the bedroom were temporally correlated (R^2 = 0.90). This means that CO increases were observed at almost the same time in both kitchens and bedrooms. Likewise, a high correlation was observed between the concentration of CO in the bedroom and the time during which the biomass fuel was kept burning in the kitchen (R^2 = 0.93).

Table 14. Concentration of $PM_{2.5}$ and CO in kitchens and bedrooms (24 hours). Mean and (S.D)

	Kitchen $PM_{2.5}$	Bedroom $PM_{2.5}$	Kitchen CO	Bedroom CO
Firewood N=9	686 (439.)	162 (176)	19.5 (13.8)	0.88 (0.52)
Charcoal N=5	90.1 (45.8)	28.1 (8.7)	-	-

3.6 $PM_{2.5}$ concentration at community level

The $PM_{2.5}$ concentration in the outdoor environment was greater in LIM, the rural village. Table 15 shows the average $PM_{2.5}$ and its carbon fraction, measured at both locations. On average, the daily concentration of $PM_{2.5}$ in LIM was 41 µg/m^3, approximately 14 micrograms (per cubic meter) higher than observed in JAS (27 µg/m^3).

OC and EC are products of the incomplete combustion of carbon-rich materials, such as fossil fuels and biomass. The rural community of LIM, where the prevalence of firewood burning was higher, TC concentration was 21 µg/m^3, seven micrograms more than in JAS (14 µg/m^3). In both communities, an estimated 50% of $PM_{2.5}$ particles were composed of matter coming from organic compounds, likely explained by the contribution of emissions from biomass burning.

Table 15. Outdoor $PM_{2.5}$ concentrations, 1-minute average and (95% CI). Carbonaceous fraction (OC, EC and TC), 24-h average and (SD).

	$PM_{2.5}$ µg/m^3	OC µg/m^3	EC µg/m^3	TC µg/m^3	TC/$PM_{2.5}$ %
JAS (n=10)	27.5 (26.7–28.3)	11.7 (3.5)	2.17 (1.27)	13.9 (4.1)	50.5%
LIM (n=14)	41.2 (40.7–41.7)	17.9 (6.6)	3.14 (1.63)	21.0 (8.1)	50.9%

As a reference, chemical analyzes carried out on $PM_{2.5}$ collected in urban and sub-urban areas of the United States[29] have described that the composition of the particle is commonly distributed in: organic material (~ 35%), sulfates (~34%), ammonium (~ 12%), elemental carbon (~3%), nitrates (~2%) and material of the earth's crust (~3%). Nonetheless, previous analyses carried out in Japan on $PM_{2.5}$ from rural areas impacted by firewood burning and agricultural residues, have reported that the TC contribution can reach over 60%[30].

EC is emitted into the atmosphere, and to a greater extent, by mobile sources using diesel or oil. The EC/TC ratio has traditionally been used as a source tracer. Table 16 shows the EC/TC and OC/EC ratios, the latter used as an agricultural burner tracer.

In both communities, an approximate EC/TC value of 0.15 was found. This value is closer to that described for biomass combustion (0.1-0.2), instead of the ratio described for zones impacted by diesel combustion (0.5)[31].

The OC/EC ratio was 6.2 in LIM and 6.9 in JAS. As a reference, values between 1-3 have been described for areas with high concentrations of emissions from mobile and industrial sources, while for rural areas with biomass combustion, values above 5 have been reported[32].

Table 16. EC/TC and OC/EC ratio for $PM_{2.5}$ collected in outdoor environments. Mean and (SD)

	EC/TC	OC/EC
JAS (n=10)	0.15 (0.07)	6.89 (3.74)
LIM (n=14)	0.15 (0.03)	6.17 (1.51)

Table 17 shows the average concentrations of the 11 predominant elements found in the outdoor $PM_{2.5}$ samples. Decreasing in order of concentration, the major elements were potassium (K), sulfur (S), magnesium (Mg) and elements of the earth's crust (Mg, Si, Al, Fe, Na, Ca). In total, the mass of all the elements reported by the XRF analysis, contributed with 11% and 7.6% of the mass of $PM_{2.5}$ collected in JAS and LIM.

Table 17. 24-h average concentrations (µg/m^3) of elements in outdoor $PM_{2.5}$. Mean and (SD).

	JAS	LIM
K	1.47 (0.79)	1.22 (0.35)
S	0.59 (0.28)	0.75 (0.26)
Mg	0.39 (0.21)	0.37 (0.18)
Si	0.10 (0.06)	0.24 (0.13)
Al	0.12 (0.08)	0.19 (0.10)
Fe	0.07 (0.03)	0.13 (0.06)
Na	0.05 (0.03)	0.13 (0.07)
Cl	0.10 (0.14)	0.06 (0.04)
Ca	0.06 (0.02)	0.05 (0.02)
Zn	0.015 (0.007)	0.020 (0.008)
Ti	0.009 (0.006)	0.015 (0.010)
Others*	0.100	0.076

*sum of average concentrations of Ga, Ag, Ba, Nb, Tl, Co, Au, Ni, Hg, V, In, Y, Zr, Pd, Cd, Sn, Sb, As, Mo, Cr, Se, Sr, Mn, W, Pb, Eu, Cu, P, Cs, Rb, Ce, Br, Sc, La, Sm, Tb.

In the literature, associations between different elements and different sources of contamination have been widely described[33,34]. For example, K has been proposed as a tracer of biomass burning, while S has been associated with diesel combustion.

In both villages, a similar $PM_{2.5}$ elemental composition was observed (Figure 10). The predominance of K evidences the impact that the biomass burning has on the community environment.

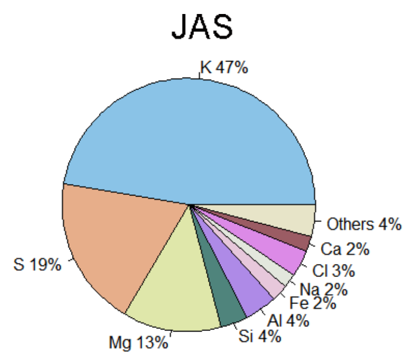

Figure 10. Contribution in the total concentration of elements analyzed in outdoor $PM_{2.5}$.

In the last decade, the country has progressively decreased the S content in diesel, from 4000 ppm in 2008 to 50 ppm in 2016. In rural villages, the S was the second element with the highest average concentration, which suggests that transport could be a major source of particles even in these areas. As a reference, the sulfur concentration in rural Paraguay was similar to the S concentration estimated in urban $PM_{2.5}$ at Boston, the United States[35] (0.980 $\mu g/m^3$) and lower than the value estimated for Mexico City[34] (1.64 $\mu g/m^3$).

The PCA suggested possible sources of pollution in rural villages, labeled "dimensions" (Dim) in Figure 11. The Figure shows a plot representing the degree of correlation between each element with each dimension, or principal component. For JAS, it was obtained a 4-solution result (91% of variance explained). Elements such as K, S, Pb, Br and EC are strongly correlated in Dim.1. This source can be associated with a mixture between biomass and diesel combustion, besides street dust, due to the presence of Pb. Dim.1 is also the component with the greatest correlation with the $PM_{2.5}$ mass, suggesting a considerable contribution of this source. The presence of particles coming from natural soil is observed in Dim. 2. Elements such as Fe, Si, Al, Ti and Na, are strongly correlated but with a smaller contribution in the total mass. The third solution, Dim. 3, shows that the OC, K and Cl have a strong degree of association, suggesting as a possible source the biomass burning.

