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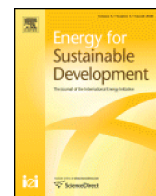
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Government policy, clean fuel access, and persistent fuel stacking in Ecuador[☆]

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ABSTRACT

After more than three decades of access to low-cost liquefied petroleum gas (LPG) financed by large direct government subsidies, >90% of Ecuadorian households cook primarily with LPG. Due to the large fiscal burden of the LPG subsidy, increases in electricity from hydropower, and other socio-political factors, the Government of Ecuador has launched a major induction stove program (PEC) to reduce the demand for LPG. We assess the effects of the LPG subsidies and PEC using government records, interviews, academic literature, newspaper reports, household surveys, and focus groups. Household surveys, conducted in rural, northern Ecuadorian households ($n = 383$), characterized cooking patterns and fuel access. Focus groups ($n = 6$) were carried out with a subset of surveyed households to better characterize survey findings. The LPG subsidy was developed as part of broad social support reforms in the early 1970s, without specific aims to reduce the health impacts of household air pollution from woodfuel or provide economic benefits as part of the transition to a clean cooking fuel. Nonetheless, the subsidy has resulted in nearly all Ecuadorian households cooking primarily with LPG. PEC has generated the sale of 740,000 induction stoves since its inception in 2014, short of the goal of 3.5 million. Among the rural households surveyed, LPG use, acceptance, and satisfaction was high, however, more than three-quarters of those surveyed reported weekly woodfuel use. Induction stove ownership (17%) and use as a primary cooking fuel (1%) was low among the rural households surveyed; furthermore, households owning induction stoves reported very low satisfaction with the stoves. Here we show that nationally-representative surveys reporting only “primary cooking fuel” use may underestimate solid fuel use as a supplemental household cooking energy, particularly in rural areas where fuel availability issues play a stronger role in decisions about what fuels to use.

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Introduction

Ecuador offers a striking example of cooking fuel use dynamics in an emerging middle-income country where significant subsidies for liquefied petroleum gas (LPG) have been provided for nearly 40 years (Troncoso & Soares Da Silva, 2017). Ecuador's experience illustrates

the potential benefits and pitfalls of sustained LPG subsidies. A 15 kg cylinder of LPG currently costs US\$1.60¹ (retail), a price that has not changed since 2001, providing a per-15 kg cylinder subsidy of approximately \$11.50 (Guillén & Robalino, 2016; Ministry of Hydrocarbons of Ecuador, 2015). Approximately 90% of Ecuadorian households now cook primarily with LPG. However, the fiscal burden of the subsidy is large; in 2014, the Government of Ecuador spent US\$716 million (around 1% of GDP) subsidizing national LPG use.

Developed in part to create demand for Ecuador's growing hydroelectric capacity and to address the cost of LPG subsidies, the Ecuadorian government has launched *La Programa de Eficiencia Energética para la Cocción*

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¹ All dollar amounts in manuscript text and figures refer to US Dollars. All prices are current prices (i.e., not inflation adjusted). Ecuador adopted the US Dollar as its official currency in 2000.

(“The program for energy efficient cooking”; PEC), which is built around incentives to install and use induction stoves (Ministry of Electricity and Renewable Energy of Ecuador, 2014). Induction stoves work by passing an alternating current through an electromagnet; the resulting oscillating magnetic field generates heat in any pot made of magnetic material, which then heats the contents of the pot. Induction cookstoves are safe, non-polluting, highly efficient, and have been identified as a potential “leapfrog technology” in settings where biomass cooking is common (Banerjee, Prasad, Rehman, & Gill, 2016; Smith, 2014). PEC includes a consumer credit for stove purchase provided through state electric utilities and overseen by the Ministry of Electricity and Renewable Energy that allows participants to make monthly payments as part of their electricity bill. PEC participants also receive 80 kWh of electricity per month free—an amount projected to cover household cooking for a family of five.

Here, we evaluate the implementation of these policies, and assess the extent to which both the LPG subsidy and PEC have resulted in shifts to clean cooking.

Methods

Drawing on a literature review and interviews with key informants, we describe relevant national background information (*National context and energy trends*) and analyze national data to review patterns of clean fuel use across Ecuador (*Determinants of clean fuel use*). In the sections, *LPG Subsidy (1970s to Present)* and *Induction Stoves Program (2014 to Present)* we provide descriptions and assessments of each program. We then evaluate the actual impacts of the programs on rural households in northern Ecuador using surveys and focus group discussions in the section *Experiences with LPG and induction in rural communities*.

Analysis of nationally representative data

We utilized the decennial census (1974, 1982, 1990, 2001, 2010, and 2014) to characterize the distribution of clean cooking fuel use (National Institute for Statistics and Census of Ecuador, 2017a). To assess the determinants of clean cooking fuel use throughout Ecuador, we analyzed the National Survey of Employment, Unemployment, and Underemployment, a nationally-representative survey with household-level data available every four months from 2007 to 2017 (National Institute for Statistics and Census of Ecuador, 2017b). In this dataset, we dichotomized the outcome variable “primary fuel used for cooking” as clean fuel (i.e., LPG or electricity) or solid fuel (e.g., woodfuel) and included a number of covariates in multivariable logistic regressions: 1) household income (log transformed); 2) rural or urban; 3) poor; 4) extremely poor; 5) household receives government conditional cash transfer (Bono de Desarrollo Humano); 6) household receives remittances; 7) presence of a child <5 years old in the household; 8) presence of a child 5–18 years old; 9) presence of elderly adult (>65 years old) in the household; 10) presence of a female in the household; 11) ethnicity reported as indigenous; and 12) ethnicity reported as afro-Ecuadorian. Separate analyses were conducted using data from two time frames—December 2008 ($n = 17,438$), and combined surveys from December 2015–March 2017 (excluding March and June 2016 due to corrupted data files) ($n = 81,480$)—to compare statistical relationships over time and because the selected surveys included all desired study variables.

Interviews with key informants

We carried out a series of interviews with current and former actors in the LPG and electricity sectors to fill in gaps in the literature and to gain a better understanding of current and historical drivers of LPG subsidies and PEC. The interviews were used to clarify the rationale for public policy decisions and processes. Seven interviews with nine key informants were undertaken in total by one to two researchers

(SS, MT, or CG). Interviews lasted from one to four hours and were not recorded in order to encourage candid responses.

Household surveys

Fieldwork was conducted between August and October 2017 in three rural communities in the northern province of Carchi. We selected Carchi because it was home to a pilot program that promoted induction stoves between 2009 and 2013 (*Plan Fronteras*). The survey obtained information on households' current cooking practices and their perceptions and preferences of different cooking fuel options.

We asked participants to name all stoves and fuels used in an average week, as well as the frequency of use and the meals cooked with each fuel. In addition, participants described the benefits and limitations of each of their stoves. Fuel cost (Beltramo, Blalock, Levine, & Simons, 2015; Puzzolo, Pope, Stanistreet, Rehfuess, & Bruce, 2016), fuel availability (Lewis & Pattanayak, 2012; Puzzolo, Pope, Stanistreet, Rehfuess, & Bruce, 2016), heating demand (Aggarwal & Chandel, 2004; Granderson, Sandhu, Vasquez, Ramirez, & Smith, 2009; Hollada et al., 2017; Simon, Bailis, Baumgartner, Hyman, & Laurent, 2014), and fuel and stove compatibility with local cooking customs (Baumgartner et al., 2011; Terrado, Eitel, McCracken, & Charron, 2005) were studied as barriers to exclusive clean fuel use in household surveys. The survey was pilot tested and refined by the authors and the field team prior to implementation in order to improve clarity and respond to themes that emerged.

