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Article

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Analysis of the "Plan Fronteras" for Clean Cooking in Ecuador

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ABSTRACT

The aim of this research is to analyze the introduction of the "Plan Fronteras" in Ecuador. The Plan Fronteras analyses the effects of introducing induction stoves in terms of electricity demand, energy consumption and greenhouse gas emissions, previous to the implementation of the National Efficient Cooking Program (NECP), which is the first program of widespread access to clean cooking alternatives, which aims to introduce 3 million of induction stoves in the country. The impact of the induction stoves on Ecuador electric network has been analyzed by measuring electric grid parameters, energy and power consumption. The results of the study show that the electric grid parameters are within the permitted levels of the regulation of the country. Further on, a coincidence factor of 0.16 for induction stoves utilization has been registered when it was found. An estimation of the electric demand has been identified when implementing the NECP with this value. The results of the study show that when analyzing the highlands and coastal regions at the same time, the peak demand in the country occurs at 19:00, whit a power requirement of 2860 MW. Finally, a study on energy demand and liquid petroleum gas savings after the implementation of the NECP has been accomplished. The study has been evaluated and compared with future business as usual scenarios and new policies from 2016 until 2032. The results of the comparison reveal a reduction of the energy demand of 20 million GJ in 2032, and a reduction of 40.8 million tons of greenhouse gas emissions, between 2016 and 2032.

Keywords: Household Survey, Clean Cooking, Access to Electricity, Induction Stoves, Cooking Fuel
JEL Classifications: L94, R52, Q4

1. INTRODUCTION

Globally 2.6 billion people do not have access to clean cooking facilities (International Energy Agency, 2012), (Smith, 2014). The World Health Organization (WHO) estimates that 1.5 million premature deaths a year are directly associated to air pollution from the use of solid fuels for cooking activities (WHO, 2009). Up to 85% of these deaths (about 1.3 million) are attributed to the use of biomass, the rest to coal (WHO, 2009). This problem is especially harmful to children, old people and women who spend more time near the kitchens stove (International Energy Agency, 2006), (Abdullahi et al., 2013) (Kafle et al., 2016).

For this reason, several programs have been developed in order to improve cooking facilities around the world. In China for example, several programs to improve household stoves have been carried out since the 1980s (Sinton et al., 2004). The objectives in Chinese programs were to delineate and evaluate the methods used to promote improved stoves, to assess the development of commercial stove production and marketing organizations (Sinton et al., 2004). Studies to understand the household energy preferences for cooking in urban Ouagadougou have been promoted to improve the clean cooking program in the case of Burkina Faso (Ouedraogo, 2006). In the case of India, energy for cooking end use accounts for a little over 80% of the total household energy consumption in rural areas (Purohit et al., 2011). For this reason, the use of biogas plants, solar stoves and improved household stoves for domestic cooking has been promoted (Purohit et al., 2011). In Ethiopia, a technical, actor-network-related document, with institutional factors that hampered the adoption of solar cookers in Africa, has been mapped out (Kebede et al., 2014). However, developing countries governments have not dedicated efforts to introduce electricity as a fuel option for cooking in their programs and projects of access to clean cooking alternatives, neither universal access to electricity.

In relation to electricity clean cooking policies, it has observed that electric coil stoves are less efficient and more power consuming in comparison to other electric devices. For this reason electric coil stoves are not a good cooking alternative in an efficient cooking policy program (Smith and Sagar, 2014), (Smith, 2014). However, induction stoves present a few advantages when they are compared to traditional liquid petroleum gas (LPG), biomass or electric coil based stoves, which can be listed below: (i) Increased energy efficiency, as the magnetic field is induced in the cookware and there is absence of calorific focus of high temperature, which reduces heat losses to the environment; (ii) a higher speed in heating, because the ferromagnetic material of the base of the pan has the ability to attract and pass electricity through the magnetic fields, as soon as it flows through the coil, which causes that the cookware is heated directly; (iii) higher safety because there is no risk to get burned when using the kitchen, or explosions, as no flame is produced; (iv) more hygienic and easy to clean, while having a smooth surface of vitroceramic; (v) easy to operate with digital controls. On the contrary, the main disadvantages are: (i) A more sophisticated technology than electrical coil and GLP stoves; (ii) fragile use, as vitroceramic can get scratches (Villacís et al., 2015), (Wong and Fong, 2013).