In LIM, it was obtained a PCA with 5 solutions and 90% of variance explained (Figure 11). The component with the major contribution in $PM_{2.5}$ mass was the biomass burning, as observed in Dim.2. In this factor a strong correlation is observed between elements such as K, Cl, Ca and Br. The elements from natural soil were grouped in Dim. 1, while the resuspended street dust is observed in Dim. 5.

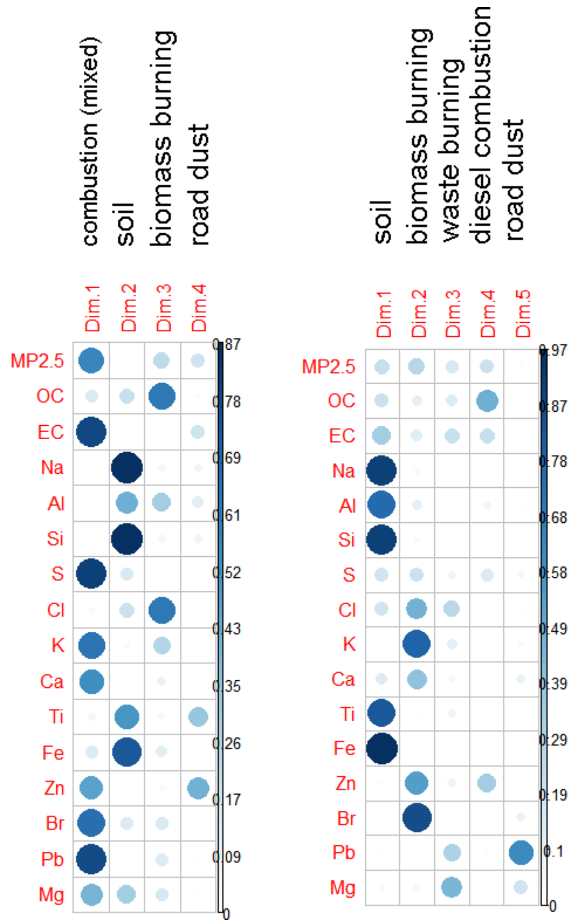

Figure 11. Correlation plot showing the contributions of elements in accounting for the variability in a given principal component (Dim). Are expressed in percentage. The plot highlights the most contributing variables for each possible source (Dim).

Through the 1-minute continuous measurements, a pattern was observed at the hourly level. The time series of $PM_{2.5}$, shown in Figure 12, indicated the presence of pollution events (concentrations > 100 µg/m^3), between the 17 and 20 hours. In both communities, the same pattern was observed, that is, increased concentrations occurring during breakfast hours (6-10) and during the afternoon. Some of these concentrations reached extreme values, near 1000 µg/m^3.

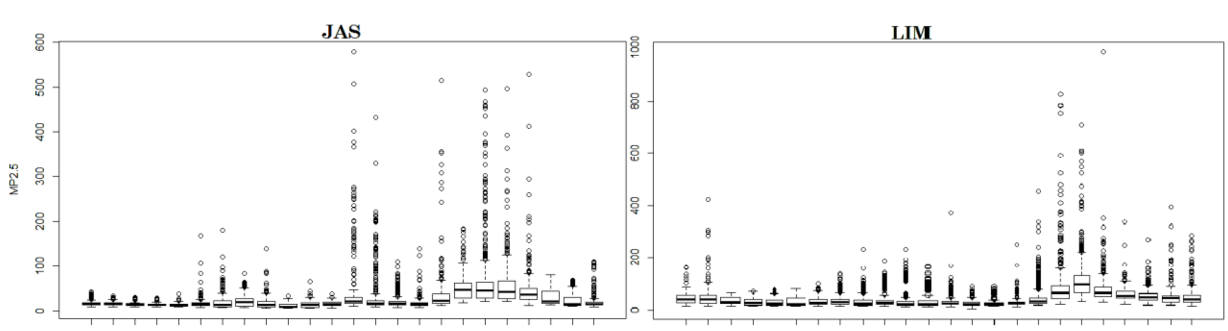

Figure 12. Hourly concentration of $PM_{2.5}$ in JAS y LIM. One-minute averages.

In both JAS and LIM, a time profile was observed that could be associated with the burning of biomass for food preparation, especially at morning. Figure 13 shows that in JAS there were three increments of $PM_{2.5}$ concentration through the day, approximately at 8 a.m., at noon and at 6 in the afternoon. During the latter, approximately 73 µg/m^3 of $PM_{2.5}$ was recorded. In LIM, a notorious increase was observed at 6 p.m., averaging more than 100 µg/m^3. In this community the lowest levels observed during breakfast or lunch hours may correspond to the lower presence of wood-burning cookstoves outside.

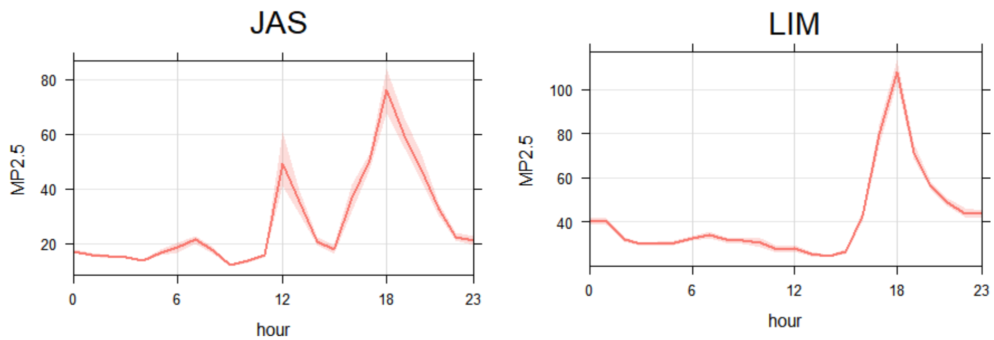

Figure 13. Hourly profile of the outdoor $PM_{2.5}$ concentrations. Red solid line indicates the mean, red-colored transparent area indicates the 95% CI in the mean.

In general, during the measurement campaign there was virtually no precipitation events (0.1 mm^3 average). The average daily temperature was 18.2 ° C, with a range that covered daily averages of 10.2 ° C to 25.6 ° C. These parameters are within what was expected for the winter season in a humid subtropical climate, such as that prevailing in the study area.

Figure 14 summarizes the prevailing wind direction and speed during the monitoring campaign. From 10 p.m. to 8 a.m., the dominant wind had a characteristic southerly direction, however, as of 9 a.m. the northeast wind became predominant.

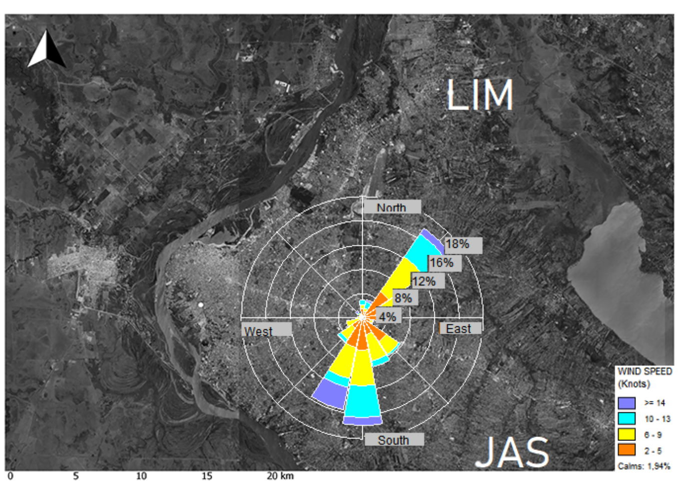

Figure 14. Wind rose plot showing the intensity and direction of the wind. Predominance in time is expressed in percentage.