Focus group discussions

Following completion of the survey phase (September 2017), focus group discussions were conducted in the same communities to more fully understand knowledge, attitudes, and practices, especially regarding observed multiple cooking fuel use practices. Primary cooks were purposively sampled from surveyed households to elucidate perceptions related to the use of solid fuel, LPG, and induction stoves. We oversampled to include households that had purchased an induction stove through PEC. Focus group discussions were conducted by two researchers and a community liaison. Participants were offered a \$5 cash incentive to cover transportation costs and for their participation.

Focus group discussions were semi-structured and included prompts to elicit an open-ended conversation about fuel use decision-making, barriers to exclusive LPG use, and perceptions of induction stoves. Open-ended questions were included to address economic, cultural, and psychological factors relevant to cooking practices and fuel choices. The focus group guide was pretested with two community members and modified based on feedback to improve clarity, flow, and face validity of the questions.

Focus group discussions were digitally recorded using a handheld device and subsequently transcribed. The analysis, led by one researcher (WW), was based on a three-stop coding procedure to elucidate emergent major dimensions of the focus group discussions (Corbin & Strauss, 1990).

Ethical considerations

This study was reviewed and approved prior to initiation of the research by the Institutional Review Boards (IRB) at the Columbia University Medical Center and the Universidad de San Francisco de Quito. All study participants provided written consent.

Results

National context and energy trends

Ecuador background

Ecuador is an upper middle-income country with a population of about 16 million and a 2016 GDP per capita of just over \$6000.

Approximately 64% of the population lives in cities; this figure is similar to other upper-middle income countries (65%) but lower than the Latin American average (80%). Household access to electricity is high in Ecuador (97%) (The World Bank, 2017).

Petroleum production plays an important role in Ecuador's economy. It is the principal export and, until recently, hydrocarbons dominated energy consumption. Since the 1970s, the Ecuadorian government has maintained a high dependence on oil revenues to support state spending, benefiting from surpluses to obtain low-interest loans during periods of high oil prices. Ecuador has also struggled with deficits and high interest rates during periods of low oil prices (e.g., in the late 1990s, during the 2000 economic crisis, and since the 2015 drop in crude oil prices) (El Universo, 2016). Dependence on oil revenues for government expenditures has contributed to alternating cycles of economic and political stability and instability (International Monetary Fund, 2015). Despite this variability, crude oil production has increased slowly over time. However, significant untapped reserves remain, due in part to limited geographic access, biodiversity considerations, and indigenous land and resource rights (BP, 2016).

Despite substantial hydrocarbon resources, Ecuador is dependent on imports to meet domestic LPG demand (Fig. 1); most of Ecuador's onshore deposits are heavy crude (yielding comparatively little LPG), and offshore natural gas deposits are underdeveloped with limited refining capacity. Historically, LPG was stored on barges near ports, which resulted in higher costs to the government. However, recent investments have increased the country's land-based LPG storage and distribution infrastructure to reduce expenditures (Espín Tobar, 2016; Llanes, 2014).

Ecuador has invested heavily in hydroelectric power over the last decade, building on substantial potential due to its high rainfall and mountainous geography (US Department of Commerce, 2016). If all planned hydroelectric power projects come online as projected, Ecuador will meet 80% of its electricity needs from hydroelectric power. The 1500 MW Coca Codo-Sinclair project (the largest of the eight planned projects) has been operational since November 2016. While the hydroelectric power plant was projected to generate 8734 Gwh in 2017 (approximately 30% of national demand), Coca Codo-Sinclair generated only 5755 GWh over the calendar year

(El Comercio, 2017c; Ministry of Electricity and Renewable Energy of Ecuador, 2017a; Ponce-Jara, Castro, Pelaez-Samaniego, Espinoza-Abad, & Ruiz, 2018). Five smaller plants are currently under construction, but have faced significant setbacks (Heredia, Astudillo, & Velasco, 2017). In addition to major investments in hydroelectric power, the government has recently committed to invest nearly \$1 billion in new transmission lines (El Universo, 2017c; Electricity Corporation of Ecuador, 2017; Ministry of Electricity and Renewable Energy of Ecuador, 2017c).

National trends in fuel use

Previous research on household energy use in Ecuador and estimates of health burdens from household air pollution (Institute for Health Metrics and Evaluation, 2012) have relied on national survey data that collect self-reported primary fuel use only (Gomelsky, 2013; Troncoso & Soares Da Silva, 2017). Here, we describe the extent of clean cooking fuel use over time and space and explore its determinants during two recent time periods.

As a result of national energy policies, urbanization, and overall increases in wealth, the use of LPG as the primary cooking fuel has increased dramatically since the 1970s (Fig. 2) (National Institute for Statistics and Census of Ecuador, 2017a). Kerosene, popular in the 1970s as a cooking fuel, has virtually disappeared. The increase in LPG use, and decline of wood as a primary cooking fuel, first started in Quito and Guayaquil, Ecuador's two largest cities. In rural areas, increases in LPG use and declines in the use of wood occurred later (Fig. 3; Fig. A.1). LPG and wood use trends have nearly leveled off since 2010, which may indicate that cooking practices have stabilized.

The majority of Ecuadorian households purchase one 15-kg cylinder of LPG per month for their cooking needs (Table 1). Data show that wealthier households purchase more LPG per capita each month; a higher fraction of wealthier households purchase two cylinders per month and have smaller household sizes on average as compared to poorer households (Fig. 4). For all households, monthly LPG cylinder expenditures comprise only a small fraction of total household expenditures (median = 0.40%; mean = 0.50%) (see Fig. A.2 for distributions of LPG purchasing patterns and fraction of total expenses). By comparison, electricity expenditures account for between three and five times as much of all monthly household expenditures.

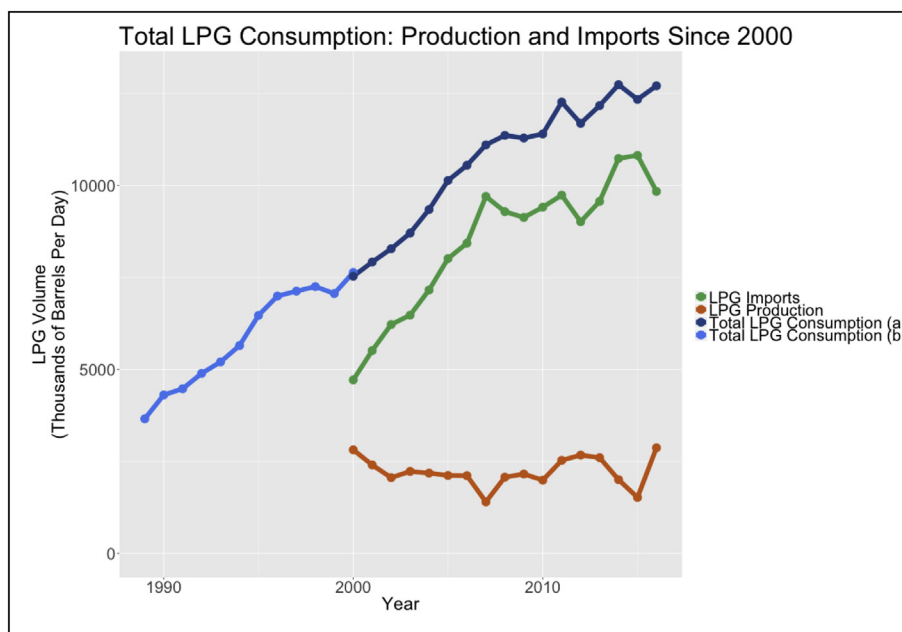


Fig. 1. Ecuador is a major LPG importer. Historical LPG consumption plotted, with descriptions of LPG imports and domestic production shown since 2000. LPG consumption data comes from two sources ((a) Central Bank of Ecuador from (Guillén & Robalino, 2016); (b) 1989–2000 data from *Petroleo al día* (Becerra, 2016)) and all data on imports and domestic production comes from the Central Bank of Ecuador from (Guillén & Robalino, 2016). One barrel equals 159 l.

