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Household fuel mixes in peri-urban and rural Ecuador: Explaining the context of LPG, patterns of continued firewood use, and the challenges of induction cooking

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Abstract

Nationwide transitions from cooking with solid fuels to clean fuels promise substantial health, climate, and environmental benefits. For decades, Ecuador has invested heavily in consumption subsidies for liquified petroleum gas (LPG), a leading clean fuel. With the goal of understanding household energy use in a context where LPG is ubiquitous and cheap, we administered 808 household surveys in peri-urban and rural communities in Coastal and Andean Ecuadorian provinces. We assess cooking fuel patterns after long-term LPG access and the reach of induction stoves promoted through a recent government program.

Nearly all participants reported using LPG for more than a decade and frequent, convenient access to highly subsidized LPG. Nonetheless, half of rural households and 20% of peri-urban households rely on firewood to meet specific household energy needs, like space heating or heating water for bathing. Induction was rare and many induction owners reported zero use because the required equipment had never been installed by electricity companies, their stove had broken, or due to fears of high electricity costs.

Our discussion is instructive for other countries because of Ecuador's long-standing clean fuel policies, robust LPG market and standardized cylinder recirculation model, and promotion of induction stoves.

Keywords

energy policy; fuel subsidy; clean cooking; Latin America; biomass cooking; fuel transition

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1. Introduction

Clean cooking fuels promise substantial benefits for the 2.8 billion people around the world that rely on solid fuels like firewood and charcoal to meet their daily cooking and heating needs (Bonjour et al., 2013). Exposure to air pollution resulting from the inefficient combustion of solid fuels is among the top environmental health risks today, accounting for an estimated 3-4 million deaths per year (Stanaway et al., 2018). Clean cooking fuels like liquified petroleum gas (LPG) are prohibitively expensive for the majority of the world's poor and rural populations—those who are most reliant on biomass combustion. Subsidies that reduce the cost to consumers of clean cooking fuel may speed the transition to widespread clean cooking (Quinn et al., 2018; Rosenthal et al., 2018; Troncoso and Soares da Silva, 2017). Unfortunately, examples of long-standing clean cooking fuel subsidies are rare and poorly described. In this study, we use household survey data from Ecuador to elucidate household cooking fuel use patterns following four decades of nationwide clean cooking fuel subsidies.

Ecuador is an upper middle-income country with a population of about 17 million and a 2018 GDP per capita of just over $6,300. Approximately 64% of the population lives in cities (The World Bank, 2019a); this figure is similar to other upper-middle income countries (66%) but lower than the Latin American average (81%) (The World Bank, 2019a).

Ecuador has two overlapping household energy subsidies. First, since the 1970s, direct consumer subsidies have facilitated the national transition of Ecuador's population from cooking with biomass and kerosene to cooking with LPG. As of 2014, more than 90% of households cook primarily with LPG, paying the subsidized price for domestic cooking fixed at 1.60 USD per 15 kg cylinder since Ecuador's dollarization in 2000 (Gould et al., 2018a; National Institute for Statistics and Census of Ecuador, 2017). Thus, Ecuador provides an unusual opportunity to assess household fuel choice in a setting where LPG is inexpensive and widely available. Second, in the past five years a government program—El *Programa de Eficiencia Energética para la Cocción* ("The program for energy efficient cooking"; PEC)—has established incentives to install and use induction stoves. This efficient clean cooking technology heats any cookware made of ferromagnetic material using oscillating magnetic fields generated by alternating current passing through an electromagnetic coil. PEC initially sought to facilitate a nationwide transition, with a goal of 3.5 million induction-using households by 2018 established in 2015. However, PEC's 3.5-million-household target was pushed back to 2023 and eventually removed in favor of slower, market-dependent sales of induction. Overall, PEC aims to create demand for Ecuador's growing hydroelectric capacity and address the high total cost of the fuel-import-dependent LPG subsidy (approximately 1% of GDP annually).

In a previous study, we found prevalent use of biomass (firewood) in conjunction with clean cooking fuels in the northern Ecuadorian province of Carchi (Gould et al., 2018a). Although some study households in Carchi were impacted by border-region-specific policies that cap monthly LPG cylinder purchases, many others reported biomass use due to factors that likely exist elsewhere in Ecuador. The costs of LPG and electricity, infrequent access to

LPG, intermittent blackouts, and heating demands emerged as central determinants of multiple fuel use. In addition, we observed fuel stacking patterns attributed to culinary, economic, and convenience factors that may not be readily altered by consumer preference-driven programs. These patterns fit the growing literature of the determinants of clean cooking fuel use and motivations for fuel stacking around the world (Andadari et al., 2014; Quinn et al., 2018; Ruiz-Mercado et al., 2011; Ruiz-Mercado and Masera, 2015; Viswanathan and Kavi Kumar, 2005).

Previous study of the determinants of cooking fuel choice has intuitively focused on rural regions where solid fuels are dominant due to poverty and limited clean fuel accessibility (Alem et al., 2016; Banerjee et al., 2016; Cheng and Urpelainen, 2014; Gould and Urpelainen, 2018; Pope et al., 2018). Clean cooking fuel use is rapidly increasing around the world, with several countries making ambitious efforts to promote clean cooking fuels to even their most resource-poor populations (Abdulai et al., 2018; Asante et al., 2018; Goldemberg et al., 2018; Pollard et al., 2018; Smith, 2018). However, the health-relevant question of to what extent households use clean cooking fuels and continue to use traditional cooking practices in the long-term cannot be answered in regions where households have only recently adopted a clean fuel.

This study makes several contributions to the literature. Ecuador provides a unique opportunity to study the impacts of two nationwide policies that facilitate the use of two promising clean cooking fuels. To date, there has been no systematic assessment of the impacts of the LPG subsidy or PEC policies on household cooking fuel choice. Our results advance the literature in two important ways. First, we offer a discussion of cooking fuel use patterns under nationwide policies extending benefits to 17 million people. Though we do not sample to make nationally-representative estimates in the present study; the policy, institutional, and infrastructural frameworks in Ecuador that support clean cooking have been implemented at a national scale, a scenario still rarely discussed and called for in the literature (Quinn et al., 2018; Rosenthal et al., 2017). Second, we assess fuel choice in peri-urban and rural households that have used a clean cooking fuel for more than a decade under a sustained subsidy, a timespan that allows for the full development of adoption behaviors.

Finally, induction cookstoves are considered a next-generation cooking technology for the world’s poor and rapidly electrifying communities, but their use in rural or peri-urban areas of a low- or middle-income country at scale has been absent from the literature because the scenario does not exist outside of Ecuador (Goldemberg et al., 2018; Smith and Sagar, 2014). A brief discussion of induction cookstoves introduced to 4,000 rural households in Himachal Pradesh, India found that only 5% of households “leapt” from firewood to electricity and that the stoves most often supplanted LPG as a secondary cooking option (Banerjee et al., 2016). Importantly, electricity access in Ecuador is widespread, long-standing, and more affordable than many countries in Latin America, suggesting a leap to induction may be feasible (Organismo Supervisor de la Inversión en Energía y Minería Peru [Supervisor Organization of Investments in Energy and Mining Peru], 2018; The World Bank, 2019b). In comparison to neighboring Colombia (0.15 USD/kWh) and the United States (0.13 USD/kWh), Ecuadorian residential consumers pay a relatively low price for electricity (0.09 USD/kWh average for unsubsidized residential consumers) (Agencia de

Regulación y Control de Electricidad [Electricity Regulation and Control Agency], 2019a). Furthermore, Ecuador has recently invested more than 1 billion USD to improve the national grid in preparation for a nationwide transition to electricity-based cooking powered by hydroelectric generation (Ministerio de Electricidad y Energia Renovable, Equipo Técnico Interinstitucional, 2017). More than 97% has electricity access, including 94% having access to the requisite 220V connection available to them and reliable electricity access (Ministerio de Electricidad y Energia Renovable, Equipo Técnico Interinstitucional, 2017; Ministerio de Electricidad y Energía Renovable [Ministry of Electricity and Renewable Energy of Ecuador], 2019). In short, Ecuador is promoting the gold-standard for clean cooking: induction cooking powered by renewables.

We present the results of household surveys deployed in rural and peri-urban communities across four Ecuadorian provinces in the country's Andean and coastal regions to assess three overarching questions:

1. How does long-term access to low-cost LPG affect cooking fuel choice?
2. What characterizes persistent biomass use in an environment where economic barriers to clean fuel use are reduced for even last-mile communities?
3. Is electric induction cooking viable as an alternative in a middle-income country where LPG is already the norm?