Hourly details of the meteorological parameters are presented in Annex 4. The hourly profile of the wind speed show that lowest records were measured from 4 p.m. In order to test the hypothesis that lower wind velocities could be associated to decreased ventilation and therefore to higher concentrations of $PM_{2.5}$, a bi-variant linear regression was performed between the logarithmic values of $PM_{2.5}$ and wind speed. The hourly data indicated that there was a negative and statistically significant association between both (Table 18). This means that the lower wind velocity was a variable significantly associated with pollution events measured in community environments.

Table 18. Regression parameters between wind speed and $PM_{2.5}$ concentration (hourly). ***: significance 0.001.

Variable	Coefficient	p-value
(Intercept)	3.195	< 2e-16 ***
Log (µg/m^3 $PM_{2.5}$)	-0.285	2.22e-7 ***

The burning of agricultural residues with household waste was common in the communities visited (Figure 11). Additionally, this practice has been documented in the last Statistical Yearbook (2014)[ix], where it is mentioned that 76% of the rural population burns their garbage, while the rest of them bury it (10%) or have it taken by collector trucks, whether public or private (9.5%).

Figure 15. Pictures of domestic waste burning together with vegetable residues.

3.7 Multivariate Statistical Analysis

For $PM_{2.5}$ concentrations a robust regression model was found (R^2 adjusted = 0.859; Figure 16), details of which are shown in Table 19.

[ix] http://www.dgeec.gov.py/Publicaciones/Biblioteca/anuario2014/Anuario%20Estadistico%202014.pdf

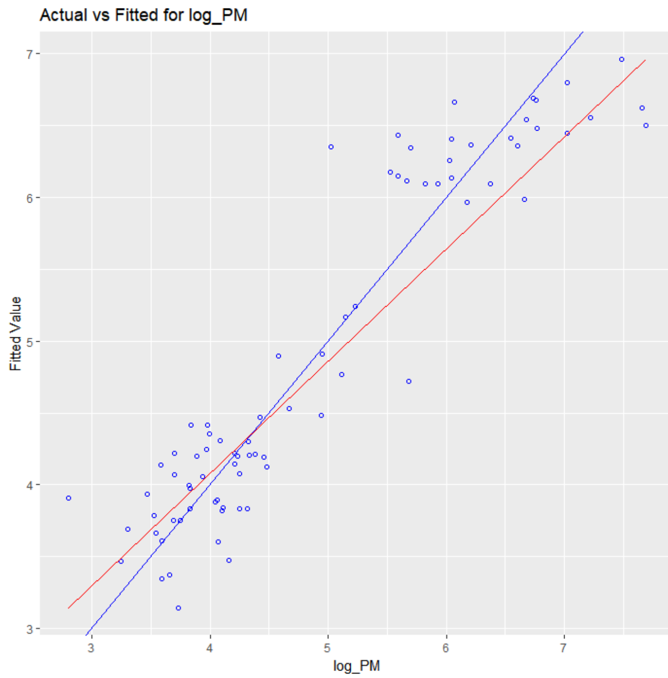

Figure 16. Goodness of fit chart for model 1.

It was determined that the highest concentrations of $PM_{2.5}$ were associated (statistically) with variables such as: type of fuel, type of community, time during which the cookstove was kept lit, and the indication of garbage burning in spaces close to home. Model 1, presented below, has 5 variables and a predictive power of 84%. This model can be considered as a useful tool to predict new concentrations of $PM_{2.5}$ that could be found in other Paraguayan kitchens of similar characteristics.

Predictive Model 1: Concentration (log) of $PM_{2.5}$ in the kitchen area. (predicted R^2= 0.837)

$$\text{Ln}(PM_{2.5}) = \beta_0 + \beta_1 *(\text{fuel}) + \beta_2*(\text{community}) + \beta_3* \text{Ln}(\text{minutes of cookstove usage}) + \beta_4*(\text{wall material}) + \beta_5*(\text{garbage burning}) + \varepsilon$$

Regression analysis confirmed that the use of fuelwood and charcoal for cooking is the main variable involved in increasing the concentration of $PM_{2.5}$ in cooking areas, followed by the duration of combustion (Table 19). The type of community, sub-urban or rural, turned out to be a significant variable. In this case, belonging to a rural community was a factor that increased the possibility of finding higher $PM_{2.5}$ levels in the kitchen area.

Table 19. Regression coefficients for Model 1.

Variable	Coefficient (β)	Std. error	*p* value	
(intercept, β_0)	0.862	0.686	0.213	
Fuel				
LPG	Reference			
Electricity	0.041	0.185	0.823	
Firewood	2.004	0.203	< 0.001	***
Charcoal	0.435	0.177	0.017	*
Community				
Sub-urban	Reference			
Rural	0.309	0.143	0.034	*
Cookstove usage				
Log (minutes)	0.521	0.124	< 0.001	***
Wall material				
Concrete	Reference			
Metal	-0.092	0.311	0.765	
Nylon	0.159	0.194	0.414	
Wood	-0.236	0.131	0.076	
Garbage burning	0.276	0.124	0.029	*

Significance: *** 0.001, ** 0.01, * 0.05

Adjusted R^2 = 0.859, residual error (ε)= 0.487

For the case of CO, a 5-variable robust regression model was obtained (Model 2). The model presents an adjusted R^2 equal to 0.857 (Figure 17), and has a predictive power of 82%.

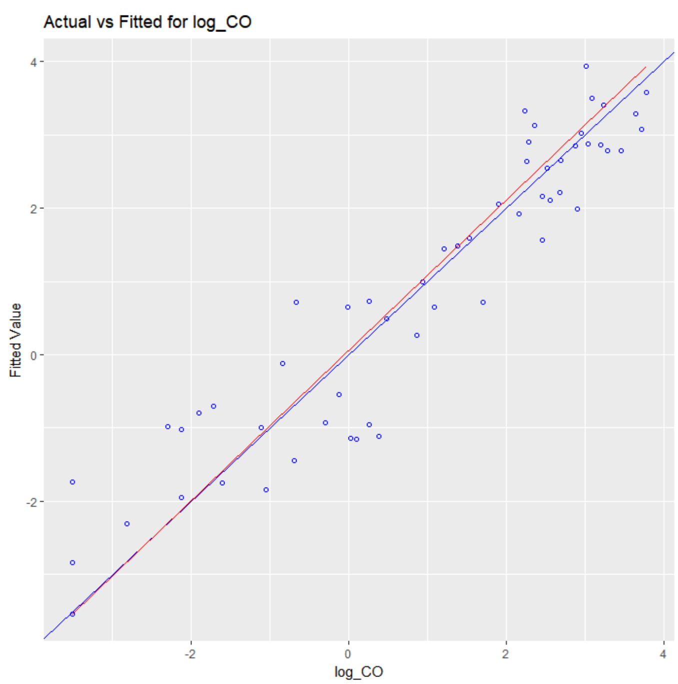

Figure 17. Goodness of fit chart for model 2.

Predictive Model 2: Concentration (log) of CO in the kitchen area. (predicted $R^2 = 0.822$)

$$\text{Ln (CO)} = \beta_0 + \beta_1 \text{*Ln} (PM_{2.5}) + \beta_2 \text{*(fuel)} + \beta_3\text{* (Floor material)}$$
$$+ \beta_4\text{*Ln (minutes of cookstove usage)} + \beta_5\text{*(garbage burning)} + \varepsilon$$

Although Model 2 explains the observed values with a high adjusted R^2 (Figure 13), the intercept of the regression is significant, which would indicate the existence of other variables not incorporated in the model, but which also explain the levels of CO.