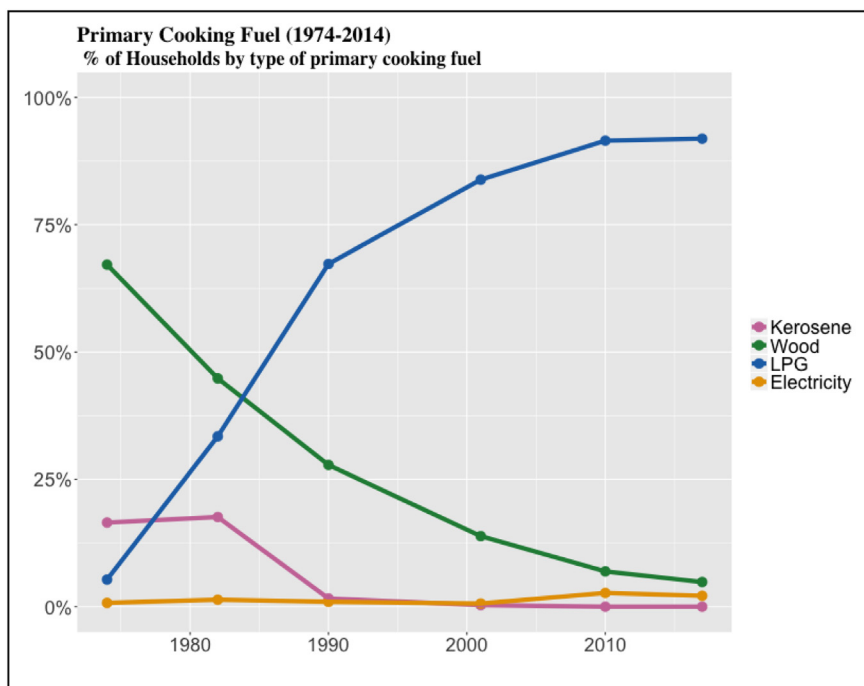


Fig. 2. Proportion of households reporting primary cooking fuel type over time using Census Data from 1974 to 2014.

Determinants of clean fuel use

While the long-term impacts of PEC are not yet clear—it is too soon to obtain an adequate time series from national surveys—we included induction stoves with LPG in the analysis of associations between clean fuel use and sociodemographic factors to capture all clean cooking

fuel use. In both the 2008 and 2015–2017 periods (summary statistics of both samples are available in Table A.1), associations between independent variables and the primary use of clean cooking fuels were in line with findings from past research (e.g., Lewis & Pattanayak, 2012; Puzzolo, Pope, Stanistreet, Rehfuess, & Bruce, 2016). Poverty, rurality, and indigeneity were all negatively associated with the reported use

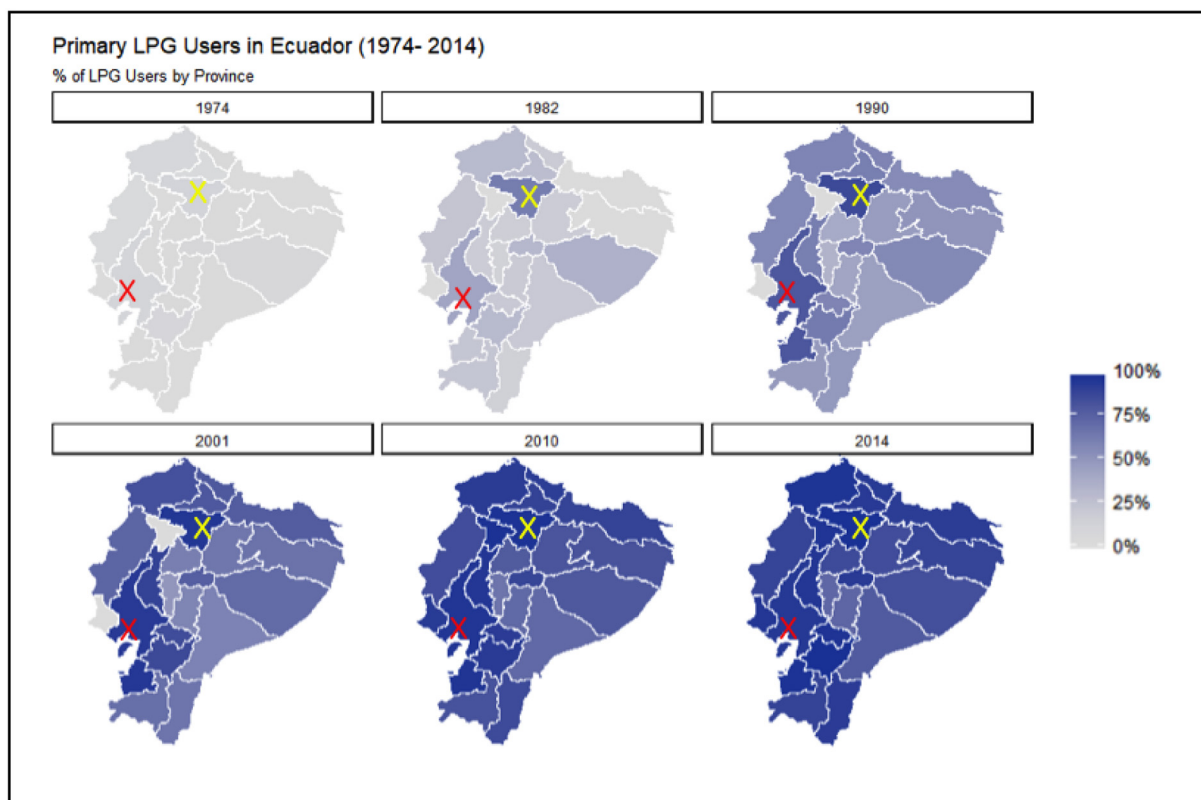


Fig. 3. Proportion of households in each province reporting LPG as primary cooking fuel using Census Data from 1974 to 2014. Xs indicate locations of major urban centers: yellow for Quito and red for Guayaquil.

Table 1
Monthly LPG and electricity purchasing patterns, by quintiles of income^{a,b}.

	N	Monthly expenditures ^c	HH size ^c	One cylinder ^d	Two cylinders ^d	LPG expenditures ^e	Electricity expenditures ^e
Poorest (Q1)	7385	\$399.28	5.11	86.46%	10.79%	0.69%	1.91%
Quintile 2	7622	\$528.89	4.37	84.87%	12.50%	0.49%	1.74%
Quintile 3	7727	\$655.61	3.90	82.65%	14.46%	0.39%	1.64%
Quintile 4	8229	\$839.46	3.42	78.83%	16.88%	0.31%	1.56%
Wealthiest (Q5)	8654	\$1234.39	2.79	70.43%	23.07%	0.22%	1.31%

^a Data come from the 2012 National Incomes and Expenditures Survey.