2. Methods

In the present study we report on results from Phase I of a two phase project. In Phase I, we administered household surveys in rural and peri-urban households to evaluate cooking fuel and stove use patterns and preferences in Ecuador. In Phase II (results forthcoming), we returned to households surveyed in Phase I to carry out 48-hour sensor-based monitoring of personal exposure to fine particulate matter and stove use to assess the potential implications of observed biomass use on air pollution exposure and, by extension, population health. We sampled both rural and peri-urban households to account for the difficulty of clean fuel penetration to last-mile communities (rural households) and the geographic, economic, and cultural extent of the influence of the LPG subsidy and the more recent induction stove promotion program in Ecuador's growing peri-urban population.

2.1 Community selection

Communities were selected according to a multistage sampling design at the provincial- and sub-provincial-level to explore the associations between household cooking fuel choice, fuel costs, and other non-cooking uses of fuels like heating. The selection process is discussed at length in Supporting Information Section 1.1. Briefly, we first selected two provinces in the Andean region of Ecuador (Pichincha, Chimborazo) and two provinces in the Coastal region (Esmeraldas, Manabí) to capture a variation in geographic conditions, population demographics, and local cooking cultures (Table 1)—these provinces combine for 30% of Ecuador's population. We did not carry out surveys in the Amazonian lowlands or in the Galapagos due to the operational challenges and cost of data collection in those regions.

Next, we classified and randomly selected two potential rural and peri-urban parishes (the smallest political geographical unit in Ecuador) in each province. In total, the peri-urban and rural populations across the four study provinces account for 750,000 households. After selecting one rural and one peri-urban parish for logistical feasibility we acquired a list of all communities within each study parish and randomly selected eight potential study communities, narrowing to four based on having a large enough community size and facilitation of study logistics based on input from local residents hired as a survey support team. Two study parishes were added to the study during Phase II (Cangahua and Ayora, in Pichincha province) based on the low number of households in Chimborazo province that expressed interest in participating in Phase II, and the opportunity to complement data collection with other public health studies currently being undertaken in the region. Parish locations are shown in Figure 1.

Participant enrollment relied on door-to-door recruitment within study communities by choosing a random direction to walk from the community center and knocking on doors. Surveys were administered to household primary cooks that were 18 years and older between June and October 2018.

2.2 Study context

We describe the context of each community in Table 1 and at length in Supporting Information Section 1.2. Briefly, the Andean peri-urban parishes represented suburban areas with significant integration into neighboring provincial capitals, while the Coastal peri-urban communities were smaller communities with greater isolation from urban centers. Rural parishes ranged from recently-urbanizing rural areas in the outskirts of the country’s capital (Pichincha) and aging, agriculture-dependent indigenous communities (Chimborazo) to densely populated, urban-area-linked *mestizo* farming communities (Manabí), and agriculturally similar but far more isolated and disperse Afro-Ecuadorian and *mestizo* communities (Esmeraldas). These broad variations in local conditions may provide context for analysis of regional trends in cooking practices and demonstrate the important variations in local culture, cooking practice, infrastructure, and demographics that are present in even a small country like Ecuador.

2.3 Household survey tool

The survey instrument deployed in this study built on a formative pilot where we administered a closed-response household survey and carried out focus groups in three communities in the northern Ecuadorian province of Carchi (Gould et al., 2018a). In this study, and drawing from past reviews of the literature (Kar and Zerriffi, 2018; Muller and Yan, 2018; Puzzolo et al., 2016a), we established that fuel costs and access, household energy demands, and perceptions of fuels were primary determinants of cooking fuel uses and capture these dimensions in the present survey (discussed at length in Supporting Information Section 1.3). Surveys were carried out in Spanish and lasted between 15 and 30 minutes.

2.4 Approach

First, we describe the household cooking fuel use patterns and discuss the context of cooking fuel choices in distinct regions of Ecuador (i.e., Peri-Urban Andean, Rural Andean, Peri-Urban Coastal, and Rural Coastal). Second, we assess the associations between potential determinants of fuel choice and key outcome measures.

To assess the associations between wealth and cooking fuel choice, we developed region-specific asset indices that were categorized into quartiles to develop a wealth ranking relative to peer study participants in the region following previous practices for establishing a common asset index across rural and peri-urban areas (Rutstein, 2008) (discussed further in Supporting Information Section 1.4). Here, we believe that relative wealth is more relevant than a study-wide measure of wealth because we are utilizing community-level dummy variables to account for potential uncontrolled community heterogeneities.

The rest of the manuscript is organized as follows. In Section 3.1, we present the primary cook and household characteristics. Then we summarize observed cooking fuel mixes in Section 3.2. Then, for each fuel (Sections 3.3-3.5), we discuss relevant cooking fuel use parameters, including frequency and timing of use, contextual characteristics relevant to fuel acquisition such as cost and access, and participant perceptions of each fuel. Finally, in Section 3.6 we discuss the results from exploratory regression models assessing the associations between key primary cook, household, and fuel context characteristics (described at length in Supporting Information Section 1.4). Briefly, characteristics were selected based on previous evidence of an association with cooking fuel choice summarized in literature reviews (Lewis and Pattanayak, 2012; Muller and Yan, 2018; Puzzolo et al., 2016b; Quinn et al., 2018) and case studies, as follows: an asset index (Filmer and Pritchett, 2001; Menghwani et al., 2019; Ravindra et al., 2019), age of the primary cook (Farsi et al., 2007; Gupta and Köhlin, 2006), primary cook's education (Abebaw, 2007; Dalaba et al., 2018; Wolf et al., 2017), gender of the decision-maker (Gould and Urpelainen, 2019), household size (Narasimha Rao and Reddy, 2007; Rahut et al., 2016), and measures of the household's LPG fuel context (Kumar et al., 2016). In Section 4 we discuss and contextualize our findings and then offer conclusions in Section 5.

2.5 Ethical considerations

The survey and consent form were first developed in Spanish because all members of the research team are bilingual in English and Spanish. Study data were collected and managed using REDCap electronic data capture hosted at Universidad San Francisco de Quito (Harris et al., 2009). This study was reviewed and approved prior to initiation of the research by the Institutional Review Boards at the Columbia University Medical Center and the Bio-Ethics Committee at the Universidad de San Francisco de Quito. REDCap's e-signature feature was used to record participant's consent after a thorough verbal explanation of the approved consent form. Paper copies of the consent form were also provided, including investigator's contact information.

3. Results

3.1 General characteristics of study households

A total of 531 rural and 277 peri-urban households completed the household survey in two Andean provinces (Chimborazo (N=183), Pichincha (N=229)) and two coastal provinces (Manabí (N=192), and Esmeraldas (N=204)) (Figure 1; Table S1). Primary cooks were on average 45 years old and ages ranged from 18 to 85 years (Table 2). Nearly half of primary cooks were also the head of household (42%) and the majority had at least a partial primary school education. Household heads who were not the primary cook were similarly educated to the primary cooks. Most households reported to make decisions about purchasing durable goods jointly between the men and women heads of household, although decisions by individuals (man or woman head-of-household) were more common than joint decision-making in coastal provinces. More than 99% of households were electrified and had been so for more than a decade. Household size was consistent throughout the study areas (Mean (standard deviation (SD): 4.5 residents per household (2.3); Median (interquartile range (IQR)): 4 residents (3-6)).

When asked about the principal source of income for the household head, about 330 participants said some form agriculture, 190 reported that the household head was a tradesperson (e.g., mason, seamstress, electrician, auto mechanic, carpenter), 170 said that they participated in non-income generating activities or were retirees, and around 30 were professionals.

3.2 Fuel stacking and patterns of fuel use

Although more than 98% of households reported using LPG for cooking, fuel stacking was common among study households (Table 3). Overall, 40% of households reported using firewood as a cooking fuel, almost always as a secondary option to LPG. Although Ecuador has been promoting induction stoves through PEC since 2015, induction stove ownership was low throughout the study sample (9%) and rarely as a household's primary cookstove. A higher proportion of rural households used firewood as compared to their peri-urban counterparts. Households in Andean provinces also used firewood in greater prevalence than Coastal households. Combined, firewood was rarest in peri-urban households in Coastal provinces (20%), and most common in rural Andean households (63%). Induction stove ownership was more common in peri-urban households than rural households, and equally common in Andean and Coastal provinces.