In spite of the above, using the parameters shown in Table 20, it is possible to predict CO levels that would be found in kitchens with similar characteristics. Predictive variables, such as the $PM_{2.5}$ level and fuel type, are the most significant parameters. Both the time spent in cooking and the burning of garbage were also significant variables in the CO contribution observed in the kitchen area.

Table 20. Regression coefficients for Model 2.

Variable	Coefficient (β)	Std. error	*p* value	
(intercept)	-8.433	1.380	< 0.001	***
$PM_{2.5}$				
Log ($PM_{2.5}$ µg/m^3)	0.547	0.191	0.006	**
Fuel				
LPG	Reference			
Electricity	-0.847	0.408	0.043	*
Firewood	2.066	0.580	< 0.001	***
Charcoal	2.469	0.362	< 0.001	***
Floor material				
Ceramic	Reference			
Concrete	0.854	0.522	0.108	
Soil	-0.138	0.562	0.807	
Wood	0.603	0.760	0.431	
Cookstove usage				
Log (minutes)	0.891	0.273	0.002	**
Garbage burning	0.563	0.258	0.034	*

Significance: *** 0.001, ** 0.01, * 0.05
Adjusted $R^2 = 0.857$, residual error (ε)= 0.797

A third model was constructed, which considered exclusively the set of households that used clean fuels, and which has 5 variables to predict the concentrations of $PM_{2.5}$ observed inside these households (Model 3). This model has decreased predictive capacity compared to the previous ones (17%).

Predictive Model 3: Concentration of $PM_{2.5}$ in kitchens using LPG and electricity. (predicted $R^2 = 0.165$)

$$PM_{2.5} = \beta_0 + \beta_1 * \text{Ln (OC/EC)} + \beta_2 * \text{Ln } (PM_{2.5} \text{ outdoor}) + \beta_3 * \text{(cookstove usage)} + \beta_4 * \text{(roof material)} + \beta_5 * \text{(garbage burning)} + \varepsilon$$

Outdoor $PM_{2.5}$ concentration as well as the presence of garbage burning in the surroundings were the only variables with significant power ($p < 0.05$). The model parameters, shown in Table 21, indicate a negative association with the OC/EC ratio, which could be due to the fact that a considerable fraction of the $PM_{2.5}$ found inside these households could come from sources that decreases the OC/EC ratio, for example, vehicular sources. Although the source apportionment analyses were not made for indoor $PM_{2.5}$ samples, the elemental analysis in outdoor $PM_{2.5}$ evidenced the relatively high contribution of S, an element that is associated with diesel-based traffic emissions.

Table 21. Regression Coefficients for Model 3.

Variable	Coefficient (β)	Std. error	*p* value	
(intercept)	-31.33	33.36	0.357	
OC/EC (μg/m³)				
Log (OC/EC)	-5.23	2.83	0.077	
$PM_{2.5}$ outdoors				
Log ($PM_{2.5}$ μg/m³)	20.88	8.93	0.028	*
Cookstove usage				
minutes/day	0.043	0.028	0.133	
Roof material				
Ceramic	Reference			
Fibrocement	10.48	6.10	0.098	
Metal	-1.08	5.25	0.838	
Garbage burning	14.42	5.28	0.011	*

Significance: *** 0.001, ** 0.01, * 0.05
Adjusted R^2 = 0.413, residual error (ε)=12.46

Discussion

Concentrations of $PM_{2.5}$ and CO observed in Paraguay and their comparison to the values described in the literature

This report presents observations on indoor and outdoor air quality that have not been described for Paraguay before. In summary, the study conducted in July 2016, showed that more than half of the households monitored were based on biomass burning for cooking, which was performed in both indoors and outdoors. Electricity, even when was available in all households, remained as the least used fuel for cooking.

The highest 24-h indoor $PM_{2.5}$ concentrations were observed in the enclosed wood-burning kitchens (851 µg/m^3). In these environments, the average concentration far exceeded the guidelines established by the WHO (Interim-Target 1)

The measurements obtained in Paraguay are comparable to other studies conducted in Latin America. In Guatemala, for example, average $PM_{2.5}$ concentrations in the range of 528 - 900 µg/m^3 were observed for kitchens of similar configuration[36,37]. When compared to other countries in Central America, higher average $PM_{2.5}$ concentrations were reported for households that cooked with firewood in Nicaragua[38] and Honduras[39]. In the first, the average $PM_{2.5}$ concentration in open-fire cooking areas was reported as 1354 µg/m^3, while in the second, the average $PM_{2.5}$ concentration reached 1002 µg/m^3. Further, at a rural community in Mexico[40], households that cooked with firewood in enclosed spaces were reported with 693 µg/m^3, lower to that observed in Paraguay. Also, in rural Mexico, it was estimated that the outdoor $PM_{2.5}$ had on average 59 µg/m^3 (95% CI: 29-92), moderately higher than the value measured at the rural LIM in Paraguay (41 µg/m^3).

The observations for CO in Paraguay are close to that detailed in studies performed in Central America. In Nicaragua, it was reported that firewood kitchens averaged 26 ppm of CO, while in Paraguay they averaged 20 ppm. Lower concentrations were observed in Guatemala, where a range of 6 to 11 ppm CO was measured in firewood kitchens[36,37].

Compared to the values obtained in this study, enclosed wood-burning kitchens in Peru had lower concentrations of both $PM_{2.5}$ (211 – 615 µg/m3) and CO (7.6 – 14 ppm) [41-43]. Different cooking behaviors could explain this difference, as the wood-burning kitchens in Peru[44] were estimated cooking 3.7 – 3.9 h/d, while the wood-burning kitchens in Paraguay were cooking for 7 h/d. This difference may also reflect the methodologies used in each study, since the estimated cooking time was based on information recorded by temperature sensors in the present study, but it was based on activity diaries in Peru. The mean cooking duration estimated for wood-burning kitchens in Paraguay is close to the average values reported in Mexico (6.5 h/d)[45] and Guatemala (6.8 h/d)[46].

Studies conducted outside the Americas have also reported high average $PM_{2.5}$ and CO concentrations for biomass-burning households. In Nepal, a 24 h $PM_{2.5}$ average of 638 – 1376 µg/m^3 and CO average of 9 – 11 ppm, were observed in households that burned biomass in open fires[47-49]. Even higher concentrations were documented in biomass-burning households in Pakistan[50], averaging 2740 µg/m^3 $PM_{2.5}$ and 29 ppm CO. In the same study, 7.5 ppm CO and 380 µg/m^3 $PM_{2.5}$ were detected in kitchens that used natural gas for cooking, higher than the values expected for a free-emission indoor environment.

The relatively high concentration of pollution within households using clean fuels has also been observed in other indoor studies, and the phenomenon has been associated with the community impact that is generated from biomass burning for cooking areas. As an example, in Dhaka, Bangladesh[51], the LPG and electric kitchens were reported to have $PM_{2.5}$ averages of 165 µg/m^3 (95% CI: 130-200), above the average observed in Paraguay, which reached 52 µg/m^3 (95% CI: 44-60). In our present study, the 24 h average $PM_{2.5}$ concentration measured in the LPG and electric kitchens is closer to the average value described for LPG kitchens in Guatemala[52] and for electric kitchens with no secondary stove in Nepal[48] (57 and 56 µg/m^3, respectively).