In the city of Kerala in India a brief study of induction stoves with other technologies has been conducted recently (Government of Kerala, 2014). Also, in the northern region of India, in the state of Himachal Pradesh a program with induction stoves based on "access to clean cooking alternatives in rural India" has been introduced in 2014. Nearly 4000 rural households provided with induction stoves have been taken into account in the program (Banerjee et al., 2016). A displacement of biomass and LPG based stoves to induction cookers was observed within this program, being the cities the most important shifting spots, because of lower electricity costs and energy availability (Smith and Sagar, 2014), (Banerjee et al., 2016). Also, according to the "Indonesia kitchen appliances market forecast and opportunities, 2019" report, the induction stoves will be adopted in the majority of the country, when the LPG prices increase (Banerjee et al., 2016).

In the case of Ecuador, the National Efficient Cooking Program (NECP) which seeks to migrate around three million LPG stoves to more efficient induction stoves across the country between 2016 and 2018, already started (Martínez-Gómez et al., 2016). To accomplish the NECP, the Ecuadorian government is improving access to electricity in the country by replacing its fossil fuels with renewable energies in its energy mix (Martínez-Gómez et al., 2016). Along with the NECP, the previous plan to study the introduction of induction stoves in the country is the "Plan Fronteras." The Plan Fronteras aims to determine the impact of use of induction cookers in 5400 households in the province of Carchi in the north of Ecuador.

The purpose of this research was to analyze the implementation of the Plan Fronteras with the goal to measure the social, economic and technical impact of change from LPG to electricity by induction stoves, previous to the implementation of the NECP. In this research the impact of induction stoves in the electric network by measuring the electric grid parameters of the total harmonics distortion of voltage (THDU) and current (THDI) has been studied. Parallel to this analysis the coincidence factor of using induction stoves in the area has been measured and registered. With the obtained measurements of the Plan Fronteras study, an estimation of the national electric demand, energy savings and emission reduction of greenhouse gases when implementing the NECP has been realized.

1.1. NECP

The LPG subsidy cost for the Ecuadorian government is about 700 MUS$ per year, (Martínez-Gómez-Gómez et al., 2016). This amount of money is a great burden for the state considering the future demand growth that is expected to be even higher to sustain in the upcoming years. For this reason, Ecuador is working in a subsidy substitution of LPG for electricity subsidies. So, in this way users of the NECP will receive a subsidy that covers the first 80 kWh, with a value of 0.04 US$/kWh, and the projected costs for the extra consumption of electricity would increase up to 0.0615 US$/kWh (MEER, 2013), (CONELEC, 2015). Nowadays, the cost of the electricity to the Ecuadorian government is 0.162 US$/kWh (CONELEC, 2014).

According to the governments new energy policies, the NECP aims to migrate around three million LPG based stoves to induction stoves, as the first energy policy program to introduce more time and energy efficient, clean and inexpensive cooking facilities for an entire country (Martínez-Gómez et. al, 2016). The NECP is linked to the change of the energy mix, which seeks the energy sovereignty and access to clean energy for all the population of Ecuador. For this purpose, between 2014 and 2022 the government is investing 11619 MUS$ in new infrastructure of hydroelectric power plants and a new electric transmission grid infrastructure. It is expected that 83.61% of the Ecuadorian electricity will be generated by hydroelectric power plants (CONELEC, 2015). The investment plan of the Ecuadorian government estimates that 6012 MUS$ will be spend in electric generation by hydropower plants, 1158 MUS$ will be spend in reinforcing the electric transmission, 3378 MUS$ will be spend in reinforcing the electric distribution to the households, and finally 1071 MUS$ will be spend in introducing induction stoves as part of the NECP and the National efficient electric heater program (CONELEC, 2015).

One of the key factors to introduce the NECP is to prevent that the countries resources keep getting misused, since about 11% of the overall countries budget was allocated exclusively to subsidize fuels in 2015 (MICSE, 2015). In Ecuador 15 kg of bottled LPG costs 1.60 US$ for the user, while in neighbor countries this price is on average 13 times higher (17 US$ and 23 US$) (Riofrio, 2015). Regarding to the LPG consumption, the approximate average consumption per household for a four member family is about 264 kg of LPG per year. It means 17.66 LPG cylinder units per year, and 1.47 cylinders of 15 kg of monthly consumption per household (MICSE, 2015).