3.3 LPG: Low cost, accessible, and dominant cooking fuel

Table 4 summarizes the context of LPG use, as well as its costs and accessibility for study households. LPG use was ubiquitous, and study households had cooked with LPG for more than 20 years on average. More than 99% of LPG-owning households reported using the fuel daily, with the vast majority cooking with LPG more than once a day.

For most households, a 15-kilogram cylinder of LPG (the only size available for household use in Ecuador) was reported to last 4 weeks (Mean (SD): 4.48 weeks (2.23)). We estimated that study households used on average 60 kilograms of LPG per person per year based on reported purchase frequency and household size. The median annual per capita LPG consumption was 48.75 kilograms (IQR: 32.50 – 65.00 kg), which represents thirteen 15-kilogram cylinders purchased per year for a family of four (Figure S5). While there was some variation in average LPG consumption per person across study regions, the median kilograms consumed was the same (48.75 kg). Mean yearly LPG consumption per person is similar across households that own and do not own a firewood stove (Welch Two Sample t-test p-value = 0.50) and is weakly positively correlated with the number of years a household has used LPG ($r = 0.18$) (Figure S6).

Next, we asked households about the costs of using LPG. Ecuador uses a cylinder-recirculation model of LPG distribution. Households buy an empty cylinder for 50 – 60 USD and then exchange their empty tanks for full ones. Many households across the country own two or more cylinders to avoid interruptions in LPG use, representing a significant investment, when compared to LPG stove price which averaged 236 USD (median: 150 USD) in study households. Most regions of the country have only one LPG distributor, but cylinders are standardized between brands and exchangeable nationwide. Most households reported purchasing cylinders for 3.00 USD (range = 1.60 – 5.00 USD, reflecting the baseline subsidized price of 1.60 USD, plus last-mile distribution costs and profits). Moreover, only one-quarter of households reported having paid a higher-than-standard price at any time in the past year, and at those times, paid only 0.25 USD more on average.

As discussed elsewhere, beyond monetary costs, LPG cylinder acquisition can be challenging due to distant points of purchase and heavy, bulky cylinders and other times accessibility may be infrequent (Gould and Urpelainen, 2018). Yet, 85% of study households reported that LPG delivery trucks regularly pass through their community, and 72% of households (87% peri-urban, 65% rural) indicated that they normally purchase LPG from these delivery trucks. Two-thirds of households reported having access to cylinders more than once a week; a total of 40% said that LPG cylinders were available for purchase every day, whenever they wanted. Purchase and transport of LPG cylinders for households not receiving deliveries can be burdensome. Two-fifths of households not purchasing from delivery trucks reported walking to acquire cylinders, with the rest either taking a taxi (35%) or their own vehicle (17%). A majority of participants identified the acquisition and transportation of LPG cylinders as problematic in both rural coastal parishes and in about one-quarter of rural Andean households.

We found that participants were satisfied with their LPG stoves throughout the study sample (89% satisfied; 4% unsatisfied) for several reasons: LPG provides fast cooking (55%) and in turn saves the cook time (24%); it is easy and convenient to cook with (22%); it does not produce smoke (9%); and cooks also reported “I have always cooked with gas, it is the only fuel I am familiar with” (22%) (Table S2).

When generally satisfied household were asked to describe any limitations of cooking with LPG, one-quarter said that they were fearful of cooking with the fuel and that it is unsafe. Still, 87% of participants reported that the general perception of LPG in their community is that it is dangerous to cook with and have in the house because of the risk of fires and explosions. In addition, some participants, particularly in coastal communities reported that a downside of LPG is that cylinders can empty without them realizing and that the cylinders are heavy and difficult to transport (each 7% overall), while a small number of Andean households reported LPG's inability to meet all household fuel needs (space heating, grilling, cooking with large pots). Urban and rural participants reported similar benefits and limitations of LPG. Yet, almost 60% of participants said that they were completely satisfied with their LPG cooking situation and reported no limitations.

3.4 Firewood use: persistent and popular

Overall, more than half of rural households and one-fifth of peri-urban households reported using firewood to meet some of their household energy needs (Table 5). Most households had traditional, three-stone or similar, woodstoves without a chimney, while 10% of households had either hearth-type or improved chimney cookstoves. Most traditional stoves were located outside of the house, often adjoining an exterior wall of the kitchen and with walls on two or three sides. Reported firewood use was infrequent; three-fifths of biomass-using households reported using their woodstoves once a week or less. Even among rural households, only 22% of firewood-using households (12% of all rural households surveyed) reported daily use. Most households (79%) reported collecting their firewood rather than purchasing, although, reflective of the occasional use, three-quarters of households reporting collecting less than once a week.

Primarily, households reported using their woodstoves for lunch-time cooking; specifically, cooking potatoes, corn, grains, and soups, though many also reported using LPG for these dishes as well (Table S3). While nearly all households used firewood as a cooking fuel, households also reported using firewood to heat water for bathing (24%) and cook food for their animals (22%). In addition, one-third of Andean households (and zero coastal households) reported using firewood to meet space heating needs during some months of the year. The use of fuels other than firewood for space heating is uncommon. LPG heaters are not available in the Ecuadorian market and electric space heaters were not encountered in the study sample and are uncommon nationwide, potentially due to prior import tariffs on this type of appliance (González, 2017).

Most participants reported that they were satisfied with cooking with firewood (Table S4). More than half of participants mentioned that a benefit of firewood was that it is traditional and permits cooking large quantities of food simultaneously (26%), cooking all types of dishes (17%), and is low-cost or free (18%). Despite general overall satisfaction, half of all households reported that cooking with firewood is bad for cooks' and children's health due to smoke generation. And yet, participants consistently reported that food cooked with firewood itself is healthier than food cooked with LPG, although this may reflect opinions about cooking styles (grilling over firewood compared to frying in oil with an LPG stove) rather than cooking fuels.

3.5 The use and acquisition of induction stoves

Induction stove ownership was rare throughout the study sample (10% of households). However, significant variations were found at the community level; between 2% and 23% of participants had an induction stove across study communities. Still, reported use was limited among those with induction stoves (Table 6). Nearly one-quarter of induction-owning households reported that they never used their stoves, often because electric utility personnel had not installed the requisite 220V electric connection and meter, homeowners had been unable to find a private electrician to install a 220V circuit and outlet for the stove, or due to fears about the cost of increased electricity consumption. Among the 77% of participants reporting any use of their induction stove, 29% used it as their primary cookstove and only 42% cooked with induction at least once every day. Almost all households using their induction stove reported using it for breakfast and viewed it as an easy and quick way to cook.

Households with induction stoves reported having paid an average of 629 USD (IQR: 600-760 USD), generally including the cost of credit, and most purchased their stove two years previously (approximately in 2016). Nearly all observed stoves were four-burner models with integrated electric-resistance ovens. More than half of induction-owning respondents considered their stoves to have been expensive. Television advertisements, demonstration stands at local fairs or markets, and door-to-door sales were the most common ways in which respondents first became aware of induction stoves. Indeed, almost 40% of respondents also acquired their induction stoves from door-to-door salespersons, though many purchased directly at the offices of the local public electric utility (34%) or from appliance stores located in larger cities (21%). Households largely found it easy to acquire stoves and for about two-thirds of households the process—including buying the stove, installing the 220V line and meter, installing the dedicated 220V circuit and outlet, and enrolling in the subsidy program—took less than two weeks. Nonetheless, the process took more than three months for one-quarter of the households; in particular, coastal households reported long delays in the installation of the 220V service drop line and meter.

Less than half of participants with induction stoves reported overall satisfaction, and one-third reported that they were unsatisfied (Table S5). Users that were satisfied highlighted the speed of induction cooking and its cleanliness, as it keeps pots clean and produces no smoke. One-quarter of households also reported satisfaction with induction stoves because they are clean for the environment and good for the health of users. More than half of induction-owning households identified the high costs of induction stove use as a basis for their complaint and 40% also reported that they perceived the stoves to be delicate and at risk of being damaged.

Lack of information about induction stoves characterized much of the reported experience for non-users and users alike. While three-quarters of households had encountered some form of messaging about induction stoves, most participants reported lack of knowledge about key PEC-related policies (Table S6). PEC provides up to 80kWh/month of free electricity—intended to mirror LPG consumption for cooking—and the opportunity to buy induction stoves and cookware with credit paid through users' monthly electric bills over a period of up to six years. Nonetheless, 20% of induction owners reported not receiving the subsidy and an additional 26% were unsure if they received the subsidy. Most non-users thought that the acquiring an induction stove was either expensive and difficult or they had no sense of the process or costs.