Based on the 24-h personal monitoring, women who participated in this study experienced average $PM_{2.5}$ concentrations of 41 µg/m^3, those who cooked with charcoal outdoors, and 233 µg/m^3, those who cooked with firewood indoors. In Guatemala[53] the personal exposure in women with comparable kitchens was estimated in 270 µg/m^3.

Regarding the physical characteristics of Paraguayan kitchens, similarities have been reported with the type of kitchens found in a rural community in central Ghana[28]. In both have been reported kitchens burning biomass in enclosed and semi-enclosed structures. In Ghana, semi-enclosed firewood kitchens averaged 559 µg/m^3 of $PM_{2.5}$, while in Paraguay they averaged 681 µg/m^3. Personal exposure to $PM_{2.5}$ in women who cooked with firewood in Ghana, had an average of 142 µg/m^3, lower than that estimated in Paraguay (233 µg/m^3). However, it should be noted that the sample size in the present study (n = 4) does not allow a statistical analysis to determine if this difference is significant.

Compared to the data provided by the first review that summarized the results from different studies on indoor air quality conducted in households that use solid fuels[54], our measurements fall within the reported range. For example, the weighted mean value for 24-h personal exposure to EC (n = 6 studies), was 5.6 ± 4.0 µg/m^3 with a range of 3.2 –

10.3 μg/m^3. In Paraguay, the average EC concentration measured in women cooking with firewood was 15 μg/m^3, while women cooking with charcoal averaged 4.4 μg/m^3.

In the review study, the daily mean cooking area EC and OC concentrations ranged from 4.3 – 41.0 μg/m^3 and 54.6 – 103.2 μg/m^3, respectively. Both species were reported higher in households burning firewood in open fires than homes burning charcoal, as same as that observed in our study. The maximum values presented in the review are lower than the maximums averages observed in Paraguay, specifically to the EC and OC averages measured in the enclosed firewood-burning kitchens (166 and 498 μg/m^3, respectively).

The heterogeneity in combustion conditions, firewood species, measurement type as well as other factors are possible reasons to explain the difference in the previous values.

From the baseline described in this document, two robust statistical models were developed. These models are useful for predicting new observations of $PM_{2.5}$ and CO in other Paraguayan sub-urban and rural kitchens. The models have a predictive power over 80%, and share similarities with other statistical models found in the literature. For instance, in rural China[55] it was determined that belonging to a specific rural community was a significant predictor variable in $PM_{2.5}$ levels, similarly to what was observed in Paraguay. Additionally, in Pakistan[50], it was determined that an associated variable was the duration of biomass burning, similar to that observed in Paraguay for the $PM_{2.5}$ and CO regression models.

There is relatively little literature presenting a multivariate analysis on $PM_{2.5}$ data collected in kitchens that use biomass. In the capital of Ghana, in a study of low-income populations with high prevalence of firewood and charcoal consumption[56], the models present an adjusted R^2 of the order 0.50 - 0.68, in contrast to the value obtained with the study in Paraguay (adjusted R^2 = 0.86). In Ghana, it was determined that the use of biomass, both at home and at community level, was statistically associated to the increase of $PM_{2.5}$ concentrations within the kitchen area, as same as observed in the models developed in this project.

The results of our study support the relevance of using the indoor CO concentration as a proxy for indoor $PM_{2.5}$. This issue has been discussed in the literature, as some studies reported a relatively strong correlation (Pearson's $r > 0.8$) between both pollutants[52,57], while others found a weaker correlation[36,47]. Our regression model for CO (Table 20) indicated the $PM_{2.5}$ concentration was a strongly and significantly correlated with the CO concentration (p-value = 0.006).

Conclusions and Recommendations

The document has been intended to provide a baseline that may be useful for the needs that PAHO and DIGESA may have in their future institutional programs. For example, there has been presented regression models to estimate changes in indoor air pollution, which can be useful in designing intervention projects or cost-benefit analysis.

The study has limitations, such as the lack of socioeconomic information of the households and the better identification of possible secondary stoves that could potentially have affected the results. It also was able to monitor a relatively small number of households and only do so once.

Nevertheless, for the first time, the air quality status in kitchens from sub-urban and rural populations of Paraguay has been described. The study based on a cross-sectional sampling, reported the $PM_{2.5}$ and CO pollution, to which households in the country are exposed. In summary, kitchens that used firewood open fires for cooking had higher concentrations of $PM_{2.5}$ and CO, compared to kitchens that used charcoal, LPG and electricity.

The chemical analysis to outdoor $PM_{2.5}$ evidenced that K is the predominant element. It can be concluded that the biomass burning effectively has an impact on the outdoor air quality. It is presumed that external air pollution can be infiltrated into households using free-emission fuels, since levels were recorded above what was expected for a clean environment.

The high prevalence of firewood consumption for cooking resulted in daily concentrations in the order of 850 $\mu g/m^3$ of $PM_{2.5}$ and 20 ppm of CO for those enclosed kitchens. Exposure to $PM_{2.5}$, both at personal and cooking area, easily reach concentrations well above that suggested by WHO as safe for health.

The first recommendation to this problem is to progressively reduce dependence on biomass consumption, with the priority being to reduce fuelwood consumption. Given the national availability of electricity connections and supply, this can be achieved through the introduction of electric cookers, preferably those of the induction type, or in the absence, of the "hot plate" type, since is the most established design among the communities visited. In addition, efforts may be needed to expand LPG penetration in rural areas. It is recommended that a future project of intervention, or replacement of cookstoves, should consider a pilot phase in which the adoption process could be followed. It is suggested also to monitor the air quality again in those households that were subjected to an exchange intervention.

The second conclusion relates to the fact that in Paraguay the kitchen stoves using firewood do not have a defined construction, that is to say, an appliance made of mud or bricks. While electricity or other clean fuels are the long-term goal, in the meantime it is recommended to introduce more efficient and cleaner stove designs with modern combustion chambers and chimneys to the outside. In other parts of the world, such as in Mexico, wood stoves have been improved in rural areas, being the most popular design the *Patsari* cookstove. It is suggested to consider this recommendation only in case when introduction of electric stoves could not be feasible. This is due the reason that the outdoor environment may already present a considerable load of air pollution.

In the long term, it is recommended to follow an action plan that contemplates the identification of new communities with high demand of biomass, and that potentially could become candidates to receive a replacement cookstove. It should be discussed the training in rural communities, which do not have a garbage collection service, in order to uproot the practices of burning garbage. It is suggested to hold discussion tables with the Ministry of the Environment, since $PM_{2.5}$ levels in rural communities are exceeding the 24-hour rule dictated by the Resolution of Air Quality Standards.

According to the last national energy balance, in 2016 LPG consumption decreased, at the same time that fuelwood and electricity consumption increased in the kitchens, a phenomenon presumably primarily due to changes in prices of LPG. Considering that the price of electricity is one of the most affordable in the entire South American region, it is suggested to conduct a pilot study to show the benefits of substituting polluting cookstoves for clean cooking. In the current scenario of economic growth that Paraguay experiences, the introduction of electric cookstoves could be a feasible option to account in the next public policies.