^b Income quintile breaks occur at: 1 = \$264.17, 2 = \$419.13, 3 = \$625.86, 4 = \$1027.95.

^c Median values are shown.

^d Shows the fraction of households buying exactly one or two cylinders per month, respectively.

^e Shows the percentage of total monthly expenditures dedicated to LPG cylinders and electricity.

of clean cooking fuels, while wealth, the presence of children in the household, and the presence of a female in the household were positively associated with the use of a clean cooking fuel (Fig. 5). While none of the associations changed direction between the two time periods, the strength of associations changed for some of the variables. The negative association with a household being classified as rural was comparatively large in magnitude in both regressions, but diminished substantially in the more recent period. Also, the negative association with the presence of an older adult in the household nearly disappeared in the more recent period.

LPG subsidy (1970s to present)

Beginning as a part of limited social welfare efforts, Ecuador's military government in the 1970s instituted direct consumer subsidies for diesel and gasoline to reduce transportation costs and LPG to provide cheap cooking fuel. As hydrocarbon prices increased (usually there is a

high correlation between crude oil and LPG pricing on the international market), the subsidies increased for all fuels in order to maintain a fixed retail price. As overall LPG consumption increased over the past four decades because of growth in population (2–3% annually (The World Bank, 2017)), per capita use (which has increased since 1990), and fuel access, Ecuador has been unable to produce enough LPG to meet internal demand, forcing the country to rely on more expensive LPG imports. These fuel subsidies are available to all Ecuadorians and are popular around the country. As a result, a key policy of successive governments has been to maintain subsidies for gasoline, diesel, and LPG in order to generate and maintain political capital (Andrade Herrera, 2011). However, managing these fuel subsidies has been a delicate balancing act. Occasional efforts to remove or significantly reduce the subsidy, notably by presidents Abdalá Bucaram in 1996 and Jamil Mahuad in 2000, were met with major public protests. In fact, popular resistance to subsidy removal may have contributed to the removal of both leaders (Andrade Herrera, 2011; Castillo, 2007).

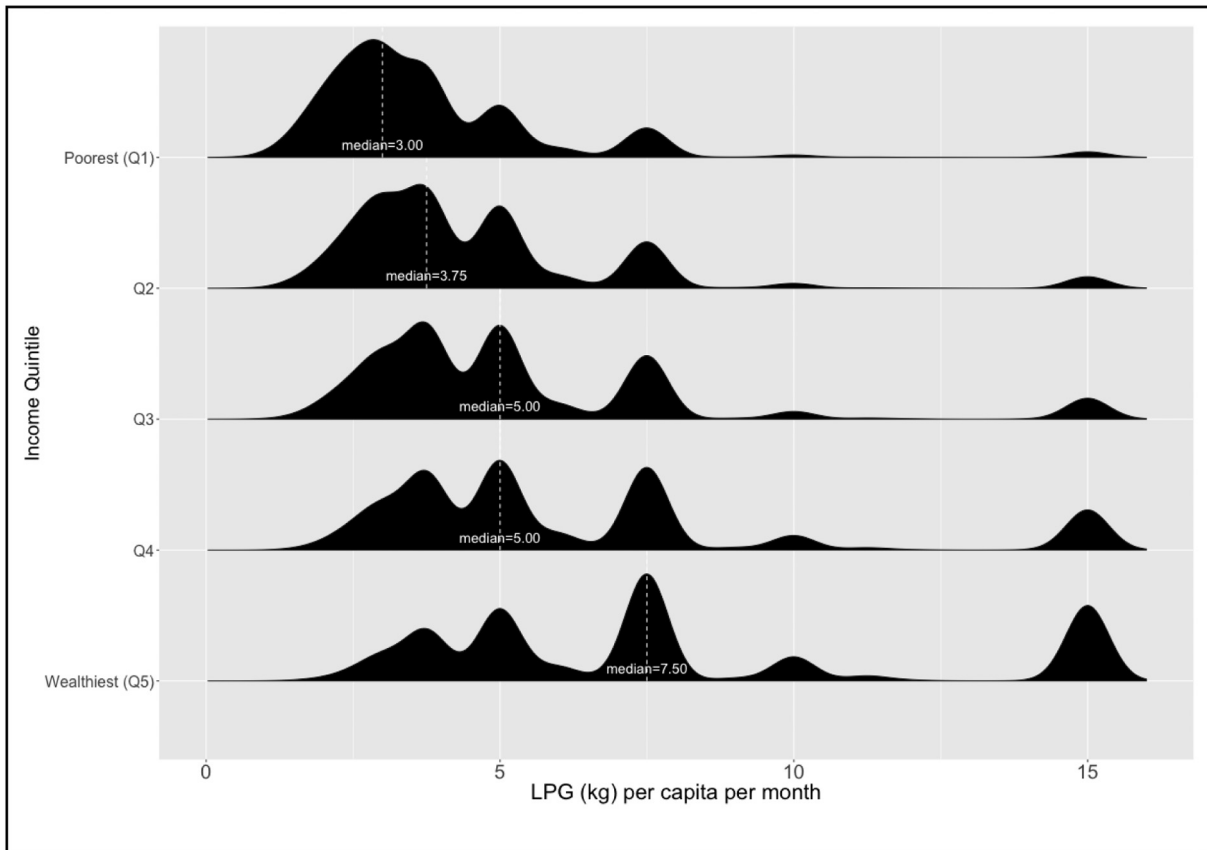


Fig. 4. Density plots of LPG (kg) purchased per capita by income quintiles. Plots truncated at 16 kg/per capita/month but still contribute to the distributions (<0.5% of data not pictured). Data come from the 2012 National Incomes and Expenditures Survey. “Bumps” in the density plot due to the lumpiness of reported purchases of whole 15 kg cylinders being divided by the number of individuals in a household (e.g., 7.5 kg/per capita/month may represent a two-person household that consumes one cylinder per month).

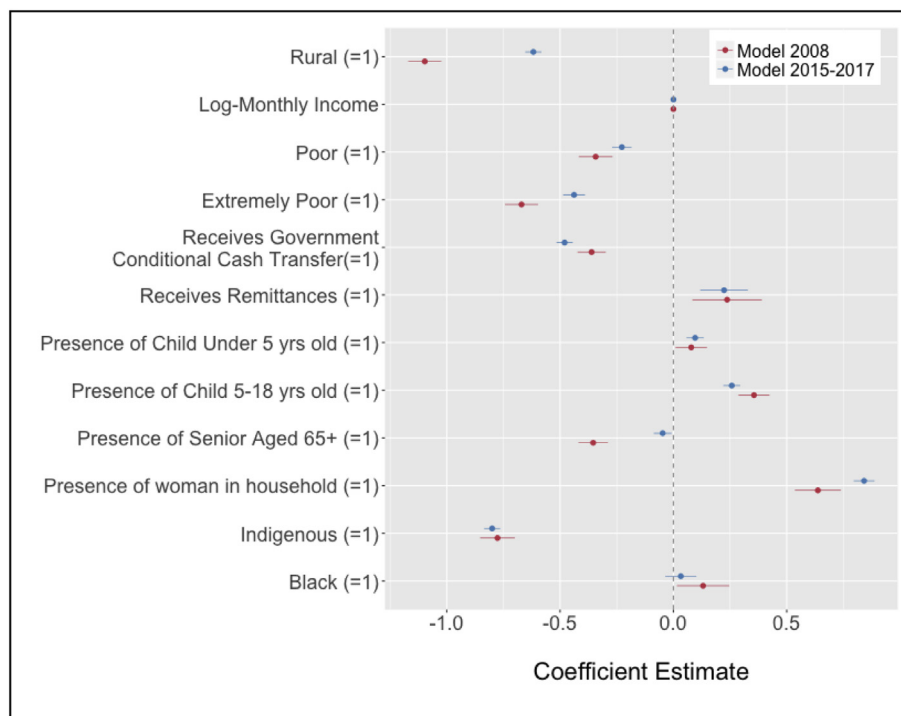


Fig. 5. Coefficients and 95% confidence intervals plotted for 2008 and 2015–2017 probit regressions. Coefficients represent the covariates' association with reported primary clean cooking fuel (LPG or electricity) use in multivariable models. Data come from National Survey of Income and Expenditures.