3.6 Determinants of fuel use

Next, we turn to results from regressions to assess the determinants of fuel use patterns (Figure 2). The factors associated with reporting to have a firewood stove and reporting to use it at least weekly or twice weekly were similar.

Accounting for baseline variations within communities and other covariates, formal educational achievement of the household head was positively associated with not having a firewood stove. For example, as compared to households where the household head had no formal education, households where the household head had completed secondary school had 0.15 times the odds (95% CI: 0.07-0.35) of having a firewood stove. Additionally, households in the wealthiest quartile had 0.75 times the odds (95% CI: 0.48-1.25) of owning firewood stoves as compared to those in the poorest quartile. Compared to families where men controlled decisions on major acquisitions, woman-led households had somewhat higher odds of owning firewood stoves (OR (95% CI): 1.17 (0.67-2.05). Family size was positively associated with owning firewood stoves, perhaps owing to increased household energy demands. With respect to LPG context, households reporting to get LPG delivered had lower odds of having a firewood stove (OR (95% CI): 0.69 (0.43-1.11). And yet, constant LPG availability, years of LPG use, and the age of the primary cook were not associated with the ownership of firewood stoves.

Overall LPG use (kilograms per capita per month) was positively associated with having an older primary cook, a woman decision-maker, and reported years of cooking with LPG, but not significantly associated with education achievement or LPG context variables like the availability of delivery or reported price changes.

Among those with access to induction stoves, induction owners were more educated than non-owners. When the primary cook had completed secondary school, households had 6.57 times higher odds (95% CI: 1.44-30.04) of having an induction stove when the primary cook had completed secondary school as compared to no formal education. In addition, age of the primary cook and women’s participation in decision-making was positively associated with owning and induction stove.

3.6.1 Community-level patterns of cooking fuel access and use—Following common practice in the literature (e.g., Ahmad & Puppim de Oliveira, 2015; Cheng & Urpelainen, 2014; Farsi, Filippini, & Pachauri, 2007), we controlled for potential uncontrolled spatial confounding by including indicator variables for study communities. In doing so, we are able to better estimate the effect of covariates across multiple contexts – both the regional geographic factors described previously but also cultural patterns that vary at the community-level. Yet, this broader context of household energy decision-making, including infrastructure, fuel accessibility, and climate, is important in its own right and merits further discussion; we elaborate fully on this topic in Supporting Information Section 2.2.

Briefly, Andean peri-urban communities shared a nearly 30-year history of access to both LPG and electricity, with steady and below-average LPG prices with multiple cylinder delivery opportunities each week for over 90% of households. Both parishes had relatively low levels of firewood use. Non-cooking uses of biomass like space heating, heating water for bathing, and cooking for animals were common among biomass users in Calpi (Chimborazo), representing a recent transition from rural to peri-urban area and a response to cold climate. In addition, households in the more consolidated urban area of Machachi (Pichincha) had lower average consumption of LPG and spent fewer hours cooking (15% of households reported cooking only once daily) than those of Calpi, potentially reflecting both dietary and lifestyle changes.

Meanwhile, the Andean rural parishes of Licto (Chimborazo) and La Merced (Pichincha) showed greater variation in fuel use and choices than their peri-urban counterparts. While both parishes share similar historical access to LPG and electricity, Licto had higher levels of regular biomass cooking and fewer induction-owning and induction-using households. These observed fuel use variations, and Licto's higher consumption of LPG, may be explained by greater dietary dependence on traditional energy-intensive dishes in the more heavily indigenous communities of Chimborazo, both rural and peri-urban. Additionally, climate factors likely play a role, as secondary biomass use for space heating was three times more common in Licto than in La Merced. Whereas 13% of participants in La Merced made weekly or more frequent use of induction stoves, Licto's low overall induction ownership (3%) is common throughout Chimborazo province, where political opposition likely predisposed residents to resist any government-sponsored fuel transition.

While more than 75% of respondents in both parishes in Chimborazo province affirmed the cultural necessity for biomass cooking, the significant drop in usage between the rural and urban area in biomass prevalence, frequency, and fuel consumption do not appear to respond to biomass access, but rather to the convenience of LPG. Calpi's high LPG consumption may indicate the replacement of biomass without significant dietary changes, and without significant changes in the recognition of biomass cooking's health risks.

In the Coastal region, peri-urban parishes displayed many similarities: frequent LPG access and delivery availability, relatively rare firewood use (24% in Jama and 15% in San Mateo), and limited induction ownership. Coastal rural study parishes were among the studies' most isolated. Still, most households San Gregorio (Esmeraldas) had LPG delivery available to them; however, distribution costs resulted in higher prices and greater price variability. In contrast, the better-connected communities of Alajuela (Manabí) were unexpectedly the only area studied where LPG delivery was not available to a majority of homes. While the frequency of LPG access remained high and cylinder costs low, participants without household delivery traveled over 2 km on average to acquire LPG, many making the trip on foot or with a pack animal. While the lack of last-mile truck distribution for cylinders led to reduced monetary expenses, the additional time invested in travel for LPG acquisition may have motivated greater reliance on other cooking fuels. In this same community (Alajuela), half of participants reported firewood use, with one-third using it at least weekly. In the central coastal region, local culinary habits and preferences have a high focus on cooking with firewood to achieve the desired and expected smoky flavor. In addition, firewood met household needs beyond cooking, primarily heating water to bathe (26%) and cooking food for animals (33%) in both parishes.

Induction stove ownership in the coastal region was extremely low (3%). Further induction penetration may be limited by the prevalence of informal grid connections (31%), insufficient grid infrastructure in some communities, and concerns about frequent blackouts interrupting cooking activities. One-quarter of households in Alajuela and four-fifths of households in in San Gregorio reported a blackout lasting longer than one hour in the previous month. Indeed, while around half of households across other regions thought that induction stoves would be used by future generations, only one-quarter of participants thought that induction stoves were going to be used by future generations in Esmeraldas. Intuitively, these communities had relatively few induction stove users and non-users had strong perceptions that induction stoves were difficult and expensive to acquire and use. These results suggest that a focus on clear information and infrastructure may facilitate the expansion of induction into these communities.

4. Discussion

Nearly all Ecuadorian households cook primarily with LPG to meet their daily cooking needs, benefitting from 40 years of direct consumer subsidies that have led to among the lowest LPG costs in the world (Range: 0.11–0.33 USD/kg; Mean: 0.20 USD/kg including distribution costs). As evidenced in the case of Ecuador, persistent subsidies for a largely imported fuel can incur a high fiscal burden and can be a political liability with limited options for removal or reduction (Gould et al., 2018a). And yet, Ecuador's nationwide transition suggests that clean fuel subsidies may have major public health benefits. Yet, households must largely cease to use biomass fuels for routine cooking tasks to meet health-based household air pollution targets and obtain the suggested benefits of clean cooking (Johnson and Chiang, 2015). Indeed, the Pan-American Heath Organization has established the goal of eliminating the use of all polluting cooking fuels (solid fuels and kerosene) in the region (Soares da Silva and Smith, 2019). In this light, while we show that LPG is popular and used frequently, the many Ecuadorians living in rural and peri-urban communities who continue to use their traditional biomass stoves for cooking and non-cooking tasks bring the health benefits of the subsidy program into question.

Despite a well-developed and robust LPG market leading to low cylinder costs and high accessibility, we find that 51% of rural (59% in the Andean region and 43% of in the Coastal region) and 19% of peri-urban study participants use firewood to meet some of their household energy needs. Nearly all of these participants (96%) reported using firewood for cooking. We estimate that between 11%–33% of all households in each study province use firewood at least occasionally for cooking, totaling an estimated 250,000 households across these four provinces. Compared to the 2010 national census, which reports only primary cooking fuel use, our estimates represent between a 15% (Chimborazo) and 400% (Pichincha) increase in the prevalence of firewood combustion for cooking. Future work will report on the air pollution exposure implications of this continued firewood use.

Firewood-users reported using their traditional stoves to cook energy-intensive staples like potatoes, grains, and soups, as well as to grill meats and fish in the Coastal region. Non-cooking firewood uses were prevalent as well, but generally concurrent with cooking: space heating in the Andean region (33%) and heating water to bathe (22%) and cooking food for animals (24%) in both regions. On average, firewood users were poorer, less educated, and had more household members than non-users. Furthermore, we also observed that study communities within geographic sub-regions had distinct cooking fuel mixes. In total, 60% of firewood-using participants reported at least weekly use and 20% reported daily use. As countries around the world consider LPG subsidies as a policy measure to promote clean cooking to reap the benefits of transitions away from solid fuels, we show that traditional cooking practices have a continued presence in peri-urban and rural households and cautiously suggest that even aggressive LPG policies may have their benefits curbed by minimal traditional cooking cessation, requiring additional, targeted social interventions to fully displace traditional fuels.