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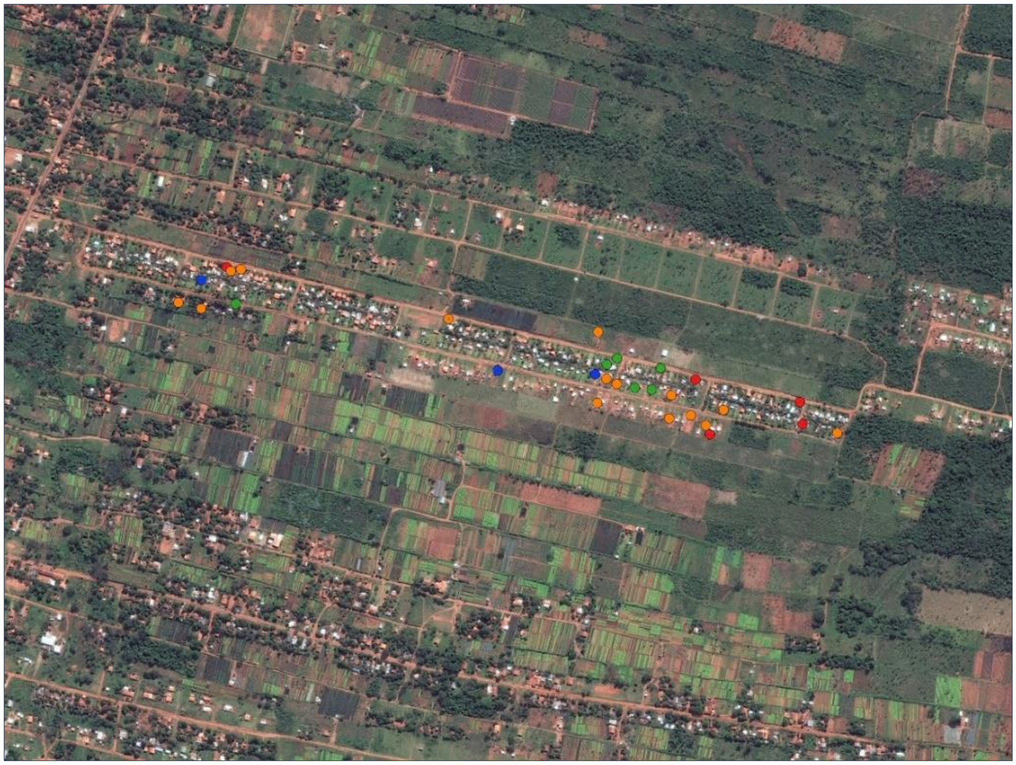
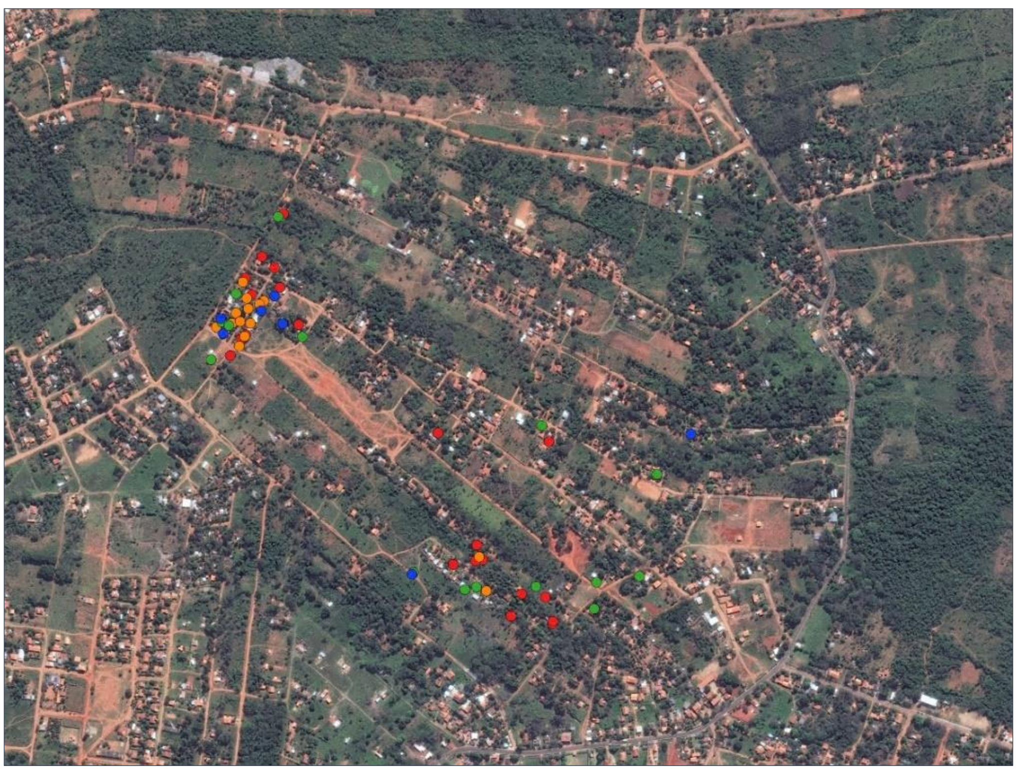
ANNEX 1.
GEOREFERENCING OF PARTICIPATING HOMES



JAS (Julian Augusto Saldivar). Households by fuel type:
●LPG ●electricity ●wood ●charcoal



LIM (Limpio). Households by fuel type:
●LPG ●electricity ●wood ●charcoal

ANNEX 2.
INSTRUMENT CALIBRATION

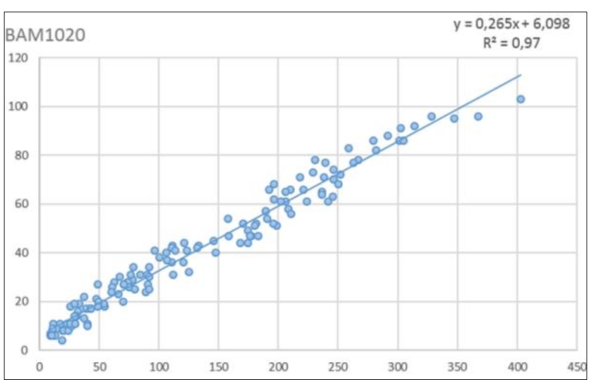
EL-USB-CO Data Logger (Lascar)

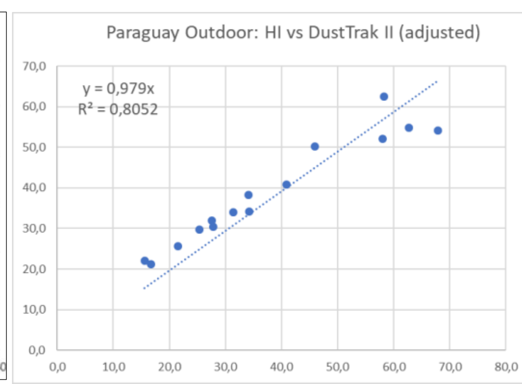
The CO monitors were inter-compared in September 2016, inside a smoke chamber belonging to the Energy, Climate and Health Laboratory (UC Berkeley), using an incense as a source of CO. The table below shows the slope of the regression for each inter-comparison after two hours of measurements (10 seconds average). This value was used as a correction factor, with the SN 160408 being the reference instrument.

EL-USB-CO (SN)	Correction factor
14664	1.22
16068	1.06
16044	0.95
16663	1.13

DustTrak II Model 8532 (TSI) v BAM-1020 (MetOne).

In June 2016, the DustTrak II equipment was calibrated through the inter-comparison of simultaneous measurements obtained with the BAM-1020 instrument, located at the air quality monitoring station, Las Condes, Santiago, Chile[x]. The BAM-1020 measures $PM_{2.5}$ mass concentration using the beta attenuation principle. The hourly averages obtained with both instruments were compared in order to assess the degree of correlation. A high correlation (0.97) was reported between the data. The slope of the linear regression of parallel measurements was used as a correction factor for the data obtained by the DustTrak II. Although the correlation between the adjusted DustTrak and the gravimetric result is high, a slight deviation was observed in maximum values. For this reason, it was on used only the calibration made with the reference instrument.