1.2. The Plan Fronteras

The Plan Fronteras is the first program to investigate the impact of using induction stoves in 5400 households in the province of Carchi in the north of Ecuador (CONELEC, 2015). With this program, a remarkable effort to reorder, plan, strengthen and modernize the electric distribution network to provide secure and reliable services has been realized (Riofrio and Carrion, 2014). For this reason, the electric distribution network requires an adjustment of the electrical grid system, especially at the level of energy distribution as transformers, primary feeders and connections (Sazak and Cetin, 2009). With the introduction of new hydroelectric power plans no disadvantages have been observed to meet the energy demand generated by induction stoves (CONELEC, 2015). Thus, the implementation of induction stoves will affect the low voltage transformers which are connected to common households (Sazak and Cetin, 2009), (Crisafulli, 2016). For this reason, the Plan Fronteras implemented connections for proper operation of the induction stoves at the household level. The following materials were needed: (i) Electronic meter, (ii) thermo-magnetic limiter to 20 A, (iii) copper conductor twin 2 × 10 AWG (120/240 V), (iv) strips and staples for fastening functional and aesthetic cables. The amount invested for the implementation of electrical readjustments at households, for the project implementation went from 66 US$ to 118 US$ per household (CONELEC, 2015), (Riofrio and Carrion, 2014).

Cooking with LPG is strongly rooted in the habits of Ecuadorians, thus effective incentives are required to achieve the transition of this energy source to electricity (Carrión and Carvajal-Pérez, 2015). The installation of a power meter in each household taking part of the project in order to promote the use of induction stoves in the Plan Fronteras has been considered as an incentive to the user (CONELEC, 2015). With the power meter the user has an estimation of the energy consumption reduction when changing to an induction stove. The power meter provides accurate consumption data, which will be the most appropriate mechanism for massive implementation of the NECP. Also during the 6 months of the implementation of the Plan Fronteras, there were no electricity costs to the user of induction stoves, in order to promote its use (MEER, 2013).

The families that participated in the Plan Fronteras program received two induction stoves with one hob each, an aluminum cookware set of two pots and one pan with AISI 430 stainless steel composition in its bottom and two glass lids (CONELEC, 2015). To access to the Plan Fronteras program and receive the induction stoves, the interested families participated in three workshops to learn how to use the induction stoves while cooking traditional meals (MEER, 2013).

1.3. Case Study Area

Considering the residential sector of Ecuador, it has been observed that energy consumption in the residential sector is divided in three main fuels: Firewood, electricity and LPG (MICSE, 2015). In 2015, the consumption of firewood was about 7750 TJ, being the rural zones of the highlands and Amazonia the principal consumers of this fuel resource. The consumption of electricity was about 19250 TJ, being the urban zones the principal consumers. The principal fuel used in Ecuador is LPG with about 40700 TJ (MICSE, 2015). In addition, it should be considered that 83% of the LGP is imported (CONELEC, 2015).

The consumption of LPG in Ecuador has been separated in five economic layers as shown in Table 1 (MICSE, 2015). It can be observed that the 91.09% of the LPG was used for cooking activities. 5.3% of LPG was used in the industry, 0.6% for transport, and 3.06% for heating. Furthermore, the 20% poorest quintile of the Ecuadorian economy use 97.65% of LPG for cooking, while the richest 20% use 78.03% of the LPG for cooking and 12.46% for the water heater. In this way, it can be considered that the LPG subsidy and dependence applies to all social strata of Ecuador at the same level.

The distribution of fuel resources used for cooking in the Ecuadorian households is show in Table 2 (MICSE, 2015). According to the table most of the households use LPG with cylinder for cooking in Ecuador (96.24%). Meanwhile in Ecuador 0.73% use wood and carbon for cooking, while in the case of the province of Carchi the 6.69% uses wood food cooking.

2. EXPERIMENTAL METHODS

2.1. Instruments

The free shipping induction stove model identified for the study was IH-MS2050C (Figure 1), is manufactured by Fusibo in China. The model has an operating voltage of 220-240 volts and a maximum power consumption of 1000 watts. It has eight temperature levels from 80°C to 240°C, which are operated by a push button control system to make it user friendly. This model was selected based on the power consumption, cost, user friendly lines and availability of distribution in the region.

Table 1: Distribution of LPG consumption in Ecuador, divided in five quintiles of the social economy in 2015

Quintile	Cooking (%)	Industry (%)	Transport (%)	Heating (%)
20% poorest	97.65	2.32	0.00	0.03
Second	94.04	3.08	2.71	0.17
Third	93.12	6.11	0.00	0.77
Fourth	92.61	5.74	0.00	1.65
20% richest	78.03	9.23	0.28	12.46
Country	91.09	5.30	0.60	3.06

LPG: Liquid petroleum gas

Table 2: Distribution of fuel resources used for cooking in Ecuadorian households 2015

Fuel used for cooking	Households	(%)
LPG with cylinder	3673000	96.24
LPG centralized	18700	0.49
Electricity	22500	0.59
Wood and carbon	27800	0.73
Plant and animal residues	100	0
Others (oil, kerosene, .)	400	0.01
No cooking	74000	1.94
Total	3816500	100.00

LPG: Liquid petroleum gas

Figure 1: Induction stoves and cookware pack delivered to each family taking part of the Plan Fronteras program

2.2. Procedure to Measure the Electric Grid Parameters

In order to analyze the feasibility of the introduction of induction stoves from the electrical grid point of view, an analysis of induction stoves installed in the homes of beneficiaries were made. This included measurements such as: (i) Voltage, (ii) current, (iii) THDU, (iv) THDI, (v) power factor, (vi) active power, (vii) apparent power and (viii) energy consumption. For the tests, 36 electric grid transformers of the Carchi region have been used during a period of 1-month.