In addition to cooking, LPG is used in domestic hot water heaters (in an estimated 7% of all households) (Expert in the LPG Industry, 2017), and for some non-household uses. Commercial LPG users are required to pay the full market price for LPG, but leakage of subsidized LPG into the commercial sector is frequently reported (Expert in the LPG Industry, 2017). Furthermore, LPG smuggling to neighboring Peru and Colombia (estimated to be <5% of total volume), and unreported recovery of subsidized tank remnants by distributors (approximately 3–5% of the volume of each 15 kg cylinder) for resale at commercial prices contribute to leakage out of the residential sector (Agency for the Regulation of Hydrocarbons Personnel, 2017; Araujo, 2014a). However, reliable data fully quantifying leakage are not available.

Paralleling growth in total LPG consumption, the burden of Ecuador's LPG subsidy has increased substantially over the past two decades. Volatility in international market prices plays a large role in determining the commercial unsubsidized cost of LPG, which ranged from \$1.65 to \$12.30 per 15 kg cylinder between 1990 and 2015, with year-to-year variations of up to 50% (Fig. 6A). Correspondingly, the total cost of the LPG subsidy has gone from \$60 M in 1990 to an average of \$681 M from 2010 to 2015 (Fig. 6B). Total fuel subsidies accounted for 7% of the national gross domestic product from 2011 to 2013, making Ecuador the second most subsidized energy sector in Latin America (Di Bella, Norton, Ntamungiro, Samaké, & Santoro, 2015). However, at its peak, LPG accounted for only 15% of Ecuador's total fuel subsidies; the remainder go to liquid fuels for transportation (Heredia, 2016).

Following Ecuador's adoption of the US dollar as the national currency in 2000, the price of a subsidized residential 15 kg LPG cylinder was set at \$1.60 and has not changed. Prices to households from distributors range from \$2.50 up to \$5.00 (Fig. A3). Distribution costs are passed on to the consumer and additional transportation costs are borne by residents for cylinder transport from local distributors to households when home delivery is unavailable.

Risks associated with the use of LPG

Substandard installations, corroded stove and cylinder parts, and faulty appliance design, all contribute to the potential dangers

associated with LPG. Substandard installations, particularly for water heaters, have resulted in multiple CO-poisoning cases (El Comercio, 2017a) and may have health effects associated with exposure to high levels of SO₂ and NO_x (Kampa & Castanas, 2008; Perez-Padilla, Schilman, & Riojas-Rodriguez, 2010; World Health Organization, 2017). These problems tend to affect urban households with inline gas water heaters common in high-altitude areas. In addition, Quito's fire department alone reported 1012 residential and business LPG-related incidents (e.g., leaks, explosions) in the first half of 2017, some of which proved fatal (El Comercio, 2017a). While the associated risks of extensive LPG use are significantly reduced with proper installation (Official in the Society of Petroleum Engineers, Ecuador Branch, 2017), the economic advantages of illegal appropriation of subsidized residential-use cylinders for commercial use often involves precarious installations, with occasionally disastrous results (El Comercio, 2017b). Concerns about gas leaks and explosions are common in political discourse and in public dialogue.

Induction stoves program (2014 to present)

A national-level induction stoves program began in mid-2014, following pilot efforts to introduce induction stoves in northern Ecuador (2009–13). PEC aims to reduce government expenditures on LPG subsidies in a politically palatable manner and create new sources of electricity consumption for new hydroelectric projects. The initial program target was 3.5 million households (>80% of all households) using induction cookstoves by 2018. However, induction stove adoption through PEC has lagged behind initial government estimates, reaching 740,000 stoves purchased by the end of 2017. Overall program growth has been generally linear since 2014, with Quito and Guayaquil, and surrounding suburban areas, responsible for much of the overall induction stove uptake (Figs. A4–5). Yet, recent reports indicate that induction stove sales fell in 2017, while LPG cylinder purchases increased (Serrano, 2018). In response to lower-than-projected induction stove growth, the program target has recently been adjusted to 3.5 million households by 2023. PEC now looks to be a slow growing, consumer-driven program with