[x] http://sinca.mma.gob.cl/index.php/estacion/index/id/163

ANNEX 3.
KITCHEN CHARACTERIZATION QUESTIONNAIRE

CUESTIONARIO

	Fecha	Hora
Inicio		

□ Leña □Carbón □Gas □Electricidad □Urbano □Rural

A.1. ¿Es usted el cocinero principal de su hogar?
□No [No continúe hasta que hable con el cocinero principal]
□Sí

A.2 [Por favor anote si el encuestado es hombre o mujer.]
□Mujer □Hombre

A.3 De qué está hecho el techo de su casa?[Observar]
□ Metal □Teja □ Concreto □ Madera
□ Paja/hoja □ Otro ______________________

A.4. ¿De qué está hecho el piso de su casa?
□Concreto desnudo □Concreto revestido □Madera
□Tierra □Baldosa □ Otro ______________

A.5. ¿De qué está hecho los muros de su casa?
□Concreto o ladrillos □Metal □Madera
□Barro □ Otro ______________________

A.6. ¿Cuantas habitaciones tiene su casa? No incluye baños.
□1 □2 □3 □4+

A.7. ¿De qué está hecho el piso de su cocina?
□Concreto desnudo □Concreto revestido □Madera
□Tierra □Baldosa □Otro____

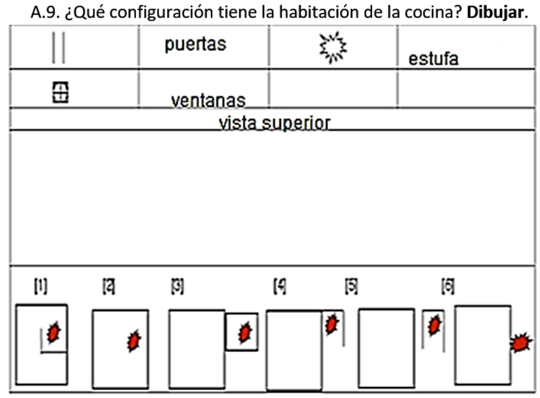
A.8. ¿De qué está hecho los muros de su cocina?
□Concreto o ladrillos □Metal
□Madera □Barro □Otro ______________

B.1 ¿Qué tipo es la estufa?
□ Fuego abierto □Arcilla/barro (puede tener metal)
□ Cemento/ladrillo □Solo de metal □Otro___________

B.2 ¿La estufa tiene chimenea o ducto al exterior?
No [omita la siguiente pregunta] □ Sí

B.3 ¿Qué tipo de chimenea tiene?
□ Chimenea sobresale del techo. □ Chimenea no pasa el techo.
□ Tipo campana

A.9. ¿Qué configuración tiene la habitación de la cocina? **Dibujar.**



[1] Dentro de la casa con muro o puerta (cocina y living están separados, pero en la misma construcción)
[2] Dentro de la casa sin separación. (cocina y living en el mismo espacio)
[3] Cocina en construcción aparte (habitación contigua)
[4] Cocina en construcción aparte pero pegada a la casa (estructura parcialmente abierta)
[5] Cocina en construcción aparte no pegada al área del living. (estructura parcialmente abierta)
[6] Cocina al aire libre (intemperie)
[7] Combinación de tipos 1-5. especificar:

B.4. ¿La estufa tiene puerta/cabina para depositar la leña/carbón?
□No □ Sí

POST-MONITOREO

D.1. ¿Para cuanta gente cocinó durante el día de ayer?
_______ D.1.1 # adultos y adolescentes +15
_______ D.2.2 # niños 0-14 años.

D.2. ¿Mantuvo alguna puerta o ventana abierta mientras cocinaba?
□ No □puertas #_____ □ventanas #______

D.3. ¿En qué horas usted estuvo cocinando? (preguntar si fue en la mañana, tarde o noche, luego anotar la hora).

Mañana (am)	□6	□7	□8	□9	□10	□11	□12
Tarde (pm)	□1	□2	□3	□4	□5	□6	□7
Noche	□8	□9	□10	□11	□12	□1-5 am	

Humedad %	

□ CARBÓN □LEÑA

D.4. ¿Realizó alguna de las actividades a continuación?

	hora
□Barrer	____
□Fumar	____
□Quemar incienso	____
□Quemar repelente de mosquito	____
□Quemar basura (fuera de la casa)	____
□Prender fogata (fuera de la casa)	____
□Prender lámpara a kerosene	____
□Prender estufa de calefacción	____

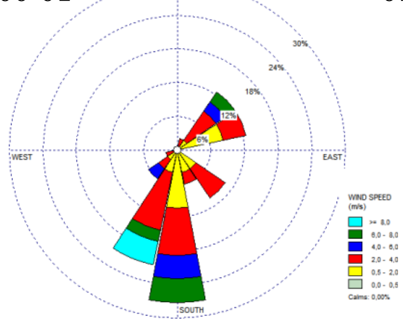
Especificar______________________

D.5. En relación a otras viviendas del área. ¿Esta casa está expuesta al viento?
□más que los otros □menos que los otros □igual

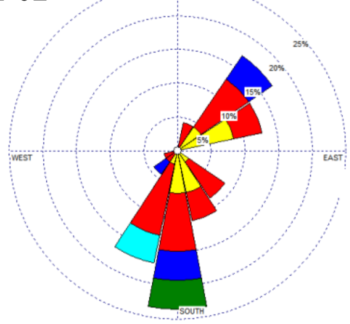
ANNEX 4.
METEOROLOGY

Wind roses at hourly level

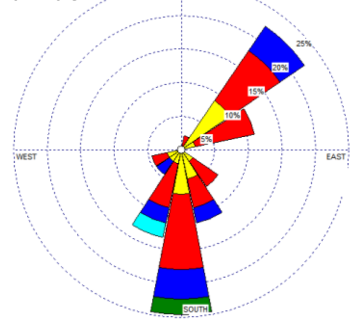
00-01



01-02



02-03



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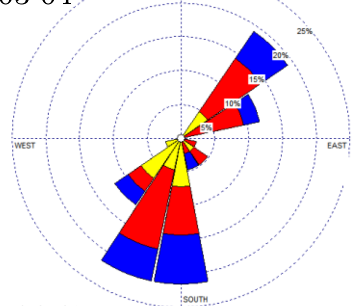

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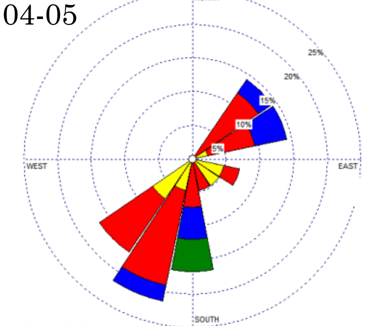

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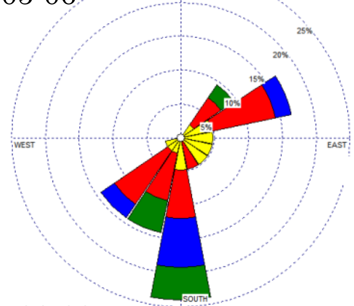

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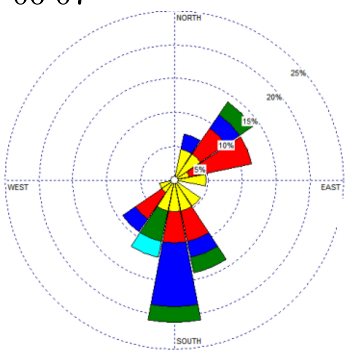