We show that Ecuador's effort to promote induction stoves has not made substantial inroads in peri-urban and rural regions of the country. An ongoing study by the project team is evaluating patterns of induction adoption and use in urban areas. As we discussed previously, PEC and its promise of widespread induction stove use was a response to the political and economic liability posed by the LPG subsidy's high costs—between 300–700 million USD each year or 1% of the national GDP for the last decade (Gould et al., 2018a). While national-level induction ownership has reached 620,000 (14% of all households) (Agencia de Regulación y Control de Electricidad [Electricity Regulation and Control Agency], 2019b), less than 10% of study participants had an induction stove and 25%-40% of owners did not use the stove at all either because the needed electricity connections had not yet been installed, the stove had broken, or due to fear of high electricity costs. When used at all, induction stoves were primarily a secondary option to cooking with LPG used for small tasks like preparing coffee or tea because users perceived induction stoves to be both too expensive and too fragile for frequent use. Compounding these perceptions, half of participants were unaware of key PEC electricity subsidies.

This study has some limitations. Our sampling scheme was budget-limited and favored rural communities. Still, we estimated cooking patterns in both peri-urban and rural households in four provinces in both the Andean and Coastal regions, greatly expanding on our previous case study which was limited to rural households in one province. At the same time, we recognize that Ecuador has experienced rapid urbanization—as have many similar middle-income countries—suggesting that our findings are not nationally representative, and providing motivation for future surveying in peri-urban and urban areas.

An additional limitation is that we estimate LPG consumption based on self-reported data regarding the frequency of cylinder refills. This estimate could be subject to potential reporting bias as well as including alternative LPG uses, like water heating or commercial cooking, though these cases were very limited in number (fewer than 10 total). Future studies might investigate the magnitude and direction of these biases, perhaps by prospectively collecting information on refills, using stove use monitors, or pairing official refill records with self-reported data. However, the median annual per capita LPG consumption estimated in this study (45 kg/person/year) is similar to our previous analysis of nationally-representative expenditure data (poorest income quintile median: 36 kg/person/year; second poorest income quintile median: 45 kg/person/year; middle income quintile: 60 kg/person/year) .

Still, our findings have great importance for other countries that may seek to enable nationwide household transitions to clean cooking fuel use. We show with great clarity that non-urban households will use a clean cooking fuel substantially and with great satisfaction but that the cessation of traditional cooking practices is not a direct product of clean cooking fuel availability or use, especially where monetary-cost-free biomass fuel is easily available. In addition, we note that while there is evidence that the purported benefits of clean cooking fuel use are limited when paired with continued traditional cooking, we have not directly evaluated personal air pollution exposure in study households, household air pollutant emissions, or local environmental changes. Finally, our cross-sectional study design has limitations in analyzing dynamic fuel stacking. While we do characterize the extent of multiple fuel use and season-specific cooking practices our discussion of seasonal and infrequent fuel use may suffer from recall bias. Future studies with multiple survey rounds in different seasons may better elucidate seasonal fuel consumption, as has been carried out elsewhere (Lam et al., 2017).

We make important contributions to the literature by discussing fuel stacking patterns after a long-standing LPG subsidy—a policy mechanism commonly discussed as a way to facilitate nationwide transitions to clean cooking fuels. Household cooking fuel use patterns in Ecuador are instructive for many countries around the world because of the country's diverse climates and cooking styles, long-standing clean cooking fuel policies, robust LPG cylinder market using a standardized cylinder recirculation model, and promotion of induction stoves. Furthermore, PEC is the first of its kind as a nationwide program promoting induction stoves in a middle-income country.

5. Conclusion and Policy Implications

Few middle-income countries share Ecuador's lengthy history of clean cooking fuel subsidies; and none have undertaken its effort to promote induction, a technology considered the gold standard for cooking based on its energy efficiency, zero household air pollutant emissions, and, in Ecuador, electricity generated from predominately hydroelectric power (Goldemberg et al., 2018; Smith, 2015).

While firewood was commonly used as a secondary fuel for cooking and for non-cooking tasks among rural households, the results of this study do demonstrate promising trends. Younger and more educated cooks had lower odds of cooking with firewood, opting instead to use LPG exclusively like the majority of peri-urban households. Rather than simply poverty, we suggest that firewood persists in household cooking fuel mixes as a traditional cooking practice and to meet specific household energy needs. Therefore, particularly for rural families, greater wealth does not imply shifts away from traditional cooking. Climatic factors also play a role—firewood for space heating was common in Andean communities, resulting in more frequent all-purpose firewood use than in warm-climate Coastal areas. We suggest that locally-tailored clean energy interventions that respond to household energy uses may have more success at eliminating solid fuel use and be less costly than nationwide universal clean cooking fuel subsidies. In addition, whereas clean cooking policies in Ecuador have historically lacked messaging about the benefits of clean cooking fuels, recent studies have shown that health messaging can be successful in promoting traditional cooking cessation under conditions of low-cost or free LPG and high accessibility (Pillarisetti et al., 2019).

PEC has fallen far short of its goal of 3.5 million households using induction by 2018. While this goal may have been overambitious given the continued LPG subsidy, we show that shortfalls of implementation have also limited shifts in cooking practice in peri-urban and rural households. Implementation of infrastructure by local electric utility contractors and private electricians appears to have lagged behind induction acquisition, evidenced by households owning induction stoves but not yet having their promised 220V connections installed. In addition, we suggest that communication of the program's aims is critical and may be an additional opportunity to also communicate the potential harms of traditional firewood cooking to help create new social norms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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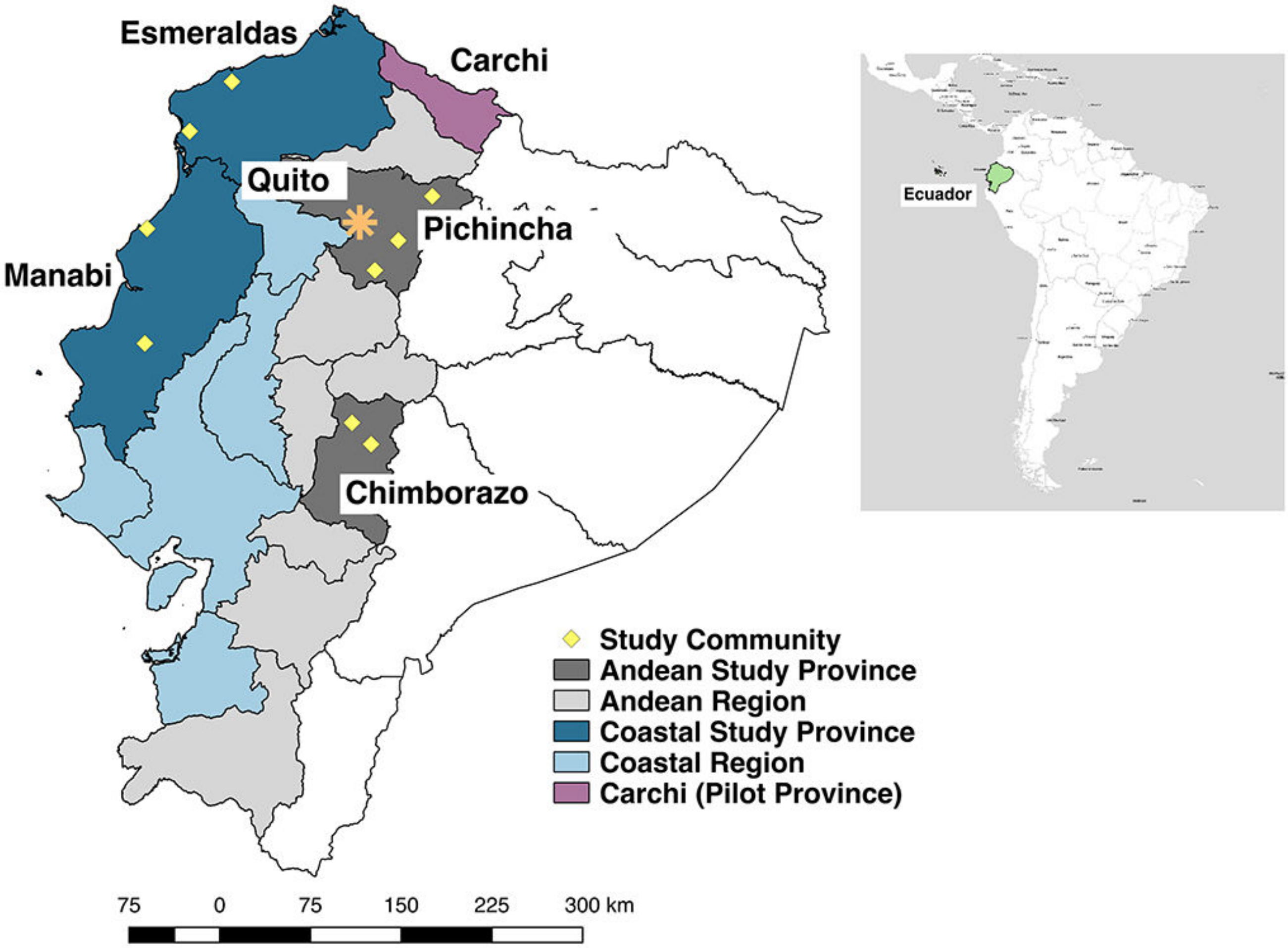