The analysis of the electric grid transformer was connected with the Fluke 1744 power quality logger, which is an everyday power meter for technicians who troubleshoot and analyze power quality issues. It included the PQ Log software quickly assesses, the quality of power at the service entrance, substation, or at the load, according to the EN50160 standard.

2.3. Electrical Demand

The electrical demand is the amount of consumed energy in a specific time interval for a determinate zone. The prediction of the electrical demand has advantages to define the electrical distribution and transmission system needs, to identify the social behavior in which the analysis is performed.

The prediction of the electrical demand is made through the distribution systems in order to get the correct dimensioning of electrical grids, and as a result the electrical grids will not suffer damage with the increment of loads in the course of time. The electrical demand in the case of Ecuador is divided into four sectors: Residential, commercial, industrial and street lighting, as shown in Figure 2 (CONELEC, 2015).

2.3.1. Demand factor (DF)

The demand factor (D_F) is the relation between the system maximum demand and the total load connected to the system. This can be calculated using (1) (Westinghouse, 1965):

$$D_F = \frac{D_{max}}{C_{total}} \tag{1}$$

Where D_F is the demand factor, D_{max} is the system maximum demand, C_{total} is the users demand. D_F helps to get a correct dimensioning of electrical grids.

2.3.2. Coincidence factor (C_F)

The coincidence factor (C_F) can be defined as the recurrent value of using an electrical artifact by a determined number of users. The C_F of a particular group of users will differ from another group, due to the load characteristics and costumer type. The C_F can be calculated applying several methods, some of them are shown in the Equations (2-5) of Table 3 (Nickel and Braunstein, 1981), (Dickert et al., 2011), (Calvo, 2010), (CEDENAR, 2010).

2.3.3. Maximum diversified demand (MDD)

The MDD is the total load requirement over a period of time of a particular group of users. It is determined using the empirical methods from mathematical models. The MDD considers the diversity among similar loads and the non-coincidence between different types of load peaks. It can be calculated using (6) (Westinghouse, 1965).

$$MDD = C_F * D_F * P \tag{6}$$

Where C_F is the coincidence factor, D_F is the final demand and P is the equipment power.

2.3.4. Case study

The massive migration from LPG based stoves to induction cookers to be conducted in Ecuador has been analyzed using the CEDENAR model as the C_F. CEDENAR is an electrical company from Nariño-Colombia. Due to the similarity between the costumes of use and the geographical proximity the CEDENAR model has been chosen. The C_F can be calculated using Equation (5) (CEDENAR, 2010)

$$C_F = \frac{1}{1 + 0.4 * \ln(n)} \tag{5}$$

Where n is number of users.

In addition, in order to analyze the energy demand until 2017, an estimation of the number of induction stoves anticipating the increase of the population has been considered, according to the population growth projection from the Instituto Nacional de Estadistica y Censos (INEC), (INEC, 2011).

The cooker use percentage during the day has been determined for the highland and the coastal regions, where is concentered most of the population of Ecuador (INEC, 2011).

Figure 2: Distribution of the residential, commercial, industrial and street lighting sectors for the electrical demand in Ecuador for 2015

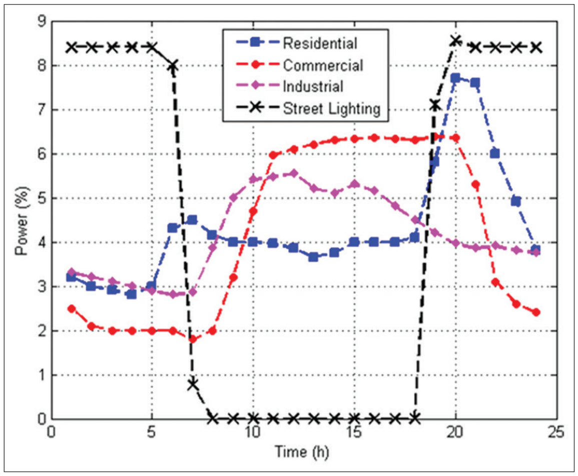


Table 3: Mathematical models for calculating the coincidence factor

Method	Equation
Dickert and Schegner	$C_F = C_\infty + \frac{(1-C_\infty)}{\sqrt{n}}$ (2)
Nickel and Braunstein	$C_F = 0.5(1+\frac{5}{2n+3})$ (3)
Westinghouse	$C_F = \frac{D_g}{\sum_{i=1}^{n} D_i}$ (4)
CEDENAR	$C_F = \frac{1}{1+0.4*\ln(n)}$ (5)