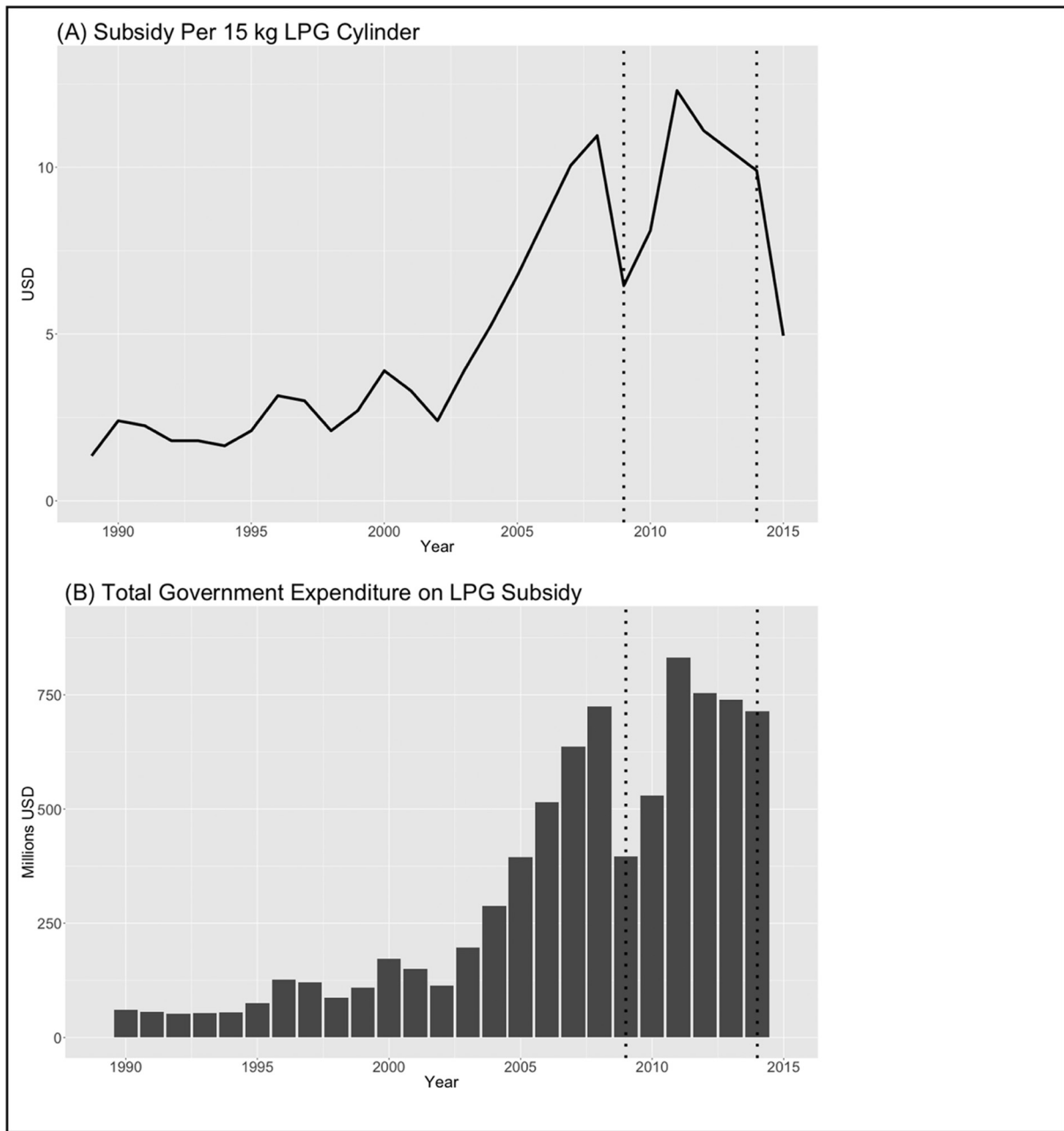


Fig. 6. Total and per-cylinder government expenditure on the LPG subsidy has increased in the past two decades significantly. Induction stove program policies have come in years subsequent to especially high LPG prices and expenditures. Fig. 6A shows the per-15 kg-cylinder subsidy (the commercial cost minus the consumer cost) and 6B shows total cost of Government expenditure on the LPG subsidy, with 2009 (beginning of *Plan Fronteras* rollout in Carchi Province) and 2014 (beginning of PEC program) marked (Becerra, 2016).

support for low-cost clean energy stacking behavior during this transition period (Experts in the Ministry of Electricity and Renewable Energy, 2017). Table 2 summarizes the key aspects of PEC.

PEC initially included numerous strategies to incentivize stove changeover, including increased taxes on locally-manufactured LPG stoves, cash incentives for LPG stove trade-in (never actualized), negotiations with local appliance manufacturers to include induction stoves in their product lines and determine payment mechanisms incorporating government-managed consumer credit, and promotion of locally-manufactured stoves through “showroom” events hosted by the Ministry of Industry and Productivity (Araujo, 2015a; El Universo, 2017c). Government negotiations with local industry prior to PEC rollout led several national manufacturers to offer induction stoves and induction-specific cookware. Local manufacturing of induction stoves initially lagged and the government began to support the importation of

Chinese-manufactured stoves as a way to scale up the program. These imports created concerns among local industries. Lower-than-projected demand for induction stoves, however, has allowed Ecuadorian companies to meet the majority of household demand (Araujo, 2014b, 2015b; Castillo, 2015). Induction stoves sold between 2013 and 2017 were primarily manufactured domestically (67%), with the remaining units imported largely from the People’s Republic of China, Brazil, and Colombia (El Universo, 2017a).

To participate in PEC and obtain an induction stove using government-provided credit, Ecuadorians need to provide a copy of their paid-in-full electric bill and a document verifying their residential address. The process of registering for consumer credit and the subsequent electricity subsidy is undertaken through a dedicated PEC website, and is generally completed at the point of sale or with door-to-door sales agents of retailers or stove manufacturers. The process, however, is

Table 2

Key aspects of the induction stoves program (PEC).

<i>Pilot program</i>	
Plan Fronteras	From 2009 to 2013 in 5000 households in Carchi, Ecuador providing two single-burner induction stoves, offering free electricity for cooking, and establishing household LPG cylinder allotments. Intended to determine acceptability of induction stove use.
<i>Program targets</i>	
Initial adoption target (2014)	Induction stoves in 3.5 million households by 2018.
Revised adoption target (2018)	Induction stoves in 3.5 million households by 2023.
Actual adoption	By the end of 2017, 740,000 stoves had been purchased.
<i>Consumer aspects</i>	
Stove purchase	Stoves range in cost from \$150–800, with most customers spending around \$500. Government-organized installment plan for payment (up to 48 monthly installments; 5.5% interest; billed via electricity bill)
Cookware purchase	Induction-compatible cookware (e.g., pots, pans) must be purchased at prices ranging from \$25–75 for a basic set (i.e., three pots with lids and a frying pan). Same installment plan as stoves.
220 V circuit and meter	Households must have a 220 V circuit. State electricity company will provide meter for free. Households must cover \$40 installation cost.
Program enrollment	Participants must register through an online system (http://www.ecuadorcambia.com/).
Electricity credit	80 kWh/month of free electricity for cooking (i.e., not billed for up to 80 kWh/month above average monthly consumption).

separate from stove sale and can be undertaken at any point after induction stove purchase. In addition, the request for a 220 V electric meter, a prerequisite for installation of induction stoves and receipt of the electricity credit, can be completed through a similar online process with local electric utilities. In the case of both processes, sales agents walk stove purchasers through the registration, or complete these processes in the name of purchasers in the case of door-to-door sales (however, this may enable the unsavory sales tactics discussed below, especially in cases where purchasers do not have internet access). Meter installation is paid for by the utilities, but 220 V circuit installation is paid for by the household (approximately \$40) (EmelNorte, 2017a). Importantly, the majority of urban households already have the 220 V circuit from previous utility modernization campaigns.

The electricity credit is up to 80 kWh/month of free electricity for cooking, measured as an increase in energy consumption from pre-induction baseline (Ministry of Electricity and Renewable Energy of Ecuador, 2017b). For instance, a household with a pre-enrollment average consumption of 100 kWh/month that consumed 175 kWh in a given month would be charged for 100 kWh. If the same household consumed 190 kWh the following month, they would be charged for 110 kWh. The subsidy is administered directly to the participant's electricity bill. The size of the subsidy was calculated by taking the average number of 15 kg cylinders of LPG consumed by a household of five (1.2) and converting this number to equivalent electricity consumption for an induction stove (Experts in the Ministry of Electricity and Renewable Energy, 2017).

The cost of an induction stove ranges from \$150 to more than \$600 (Ministry of Electricity and Renewable Energy of Ecuador, 2017b). Consumers have primarily purchased four-burner models, especially those with electric resistance ovens that can cost as much as \$800 (Quito Electric Company Personnel, 2017). Consumer credit for induction stove purchases and the electricity subsidies for induction stove use have been popular. As of early 2017, 75% of stove purchases have used the government credit (El Universo, 2017b) and 82% use the electricity subsidy (Quito Electric Company Personnel, 2017). The option to pay for induction stoves in monthly installments for up to \$800 for 48 months through electricity bills (with 5.5% annual interest) has been extended through 2024 in response to program renewal in early 2018. The program continues to include the option to purchase new induction-compatible cookware with the same mechanism (Ministry of Electricity and Renewable Energy of Ecuador, 2018).