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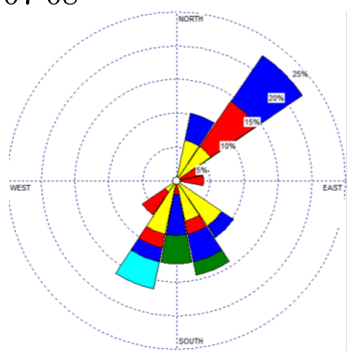

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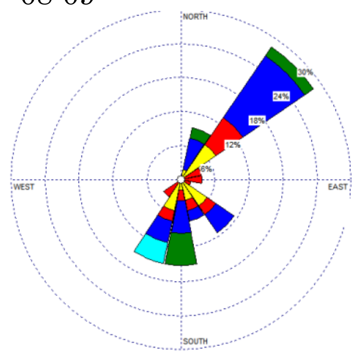

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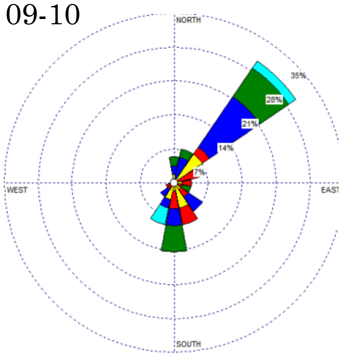
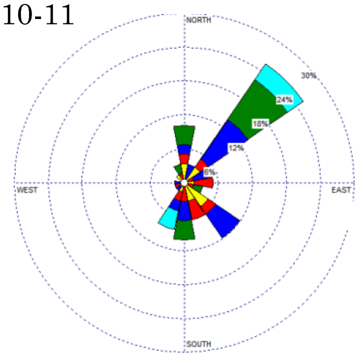
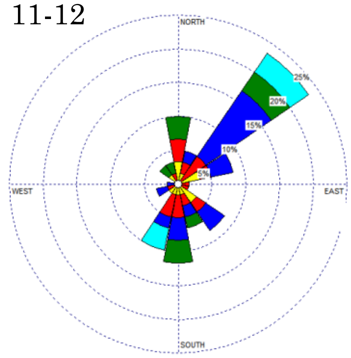


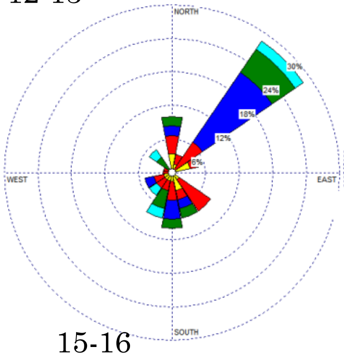
10-11



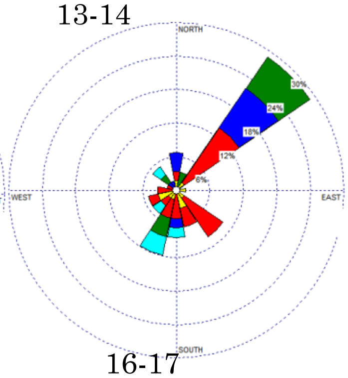
11-12



12-13



13-14



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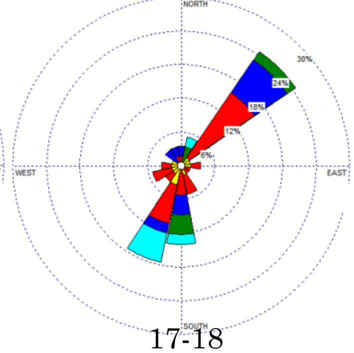

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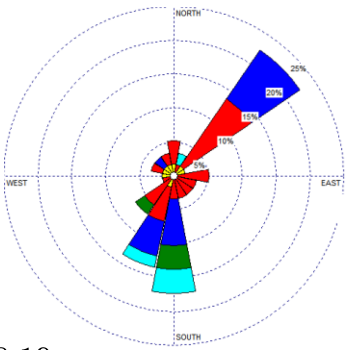

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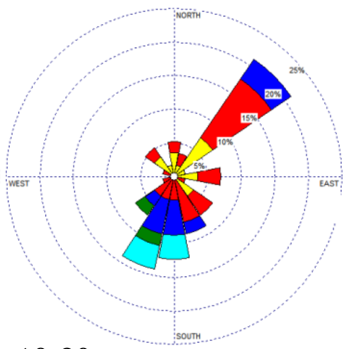

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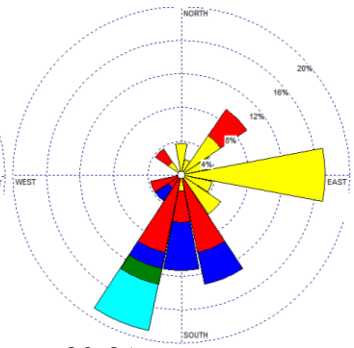

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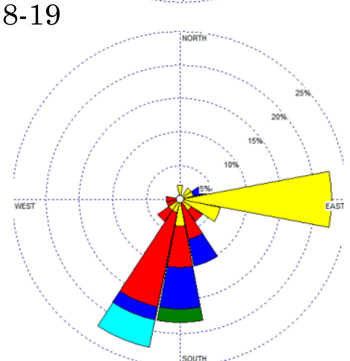
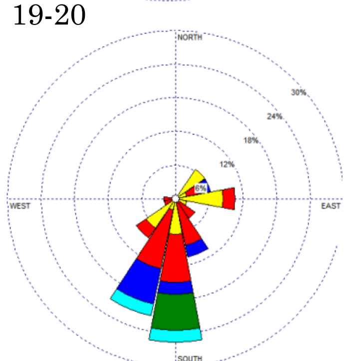
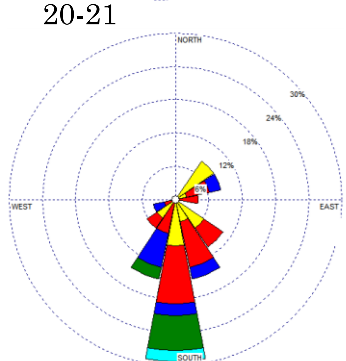


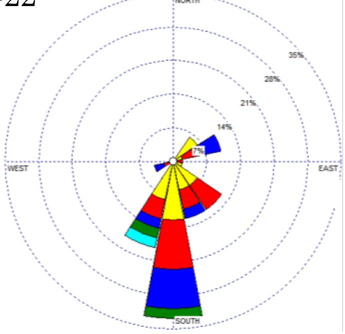
19-20



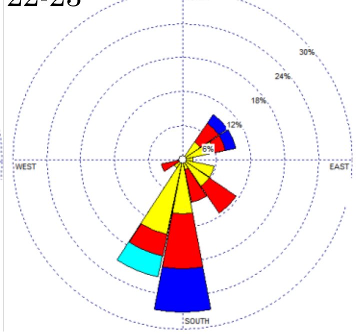
20-21



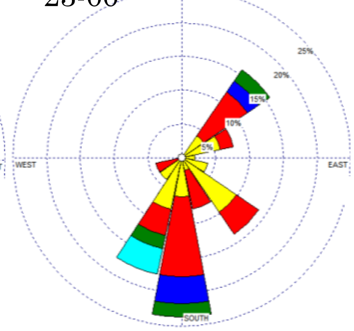
21-22



22-23



23-00



Wind speed, wind direction, temperature, and relative humidity.