2.4. Savings on LPG

To perform the analysis of savings on LPG two different scenarios have been considered. A baseline scenario BAU (Business As Usual), which considers the normal use of LPG stoves with no changes, and the mitigation scenario, which considers the implementation of the NECP. In addition, the change of the energy mix of Ecuador, which expects that 83.61% of the Ecuadorian electricity will be generated by hydroelectric power plants (CONELEC, 2015), is also considered.

2.4.1. BAU scenario

The technology migration policy of the NECP is discarded. It has been considered that 3673000 households use LPG, and the total LPG consumption in the residential sector were about 970000 tons of LPG per year (CONELEC, 2014). A four member family is contemplated to consume 264 kg of LPG per year. This value is in agreement with the values reported by (Riofrio, 2015), (Martínez-Gómez et al., 2016), which measured the energy cost of LPG and induction stoves in four member prototype families during 1 month. An estimation of the number of LPG based and of induction stoves within the increase of the population in 2032 has been considered as well, according to the population growth projection from INEC, which also contemplates a change in the number of family members per household and the consumption of LPG (INEC, 2011).

2.4.2. Mitigation scenario

The planned introduction of induction stoves in the households of Ecuador is shown in Figure 3, where two large peaks in 2017 and 2018 can be observed due to the NECP. For this scenario, it is estimated that 3000000 induction stoves will replace LPG cookers that will be introduced until 2018. These values are related to the context of the NECP, based on the population growth projection, and the projection of the number of family members in Ecuador (INEC, 2011), (CONELEC, 2015).

Monitoring, reporting and verification methods have been developed by the Gold standard to calculate the CO_2 equivalent emissions. According to the methodology of the Gold Standard, the emission reduction is calculated as demonstrated in Equation (7):

$$ER_y = \sum BE_{b,y} - \sum ME_{p,y} - \sum LE_{p,y} \quad (7)$$

Where ER_y are the CO_2 equivalent emissions reduction in the project for a year, $\Sigma BE_{b,y}$ are the CO_2 equivalent emissions in the BAU scenario, $\Sigma ME_{p,y}$ are the CO_2 equivalent emissions in the mitigation scenario and $\Sigma LE_{p,y}$ are the lost CO_2 equivalent emissions due by leakage. The units of these magnitudes are Tons of CO_2 per year.

The CO_2 equivalent emissions in the BAU scenario $\Sigma BE_{b,y}$ have been calculated by means of the Equation (8):

$$\sum BE_{b,y} = \sum (N_{b,y} * C_{b,y} + \sum (EF_{b,y} * NCV_{b,y}) \quad (8)$$

Where $N_{b,y}$ is the number of LPG stoves, $C_{b,y}$ is the specific consumption of LPG stoves, $EF_{b,y}$ is the emission factor of CO_2 equivalent emissions by LPG and $NCV_{b,y}$ are the net calorific values of LPG.

To calculate the $EF_{b,y}$ of the GLP the national inventories of greenhouse gases has been used, INGEI, which obtains the intergovernmental panel on climate change. The factor of emission of CO_2 (62.44 Tons of CO_2/TJ) of CH_4 (10 kg of CH_4/TJ with a global warming potential of 21) and N_2O in LPG (0.6 kg of N_2O/TJ with a global warming potential of 310) have been taken into account. For the $NCV_{b,y}$ the value of 45.67 GJ/Ton has been taken into account thanks to Petroecuador (Petroecuador, 2010).

In case of the CO_2 equivalent emissions in the mitigation scenario $\Sigma ME_{p,y}$, they have been calculated by mean of the Equation (9):

$$\sum ME_{p,y} = \sum C_{p,y} * E(SNI)_{p,y} \quad (9)$$

Where $C_{p,y}$ is the consumption of the replaced induction stoves, and $E(SNI)_{p,y}$ is the emission factor of the National Interconnected System of the electric network of Ecuador, which had a value of 0.2005 (Jose, 2011).