Stove promotion efforts

While the national government has invested in a media campaign to promote cooking with induction stoves, the private sector has been the main driver of stove sales. A vast majority of induction sales appear to be made through door-to-door sales by representatives of stove manufacturers and appliance retailers—estimated at 95% of total induction

stove sales as of mid-2016 (El Comercio, 2015). However, door-to-door sales have been associated with reports of unsavory sales tactics, like threats of removing the *Bono de Desarrollo Humano* (monthly \$50 transfer to below-poverty-line households and for vulnerable adults over 65 years) if a stove is not purchased and sales to households unlikely to receive a 220 V circuit in the short term, rendering their newly purchased induction stove unusable in the interim (EmelNorte, 2017b; Pacheco, 2017). Between January 2015 and November 2017, a public defender registered and filed >2000 complaints in an effort to increase the Ministry of Electricity and Renewable Energy's control over induction stove sales (Pacheco, 2017).

Plan Fronteras: An induction pilot program

Plan Fronteras (2009–2013) was an induction pilot program in northern Ecuador that aimed to determine the technical and social viability of induction cooking in Ecuador. The program was included as one aspect of a larger effort by the state to exert greater control over LPG sales in the border region (i.e., to reduce smuggling to neighboring Colombia). Participating families (approximately 5000 households) were given two low-cost, single burner induction cooktops, cookware, and electricity for cooking (through a dedicated 110 V outlet and power meter). Following the conclusion of the pilot program, dedicated power meters and outlets that were installed for the pilot program were removed, as these had provided free electricity. No additional support was provided to participant families who kept their induction stoves and cookware, leading to eventual widespread abandonment of induction cooking in the region. Ministry of Electricity and Renewable Energy analyses of Plan Fronteras were not disseminated and were used only for internal policy-making decisions. However, the program successfully demonstrated the adaptability of induction to local cooking styles and the robustness of electricity infrastructure when faced with a new source of demand (Martínez-Gómez, Guerrero, & Riofrio, 2017; Quito Electric Company Personnel, 2017).

Experiences with LPG and induction stoves in rural communities

While LPG subsidies and PEC were presented separately in the above sections, their impacts on households cannot be unlinked. In this section, we describe cooking practices and experiences with cooking fuels among surveyed households in three rural communities.

Study population

Specific communities in Carchi were selected based on publicly-available induction stove purchase data (Agencia de Regulación y Control de Electricidad, 2018) to identify low induction adoption (Chical-Maldonado), medium adoption (Julio Andrade), and high adoption (El Angel) (see Fig. A.4 for a map of study sites). These communities have similar populations, socio-economic status, and degree of rurality.

Table 3
Distribution of fuel stacking combinations in study households ($N = 383$).

	LPG primary	Wood primary	Induction primary
LPG secondary	*72 (19%)	35 (9%)	1 (<1%)
Wood secondary	200 (52%)	*4 (1%)	0 (0%)
Induction secondary	17 (4%)	0 (0%)	*0 (0%)
LPG and induction	–	2 (<1%)	2 (<1%)
Wood and induction	50 (13%)	–	0 (0%)

* Exclusive use.

All communities had near-universal access to electricity from the national grid. Census data indicated that 93% of households in the province use LPG as their primary fuel (National Institute for Statistics and Census of Ecuador, 2017a).

Importantly, household energy choices in Carchi are circumscribed by a region-specific quota system that limits households along the border to a monthly allotment of subsidized 15 kg LPG cylinders, in an effort to address the problem of LPG smuggling to Colombia. These allotments are determined by household size (1 cylinder for <4 people, 2 cylinders for 5–6 people, 3 cylinders for >6 people). As a result, in many rural communities, LPG distributors arrive with cylinders of gas on trucks only once or twice a month, and acquisition of additional tanks beyond the quota can prove arduous and expensive (i.e., purchase of LPG at commercial or grey-market prices from an urban center). Tallies of LPG cylinder purchases are recorded on government punch cards maintained by each household.

Household survey results

Household surveys were administered in 383 households; descriptive statistics of study households can be found in Table A.2. Using multiple fuels was the norm and several different combinations of fuels were observed (Table 3). All but four households reported using LPG weekly or more frequently; among LPG users, it was the primary fuel in 89% of the households. At the same time, woodfuel use was common and in only 19% of households that reported LPG as their primary fuel was LPG used exclusively. In total, 79% of households reported using woodfuel weekly or more frequently—86% of the time as a secondary fuel. Woodfuel is frequently utilized by these households: 42% of secondary woodfuel users reported daily use and 27% reported 1–6 uses per week.

Twenty-nine percent of the households surveyed participated in the *Plan Fronteras* program and received a free induction stove, and 14% had purchased an induction stove through PEC. Induction stove use, however, was low. Among PEC households that purchased an induction stove ($n = 55$), 67% reported using the stove less than once a week or never and only 20% reported daily use. Current *Plan Fronteras* induction stove use was also rare; only 22% of households that reported participating in the pilot program reported to continue to use one of the stoves, and never as a primary stove.

When LPG was a households' primary cooking fuel, it was used frequently and for all meals: 86% of these households using LPG for all cooking events (i.e., coffee/tea, breakfast, lunch, and dinner). LPG use was still high in households that also utilized woodfuel—all but two households reported cooking multiple times a day with LPG and 84% of households used LPG during all meals (Table 4). At the same time, households using woodfuel as a secondary cooking fuel reported using it frequently and for a variety of tasks: lunch (48%), dinner (38%), and

cooking for animals (24%). These results are suggestive of multiple fuel use during the same meal. In other words, LPG may be inadequate for addressing all the energy needs of households at a given meal, or households may be economizing by using cost-free biomass to complement LPG.

Table A.3 describes results from questions regarding household perceptions of cooking fuels and stoves by fuel use groups. The majority of participants felt that cooking with woodfuel was important because it is inexpensive and an aspect of their cultural identity (exclusive LPG users less so); at the same time, three-quarters of households thought that cooking with woodfuel had negative health impacts. Nearly half of all respondents felt that there were times when they could not buy LPG when desired because of lack of money and 41% said their LPG allotment was insufficient to cover their monthly cooking patterns. Current induction stove users, more than non-using households, felt that the cost of induction stoves was very high but were also more likely to think that induction stoves were worth the investment.

Results from focus groups

Six focus groups were carried out, two in each study community. Group sizes ranged from 4 to 12 individuals and lasted between 45 min and one hour. We present the results of the focus groups for each fuel type discussed.

LPG stove advantages. By far the most important advantage of LPG mentioned by participants was the low cost, with households reportedly spending between \$2.50 and \$7.50 per month on gas cylinders. Furthermore, participants reported having great familiarity and experience using gas stoves, which in addition to making cooking easier allowed for better time management of cooking tasks.

LPG stove disadvantages. As noted in the household surveys, focus group participants described LPG access as the biggest problem. Participants cited the Carchi-specific allotments as insufficient for all cooking tasks in a month. Cylinders are often delivered to a town center, requiring travel by a member of the household to acquire the gas. In more rural areas, travel distances can be long and delivery times uncertain, which participants describe as a significant time burden each month, in addition to the physical burden of transporting heavy, bulky LPG cylinders. While the cost of gas was recognized as the most important advantage, some participants stated that for the poorest households, even the apparently modest cost of cooking with LPG may represent a barrier to high use.

Wood-burning stove advantages. Especially for more rural participants, available and monetary-cost-free woodfuel, generally collected on personal property or that of family members, are an attractive option when LPG is not unavailable or scarce. Furthermore, woodfuel is used for energy-intensive dishes—including dietary staples like dry beans and grains—as a means of rationing comparatively-expensive LPG or electricity. The same rationing techniques are utilized when cooking for large numbers of people. Furthermore, wood-burning stoves heat homes (none of which have other forms of climate control), which participants described as a great additional benefit.