Fig. 1.
Map of study provinces and communities in Ecuador.

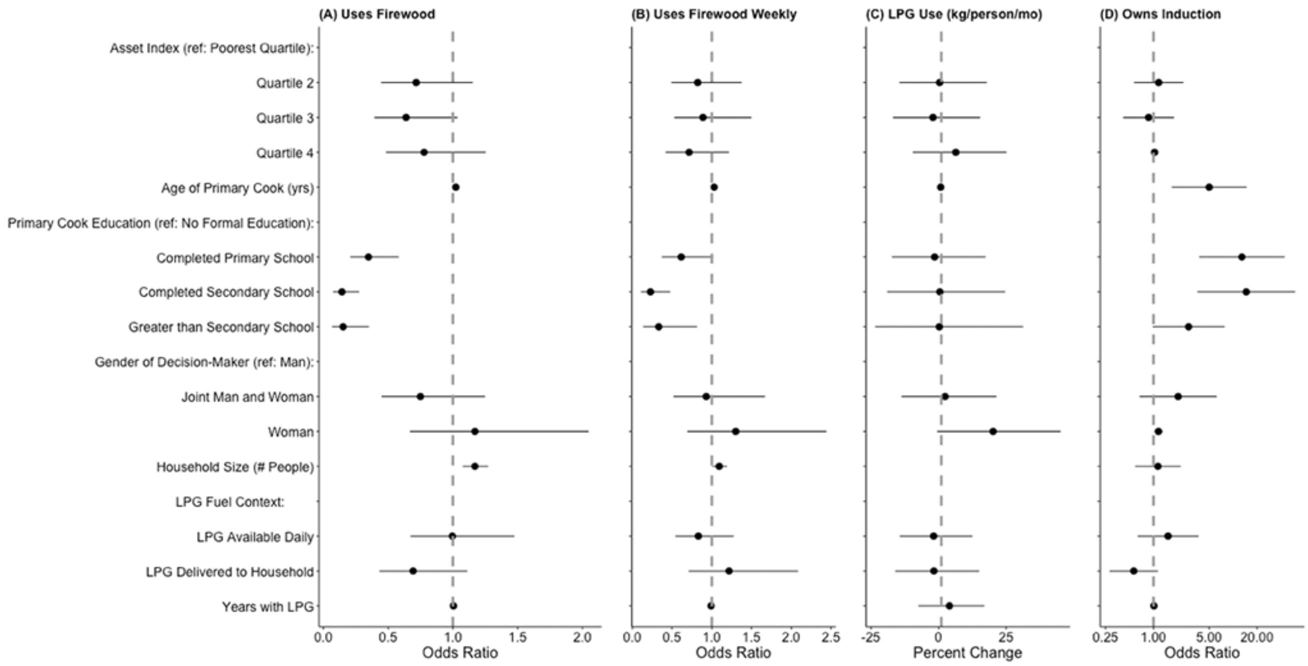

Fig. 2.

Estimates and 95% confidence intervals for associations between household and LPG fuel context characteristics and measures of cooking fuel use. In addition to the covariates shown, all regressions account for community characteristics through dummy variables (shown in Fig. S7). In (C), household size has been omitted because the outcome LPG kg/person/month has been standardized to household size. In (D), observations from Cangahua have been removed because there was no access to induction stoves at the time.

Table 1.

Summarizing study parishes and communities

Parish	Province	Population[a]	Community Types	Climate[b]	Access to Major City	Economic Activity
				Andean		
Rural						
La Merced	Pichincha	8400	Multiple low-density neighborhoods close to main road. Many dispersed households up to 30 minutes from community center.	Temperate and dry. Occasional showers and thunderstorms. 7°C - 23°C. Heating demand for some months.	Increasingly integrated with suburban Quito in last 10 years.	Most people are part of Quito´s workforce but may maintain agricultural production for household consumption or additional income.
Cangahua	Pichincha	16200	Small low-density central neighborhood. Many dispersed households up to 30 minutes away from community center.	Cold, harsh, highlands climate. 5°C - 15°C. Heating demand for many months.	Access to major highway via paved road; 20 minutes from Cayambe city (100,000 people).	Agriculture (mostly onions)
Ayora	Pichincha	11250	Several low- density neighborhoods close to major highway. Many dispersed households up to 30 minutes away from community center.	Cold nights, cool mornings and afternoons. 7°C - 19°C. Heating demand for some months.	Highly dispersed community, some areas are integrated with Cayambe city and located on a major highway.	Agriculture and animal husbandry. Extensive production of roses and other flowers on industrial-scale farms.
Licto	Chimborazo	7800	Few low-density neighborhoods around central market. Some distant households.	Cold nights, cool mornings and afternoons. 7°C - 20°C. Heating demand for some months.	Low-frequency but consistent bus access to market/urban centers	Sheep and pig farming. Agriculture (potatoes, corn, other grains)
Peri-Urban						
Machachi	Pichincha	27600	Densely populated parish center with very few low-density neighborhoods in surrounding highlands.	Temperate in town center, highland neighborhoods have cold nights, cool days. 6°C - 19°C Heating demand for some months.	Has historically been a major population center itself. Located on a major highway, 20 minutes from suburban Quito	Commerce, agriculture and cattle farming. Some people are part of Quito´s workforce.
Calpi	Chimborazo	6500	Multiple low-density neighborhoods.	Cold, harsh, highlands climate 4°C - 15°C. Heating demand for many months.	Recent transition from rural to Peri-Urban through spread of Riobamba (150,000 people). Located on a major highway that links the Andes to the coast.	Tourism. Agriculture (potatoes, corn, apples, peaches, other fruits)
				Coastal		
Rural						
Alhajuela	Manabí	3800	Homes grouped along roads. Some remote households without vehicle access.	Hot throughout the year. Dry most of the year, except for short rainy season. 19°C - 30°C. No heating demand.	Access to major highway via paved roads. 30 mins from Portoviejo (220,000 people).	Agriculture (cacao, citrus, plantain other fruit).
San Gregorio	Esmeraldas	5900	20-100 homes grouped around public area. Some remote households without vehicle access.	Hot throughout the year. Dry and rainy seasons. 22°C - 29°C. No heating demand.	Little access to major cities (10-20 km from highway via dirt roads). Inaccessible during heavy rains.	Agriculture focused on cacao, some employment from agro-business (shrimp farms + oil palm)

Parish	Province	Population[a]	Community Types	Climate[b]	Access to Major City	Economic Activity
Peri-Urban						
Jama	Manabí	23000	Multiple low-density neighborhoods around central market.	Hot and dry throughout the year. 21°C - 29°C. No heating demand.	Locally important population center due to far distance to nearest major city (50 km).	Small banana farms. Some shrimp farms.
San Mateo	Esmeraldas	5700	Densely populated parish center with very few low-density neighborhoods in neighboring valleys	Hot throughout the year. Dry and rainy seasons. 22°C - 29°C. No heating demand.	20 minutes via paved road from Esmeraldas, (170,000 people) but recent highway development has reduced traffic through San Mateo.	Most people are part of Esmeraldas' workforce. Limited agriculture.