The $\sum LE_{p,y}$ are the lost emissions due to leakages. The leaks occur when LPG is used for cooking, and afterwards replaced by other uses as for example for cook heating or by the use in restaurants or smuggling. This analysis assumes the value zero for lost emissions due to leakage, because a change in electricity as a primary fuel technology for cooking is considered.

3. RESULTS

3.1. Electric Grid Analysis

3.1.1. Voltage level distribution network

The voltage variations in 23 transformers after the implementation of the Plan Fronteras are shown in Figure 4. All transformers voltage values are within the permissible limit of 5% from the nominal of 120 V (Figure 4) by regulation (04/01) CONELEC of Ecuador. In specific cases a voltage drop outside the permitted limit occurred, for which there have been implemented the following solutions: Review and change taps of voltage in distribution transformers, changing the connections of the largest section in the distribution network and reducing distances of service. In addition, it has been observed that the power factor of the network complies with the regulation of Ecuador.

3.1.2. Voltage THD

The THD curves before and after installation of induction stoves for the Plan Fronteras are observed in Figure 5. There are no cases where the measurement of the THD voltage is

Figure 3: The planned introduction of induction stoves in the households of Ecuador

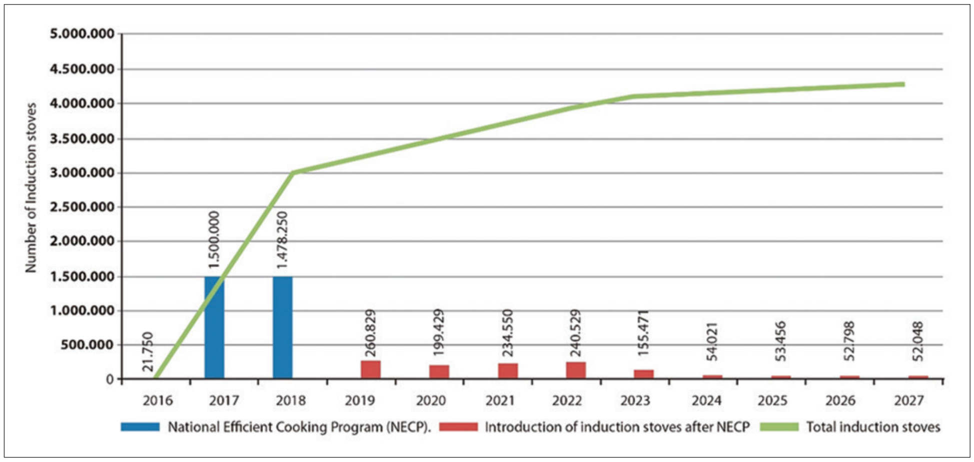


Figure 4: Voltage curves in 23 transformers affected by the installation of the Plan Fronteras, before and after installation of induction stoves

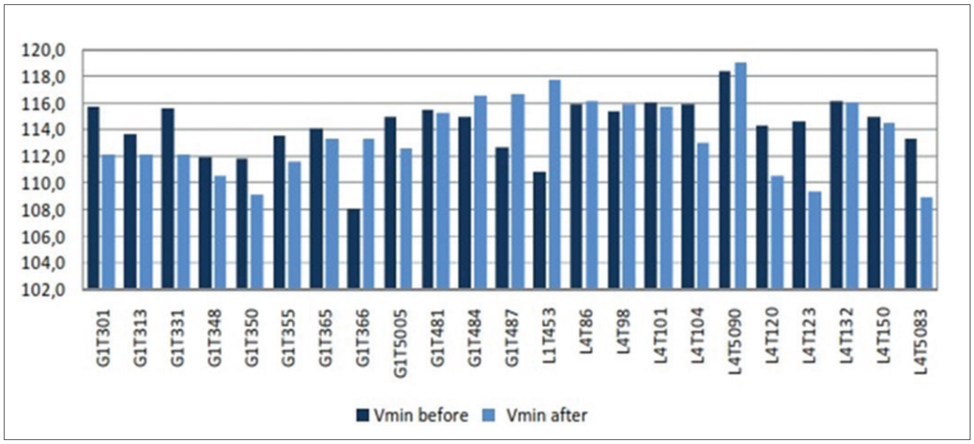
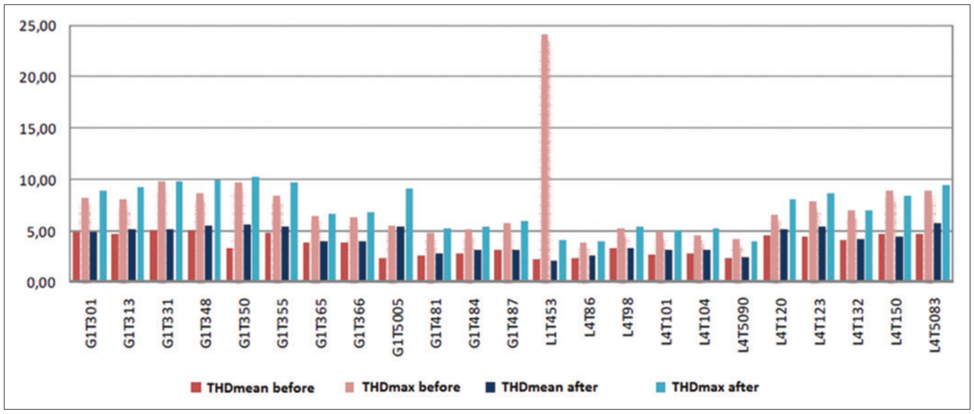