Wood-burning stove disadvantages. Participants described woodfuel as increasingly scarce on public lands, making it necessary to travel further from communities. In turn, woodfuel collection is more arduous and time consuming. During the region's nearly 6 month rainy season, maintaining sufficient dry woodfuel is a challenge. For some people, especially older adults, obtaining a sufficient and regular supply of woodfuel is a substantial barrier to its use. Finally, participants recognize that breathing smoke from biomass cooking represents a potentially serious health risk.

Table 4
Frequency of fuel use among households where the primary fuel is LPG and woodfuel is supplemental fuel (51% of the total sample).

Frequency of fuel use	LPG	Woodfuel
Multiple times a day	99%	29%
Once a day	0%	15%
1–6 times per week	1%	34%
Less than once a week	0%	22%

Induction stove experience. Since induction stoves were distributed amply and cost-free in Carchi province through *Plan Fronteras*, all participants were familiar with their use, advantages, and disadvantages whether or not they personally received or have purchased an induction stove through PEC. In general, participants reported that induction stoves are not an improvement over their current cooking situation (given that all had LPG stoves). Participants who purchased induction stoves through PEC (or who know someone who did) described rarely using them or that they regret having bought them. Several participants felt that they were pressured into the purchase, and later found that the disadvantages outweigh the advantages.

Induction stove advantages. Participants stated that cooking is very fast with induction stoves, especially when carrying out small tasks like boiling water for coffee. In addition, the glass top is perceived to be easier to clean than the tops of LPG stoves and induction stoves can be used if no LPG is available. In Carchi, people who do not have a LPG ration card, like young adults living outside of their parents' home, can use induction stoves. Participants reported that *Plan Fronteras* stoves (single burner models) were subject to power fluctuations and broke down regularly, often before 6 months of use.

Induction stove disadvantages. Overwhelmingly, participants described cost as the greatest disadvantage of induction cooking. First, when purchased from commercial outlets, the cost of induction stoves was found to be high by participants. Second, even though the government campaign included a subsidy to cover part of higher electric bills, participants who had used induction stoves or know someone who did reported that their electric bills doubled or tripled, in many cases due to payment of consumer credit for stove purchase. Third, the purchase of induction stoves usually also implied the purchase of several additional pots because compatible cookware must be used with induction stoves.

Discussion

Propelled by a long-standing LPG subsidy, >90% of Ecuador's households cook primarily with LPG. The low cost of LPG has indeed decreased the use of woodfuel as a primary cooking fuel, and in many cases the transition happened several decades ago. However, the subsidy resulted in a substantial fiscal burden to the government of Ecuador. The subsidies are not targeted and benefit many Ecuadorians who could pay more for LPG (e.g., middle- to upper-income households, restaurants).

Nearly all households in our rural study communities used LPG, and the majority as their primary cooking fuel. At the same time, low-cost and relatively abundant woodfuel remained a common alternative to LPG when the supply is limited. Study households reported using woodfuel to cook energy-intensive dishes and when cooking for large numbers of people. Wood-burning stoves offer the benefit through space heating, which is especially useful in cool, high-altitude areas. Household energy decision-making in our rural study site is uniquely circumscribed by government policies for the border region limiting the quantity of LPG cylinders purchased each month. However we hypothesize that questions of limited access to LPG is a problem that continues to affect rural households in other parts of Ecuador and indeed around the world. As demonstrated in focus group results, issues of limited access to LPG cylinders were reported to contribute to LPG rationing and led to cooking with woodfuel.

Induction stoves through PEC offer an alternative means for high-quality clean cooking, while reducing the economic burden created by the LPG subsidy and potentially capitalizing on the nation's growing hydroelectric production. Induction stove adoption has lagged behind original PEC goals, which have now been pushed back from 3.5 million induction-using households by 2018 to 2023. High initial stove and cookware costs, a need for new 220 V connections, and fears of

increased electricity costs with induction cooking have limited induction stove uptake. Furthermore, access to low-cost LPG remains high and the continuation of the LPG subsidy appears to have led to the simultaneous use of multiple clean fuels rather than outright replacement of LPG (demonstrated by a lack of notable reduction in LPG sales) (Agency for the Regulation of Hydrocarbons Personnel, 2017).

Data from surveyed rural households showed that induction stove use was very low among households with PEC stoves. In some cases, households that had purchased stoves did not use them because they did not yet have a 220 V connection, but in other households use was low because of concerns about high electricity costs. In other cases, satisfaction and use were negatively affected by limited compatibility between induction stoves and households' existing (largely aluminum) cookware. New induction-compatible cookware is expensive and households often acquire smaller, cheaper pots, which may then limit induction cooking to boiling water and cooking snacks.

Recommendations

Costs and access appear to define household decisions around cooking fuels in Ecuador. In our rural study sample, woodfuel is widely used as a secondary cooking fuel to ration LPG and provide heating benefits, in addition to a desire to maintain traditional cooking practices. Clean cooking programs should recognize non-cooking factors (e.g., compatibility, heating) as well as consistent access to fuel, in addition to fuel cost, as major barriers to exclusive use of clean cooking fuels.

The LPG subsidy has created a significant fiscal burden that may be reduced through needs-based targeted subsidies and greater enforcement. Wealthier households—for whom the cost of a less subsidized cylinder of gas is less of a burden—gain disproportionate benefit through greater per-capita LPG utilization and from ancillary gas use (e.g., on-demand hot water heaters). The universal subsidy has led to a number of illegal uses, primarily in small commercial ventures. Illicit cylinder uses have been shown to lead to poor-quality installations, which pose significant hazards including leaks and explosions. However, risks are not limited to illicit uses; low LPG prices and a vast distribution chain limit the effectiveness of oversight mechanisms and contributes to consumer complacency with substandard household and commercial installations. Results from household surveys—81% of households perceived it to be dangerous to cook with LPG—and focus group discussions highlighted that these dangers are recognized by households in our sample. Safety and education programs, as well as policies that ensure high-quality installation and cylinder quality have the potential to decrease accidents and leaks and increase household satisfaction with LPG, while simultaneously reducing overall LPG consumption.

To date, induction cookstove uptake is low across the country as the cost of the stoves and new cookware remain out of reach for many Ecuadorian households. Furthermore, the continuation of the LPG subsidy provides little incentive to households considering purchase of a new stove to transition to potentially more-costly electricity.

Conclusions

More than 90% of Ecuadorian households cook primarily with a clean fuel and have done so for several decades. The majority of households purchase one 15-kg cylinder of LPG per month, but higher income households purchase much more LPG per capita each month than lower income households. Nearly all participants in our limited rural sample reported cooking with LPG, many of them relying on it as a primary fuel for nearly all meals. At the same time, woodfuel use was reported in nearly 80% of these rural households. Lack of consistent access to LPG, and limited allotments of cylinders each month due to a region-specific policy, led to woodfuel use as a means of rationing LPG cylinders to reach the next delivery date. While the large LPG subsidy has facilitated the transition to clean cooking, it has led a large financial

burden for the government, reaching as much as \$700 million each year. To alleviate this fiscal burden and to potentially utilize the country's growing hydroelectric production, the government launched a national induction stove promotion program in 2014, now aiming to reach 3.5 million households by 2023. However, induction stove sales have been lower-than-projected, largely due to the persistence of subsidized LPG as a viable clean cooking alternative and the high costs of induction stoves, induction-compatible cookware, and electricity after adoption.

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Appendix A. Supplementary data

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