[a]Data come from the Ecuadorian National Institute of Statistics and Census 2018 population estimates (Instituto Nacional de Estadistica y Censos [National Institute of Statistics and Census] et al., 2019). For parishes with multiple small communities, population estimates may over- or under-estimate the size of study communities. These discrepancies are noted in the column "Community Types."

[b]Temperature indicates range of average daily temperatures throughout the year from Climate-Data.org (Climate-Data, 2019).

Table 2.

Descriptive statistics of study households

Characteristic	Andean Peri-Urban (N=133)	Andean Rural (N=280)	Coastal Peri-Urban (N=144)	Coastal Rural (N=251)	P-value[a]
	Primary Cook Characteristics				
Age, Mean (SD)	48.0 (18.0)	43.5 (16.0)	43.9 (17.3)	43.9 (17.6)	0.074
Household Position, N (%)					< 0.001
Head of household	60 (45%)	144 (51%)	67 (47%)	111 (44%)	
Partner of head of household	39 (30%)	103 (37%)	51 (35%)	111 (44%)	
Parent of head of household	10 (8%)	7 (2%)	12 (8%)	11 (4%)	
Child of head of household	13 (10%)	18 (6%)	7 (5%)	16 (6%)	
Other	10 (8%)	8 (3%)	7 (5%)	1 (0%)	
Civil Status, N (%)					0.095
Single	36 (27%)	57 (20%)	50 (35%)	79 (31%)	
Married	76 (58%)	183 (65%)	76 (53%)	144 (57%)	
Divorced	6 (5%)	17 (6%)	7 (5%)	11 (4%)	
Widowed	14 (11%)	23 (8%)	11 (8%)	17 (7%)	
Literate, N (%)	121 (92%)	223 (80%)	127 (88%)	210 (84%)	0.008
Education Level Completed, N (%)					< 0.001
No formal education completed	11 (8%)	58 (21%)	15 (10%)	46 (18%)	
Primary	37 (28%)	96 (34%)	51 (35%)	106 (42%)	
Part of secondary	18 (14%)	39 (14%)	24 (17%)	41 (16%)	
Secondary	35 (27%)	63 (22%)	45 (31%)	46 (18%)	
Greater than secondary	31 (23%)	24 (9%)	9 (6%)	11 (4%)	
	Household Characteristics				
Household Head Education, N (%)					< 0.001
No formal education completed	4 (5%)	27 (16%)	11 (14%)	33 (24%)	
Primary	30 (38%)	76 (45%)	36 (45%)	64 (47%)	
Part of secondary	8 (10%)	19 (11%)	14 (18%)	15 (11%)	
Secondary	23 (29%)	33 (20%)	13 (16%)	18 (13%)	
Greater than secondary	14 (18%)	13 (8%)	6 (8%)	5 (4%)	

	Andean		Coastal		
Characteristic	**Peri-Urban (N=133)**	**Rural (N=280)**	**Peri-Urban (N=144)**	**Rural (N=251)**	**P-value**[a]
Household Composition					
# Adults (>18 years), Mean (SD)	2.9 (1.3)	2.7 (1.3)	2.9 (1.6)	2.6 (1.4)	0.018
# Children (5-18 years), Mean (SD)	1.0 (1.2)	1.3 (1.4)	1.4 (1.6)	1.3 (1.5)	0.120
# Infants (<5 years), Mean (SD)	0.4 (0.8)	0.4 (0.6)	0.5 (0.8)	0.5 (0.8)	0.250
Household Decision Maker, N (%)					< 0.001
Woman Household Head	32 (24%)	72 (26%)	50 (35%)	52 (21%)	
Man Household Head	13 (10%)	13 (5%)	29 (20%)	68 (27%)	
Joint	86 (66%)	195 (70%)	65 (45%)	131 (52%)	
Electricity Connection, N (%)					< 0.001
None	0 (0%)	3 (1%)	0 (0%)	2 (1%)	
Formal grid connection with electricity company	128 (97%)	272 (98%)	124 (87%)	171 (68%)	
Personal, informal grid connection	3 (2%)	3 (1%)	16 (11%)	77 (31%)	
Other	1 (1%)	0 (0%)	3 (2%)	1 (0%)	
Years of grid electricity, Mean (SD)	30.3 (13.7)	24.4 (12.5)	23.1 (17.0)	16.7 (12.6)	< 0.001

[a]For continuous variables P-Value refers to results from a linear model ANOVA and for categorical variables results from a Pearson's Chi-squared test.

Table 3.

Distribution of cooking fuel use and fuel stacking patterns

	Andean		Coastal		
	Peri-Urban (N=133)	**Rural (N=280)**	**Peri-Urban (N=144)**	**Rural (N=251)**	**P-value**[a]
LPG Primary, N (%)					
Exclusive	98 (74%)	100 (36%)	94 (66%)	138 (55%)	< 0.001
Firewood	26 (20%)	140 (50%)	22 (15%)	104 (41%)	< 0.001
Induction	5 (4%)	12 (4%)	24 (17%)	4 (2%)	< 0.001
Firewood & Induction	3 (2%)	16 (6%)	1 (1%)	3 (1%)	0.004
Firewood Primary,[b] N (%)					
Exclusive	0 (0%)	6 (2%)	0 (0%)	1 (0%)	0.039
Induction	0 (0%)	2 (1%)	0 (0%)	1 (0%)	0.589
Induction Primary, N (%)					
Exclusive	1 (1%)	3 (1%)	2 (1%)	0 (0%)	0.377
Daily Cooking Time, N (%)					< 0.001
<1 hour	5 (4%)	24 (9%)	2 (1%)	6 (2%)	
1-2 hours	67 (51%)	146 (53%)	55 (38%)	93 (37%)	
2-3 hours	46 (35%)	83 (30%)	73 (51%)	131 (52%)	
>3 hours	14 (11%)	25 (9%)	13 (9%)	20 (8%)	

[a]For continuous variables P-Value refers to results from a linear model ANOVA and for categorical variables results from a Pearson's Chi-squared test.

[b]No households reported to cook primarily with firewood with LPG as a secondary option.

Table 4.

Summarizing LPG use, costs, and access in study households

	Andean		Coastal		
	Peri-Urban (N=133)	Rural (N=280)	Peri-Urban (N=144)	Rural (N=251)	P-value[a]
Owns LPG, N (%)	132 (99%)	269 (96%)	142 (99%)	249 (99%)	0.035
Years with LPG, Mean (SD)	27.9 (12.8)	22.8 (12.0)	25.4 (12.8)	19.0 (10.3)	< 0.001
LPG Cylinder Cost (USD), Mean (SD)	2.80 (0.42)	3.23 (0.45)	3.28 (0.41)	2.94 (0.76)	< 0.001
Frequency of LPG Use, N (%)[b]					0.378
Multiple times a day	120 (92%)	245 (92%)	134 (94%)	234 (96%)	
Once a day	10 (8%)	17 (6%)	8 (6%)	8 (3%)	
2-7 times a week	0 (0%)	3 (1%)	0 (0%)	2 (1%)	
Once per week	0 (0%)	2 (1%)	0 (0%)	0 (0%)	
Less than once per week	0 (0%)	0 (0%)	0 (0%)	1 (0%)	
Cylinder duration (weeks), Mean (SD)	4.5 (3.0)	4.8 (2.4)	4.4 (1.6)	4.0 (1.7)	0.003
LPG used (kg/person/year), Mean (SD)	64.2 (53.7)	57.7 (42.1)	54.7 (34.1)	67.9 (50.1)	0.022
LPG Available for Purchase, N (%)					< 0.001
Every day, whenever I want	110 (83%)	131 (49%)	15 (11%)	72 (29%)	
2-6 times a week	11 (8%)	78 (29%)	71 (50%)	41 (17%)	
Once per week	7 (5%)	29 (11%)	29 (20%)	71 (29%)	
Twice a month	2 (2%)	12 (5%)	22 (15%)	39 (16%)	
Once a month	1 (1%)	4 (2%)	2 (1%)	19 (8%)	
Irregular	1 (1%)	12 (5%)	3 (2%)	6 (2%)	
Direct LPG Delivery, N (%)					< 0.001
No	1 (1%)	12 (4%)	3 (2%)	79 (32%)	
Yes	117 (89%)	231 (86%)	123 (87%)	114 (46%)	
Yes, but I don't buy that way	13 (10%)	23 (9%)	12 (8%)	34 (14%)	
Yes, but infrequently or only during certain times of year	1 (1%)	3 (1%)	4 (3%)	22 (9%)	
Distance to get LPG (km), Mean (SD)	1.8 (1.8)	2.6 (3.9)	3.6 (7.0)	3.0 (3.8)	0.571
Transportation to get LPG, N (%)					< 0.001
Walk	4 (27%)	18 (47%)	11 (58%)	56 (41%)	

	Andean		Coastal		
	Peri-Urban (N=133)	Rural (N=280)	Peri-Urban (N=144)	Rural (N=251)	P-value[a]
Bus	0 (0%)	1 (3%)	0 (0%)	1 (1%)	
Taxi	2 (13%)	8 (21%)	1 (5%)	57 (42%)	
Mule or another animal	0 (0%)	0 (0%)	0 (0%)	4 (3%)	
Personal vehicle	9 (60%)	8 (21%)	6 (32%)	15 (11%)	
Other	0 (0%)	3 (8%)	1 (5%)	2 (1%)	

[a]For continuous variables P-Value refers to results from a linear model ANOVA and for categorical variables results from a Pearson's Chi-squared test.