Figure 5: Total harmonic distortion curves in 23 transformers affected by the installation of the Plan Fronteras, before and after installation of induction stoves



outside of the limit for 10% of voltage distortion. It can be noted that there is a variation of 3% of THD, compared to the measurement before to the project implementation, which is due to the induction stoves.

Detailed individual harmonic distortion of the voltage signal, which is present in the secondary distribution network for transformer G1T484, before and after installation of induction stoves, is shown in Figure 6. It only shows the odd harmonics up to order 15 because the remaining couples have a negligible extent. The most representative harmonics are 3, 5, 7, 9 and 11; shown in the chart below. It is emphasized that the penetration of induction stoves does not cause distortion in the voltage waveform. Furthermore it is noted that the third harmonic is higher in amplitude.

3.1.3. Coincidence factor

To determine the coincidence factor for induction stoves of the Plan Fronteras the consumption was collected for 7 consecutive days. Special time periods as breakfast, lunch and dinner were considered. Three analysis hours for each period while using induction stoves were taken into account between 6:00 to 9:00, 10:00 to 13:00 and 18:00 to 21:00. The results of the average coincidence factor for each meal are presented in Table 4. The highest coincidence factor was in the time period from 10:00 to 12:00 am, where a value equal to 0.16 has been obtained and been used to determine the demand.

3.2. Electrical Demand Results

Based on a survey made by different distribution companies, the cooker use percentage during the day has been determined for the highland and the coastal regions. The usage percentage data within the day can be seen in Table 5.

It tends to stabilize at a value of 0.16, so consequently this is the fixed value that will be employed in this analysis.

Figure 7a showed the electrical demand behavior for the highland region with 800 MW base power. One of the highest increases in electrical demand has been observed between 04:00 and 08:00, where the electrical demand incremented at 06:00 from 0.69 base power in 2014 to 1.2 base power in 2017. Between 10:00 and 14:00, the electrical demand incremented at 11:00 from 0.82 base power in 2014 to 1.23 base power in 2017. Furthermore, the highest increase in electrical demand has been observed between 16:00 and 20:00, where the electrical demand increment at 19:00 is approximately from 1.0 base power in 2014 to 1.43 base power in 2017.

Table 4: Average coincidence factor for each meal

Day	Meal		
	Breakfast	Lunch	Dinner
Monday	0.1	0.14	0.07
Tuesday	0.07	0.14	0.15
Wednesday	0.13	0.16	0.12
Thursday	0.13	0.16	0.14
Friday	0.13	0.16	0.07
Saturday	0.12	0.15	0.13
Sunday	0.12	0.15	0.09

Table 5: Cooker usage percentage for the highland and coastal region

Time of day	Highland (%)	Coast (%)
00:00	0	0
01:00	0	0
02:00	0	0
03:00	0	0
04:00	0	16
05:00	22	63
06:00	46	14
07:00	21	4
08:00	5	2
09:00	0	0
10:00	9	29
11:00	37	47
12:00	32	14
13:00	5	3
14:00	1	0
15:00	0	0
16:00	1	7
17:00	11	26
18:00	30	38
19:00	39	23
20:00	11	5
21:00	0	0
22:00	0	0
23:00	0	0

Figure 6: Total harmonic distortion curves of transformer G1T484 before and after installation of stoves