[b]Percent here, and for all below, refers to the fraction of LPG-owners reporting each aspect of their LPG use context.

Table 5.

Summarizing firewood use in study households

	Andean		Coastal		
	Peri-Urban (N=133)	**Rural (N=280)**	**Peri-Urban (N=144)**	**Rural (N=251)**	**P-value**[a]
Uses firewood, N (%)	29 (22%)	164 (59%)	23 (16%)	109 (43%)	< 0.001
Woodstove type, N (%)[b]					0.011
No chimney traditional, inside	7 (24%)	42 (26%)	2 (9%)	13 (12%)	
No chimney traditional, outside[c]	15 (52%)	103 (63%)	20 (87%)	88 (81%)	
Chimney traditional, inside	4 (14%)	9 (6%)	0 (0%)	1 (1%)	
Chimney traditional, outside	2 (7%)	4 (2%)	1 (4%)	4 (4%)	
Improved stove	1 (3%)	5 (3%)	0 (0%)	3 (3%)	
Frequency of use, N (%)					< 0.001
Several times a day	1 (3%)	12 (7%)	2 (9%)	15 (14%)	
Every day	4 (14%)	26 (16%)	3 (13%)	8 (7%)	
2-6 Times a week	4 (14%)	30 (18%)	3 (13%)	27 (25%)	
Once per week	8 (28%)	34 (21%)	4 (17%)	11 (10%)	
Less than once per week	10 (34%)	59 (36%)	9 (39%)	26 (24%)	
Few times a year	2 (7%)	3 (2%)	2 (9%)	21 (19%)	
When do you use firewood?, N (%)					
Morning	NA[d]	NA	4 (17%)	58 (53%)	
Lunch	NA	NA	19 (83%)	83 (76%)	
Dinner	NA	NA	4 (17%)	42 (39%)	
What do you use firewood for?, N (%)					
Cooking for family	25 (86%)	158 (96%)	22 (96%)	106 (97%)	0.068
Heating the home	12 (41%)	52 (32%)	0 (0%)	0 (0%)	< 0.001
Heating water to bathe	6 (21%)	33 (20%)	3 (13%)	28 (26%)	0.513
Cooking food for the animals	7 (24%)	29 (18%)	5 (22%)	38 (35%)	0.014
Total firewood used (kg/wk), Mean (SD)	6.6 (5.0)	8.4 (8.1)	4.0 (3.4)	9.4 (7.5)	0.012
Collection frequency, N (%)					0.001
Every day	0 (0%)	1 (1%)	0 (0%)	2 (2%)	

	Andean		Coastal		
	Peri-Urban (N=133)	Rural (N=280)	Peri-Urban (N=144)	Rural (N=251)	P-value[a]
2-6 Times a week	0 (0%)	11 (7%)	3 (13%)	1 (1%)	
Once per week	7 (24%)	26 (16%)	4 (17%)	26 (24%)	
Less than once per week	13 (45%)	88 (54%)	9 (39%)	75 (69%)	
Never	9 (31%)	38 (23%)	7 (30%)	5 (5%)	
Purchase frequency, N (%)					0.002
Every day	0 (0%)	0 (0%)	1 (4%)	0 (0%)	
2-6 Times a week	1 (3%)	1 (1%)	0 (0%)	0 (0%)	
Once per week	1 (3%)	8 (5%)	1 (4%)	1 (1%)	
Less than once per week	4 (14%)	36 (22%)	6 (26%)	8 (7%)	
Never	23 (79%)	119 (73%)	15 (65%)	99 (92%)	

[a]For continuous variables P-Value refers to results from a linear model ANOVA and for categorical variables results from a Pearson's Chi-squared test.

[b]Percent here, and for all below, refers to the fraction of firewood-users reporting each aspect of their firewood use context.

[c]Stoves were often adjoined to an exterior wall of the household and surrounded by two or three walls in total. In some cases the stove was in an enclosed room in a separate building from the household, or located directly under an elevated house in coastal communities.

[d]NA: These questions were implemented in only Coastal households in response to themes that emerged from surveys in Andean households. As a result of this change, no P-Value is reported for this question.

Table 6.

Induction stoves and context in study households

	Andean		Coastal		
	Peri-Urban (N=133)	Rural (N=280)	Peri-Urban (N=144)	Rural (N=251)	P-value[a]
Has an induction stove, N (%)	9 (7%)	33 (12%)	27 (19%)	8 (3%)	< 0.001
If so, is it your primary stove?, N (%)[b]	1 (11%)	8 (24%)	4 (15%)	4 (50%)	0.480
Frequency of induction stove use, N (%)					
Several times a day	1 (11%)	7 (21%)	6 (22%)	2 (25%)	
Every day	1 (11%)	4 (12%)	1 (4%)	3 (38%)	
2-6 times per week	1 (11%)	2 (6%)	2 (7%)	0 (0%)	
Once per week	1 (11%)	8 (24%)	0 (0%)	0 (0%)	
Less than once a week	5 (44%)	13 (39%)	3 (11%)	1 (12%)	
Never because it doesn't work	NA[c]	NA	3 (11%)	0 (0%)	
Never, for another reason	NA	NA	13 (48%)	2 (25%)	
Induction stove cost (USD), Mean (SD)	558 (191)	602 (225)	623 (239)	666 (184)	0.770
For how long have you had your induction stove? (years), Mean (SD)	2.6 (0.9)	2.2 (1.4)	2.8 (0.9)	2.5 (0.8)	0.426
Where did you get your induction stove?, N (%)					0.131
Somebody came to my home	1 (11%)	12 (36%)	13 (48%)	3 (38%)	
Store in a bigger city	2 (22%)	9 (27%)	3 (11%)	1 (12%)	
Electricity company	4 (44%)	11 (33%)	9 (33%)	4 (50%)	
Family / Friend	2 (22%)	0 (0%)	1 (4%)	0 (0%)	
Other	0 (0%)	1 (3%)	1 (4%)	0 (0%)	
How much time did the process of acquiring induction take, including the paperwork for the line of credit, the installation of the plug and monitor, and getting the subsidy?, N (%)					0.413
< 1 week	3 (33%)	17 (52%)	12 (44%)	3 (38%)	
1-2 weeks	2 (22%)	4 (12%)	5 (19%)	2 (25%)	
3 weeks – 1 month	0 (0%)	4 (12%)	2 (7%)	1 (12%)	
1-3 months	2 (22%)	3 (9%)	1 (4%)	0 (0%)	
>3 months	2 (22%)	5 (15%)	7 (26%)	2 (25%)	
Sources of initial induction stove info, N (%)					0.013
Friend or family	0 (0%)	8 (24%)	0 (0%)	0 (0%)	

	Andean		Coastal		
	Peri-Urban (N=133)	Rural (N=280)	Peri-Urban (N=144)	Rural (N=251)	P-value[a]
Radio advertisement	1 (11%)	2 (6%)	3 (11%)	2 (25%)	
Television advertisement	5 (56%)	24 (73%)	11 (41%)	4 (50%)	
Newspaper advertisement	0 (0%)	0 (0%)	0 (0%)	1 (12%)	
Stand at a fair / door-to-door sales	1 (11%)	17 (52%)	11 (41%)	3 (38%)	

[a]For continuous variables P-Value refers to results from a linear model ANOVA and for categorical variables results from a Pearson's Chi-squared test.

[b]Percent here, and for all below, refers to the fraction of induction-owners reporting each aspect of their induction use context.

[c]NA: These questions were implemented in only Coastal households in response to themes that emerged from surveys in Andean households. As a result of the change, no P-Value is reported for this question.