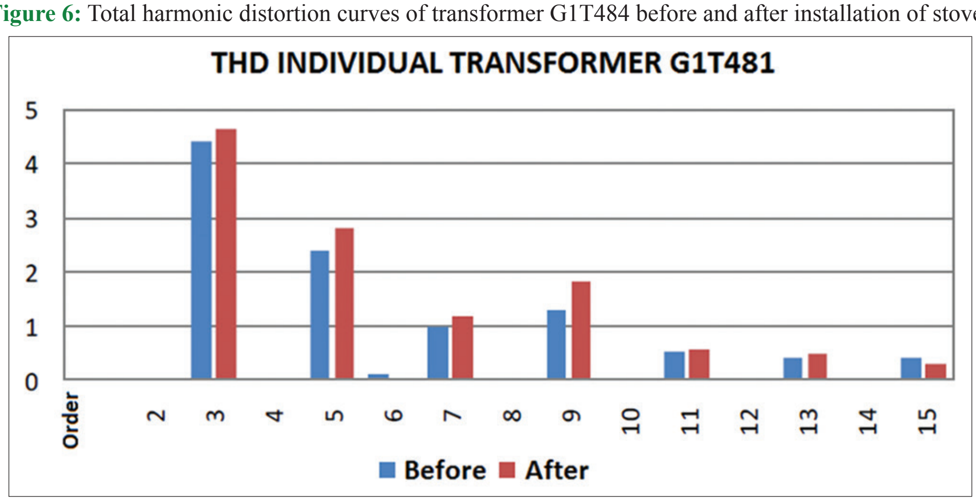


Figure 7: (a) Demand response for the highland region, (b) demand response for the coastal region, (c) demand response for total region

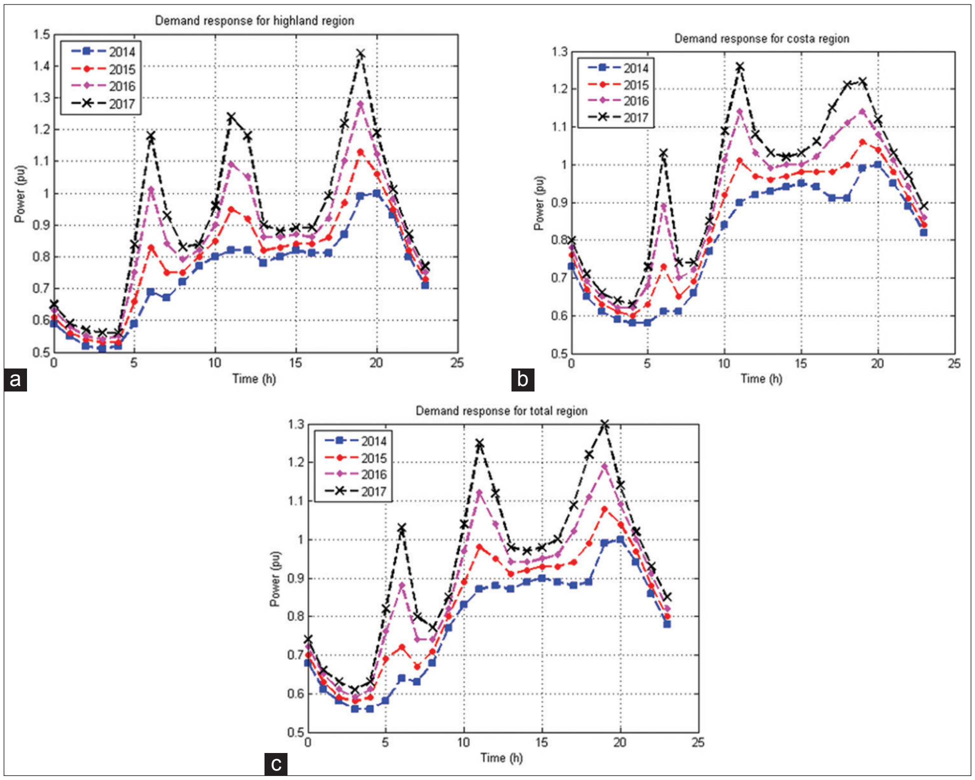


Figure 7b showed the electrical demand behavior for the highland region with 1300 MW of base power. A similar behavior of the highland region of the electrical demand has been noticed. For example, at 06:00 the electrical demand incremented from 0.61 base power in 2014 to 1.02 base power in 2017. Meanwhile, at 11:00 the increment were from 0.9 base power in 2014 to 1.27 base power in 2017. Furthermore, at 19:00 the electrical demand incremented from 0.99 base power in 2014 to 1.21 base power in 2017.

Once the demand behavior is known, and based on the analysis of cooking habits by region, it is important to analyze the overall performance with 2200 MW of base power, which can be seen in Figure 7c. The electrical demand behavior corresponds to the sum of the two previous cases.

3.3. Savings on LPG and Firewood

The energy demand increment in the BAU scenario is shown in Figure 8a. The principal energy resource demand is LPG, meanwhile the demand of electricity for cooking is minimum. The energy demand of LPG increases from 30 million GJ in 2013, to 53 million GJ in 2032.

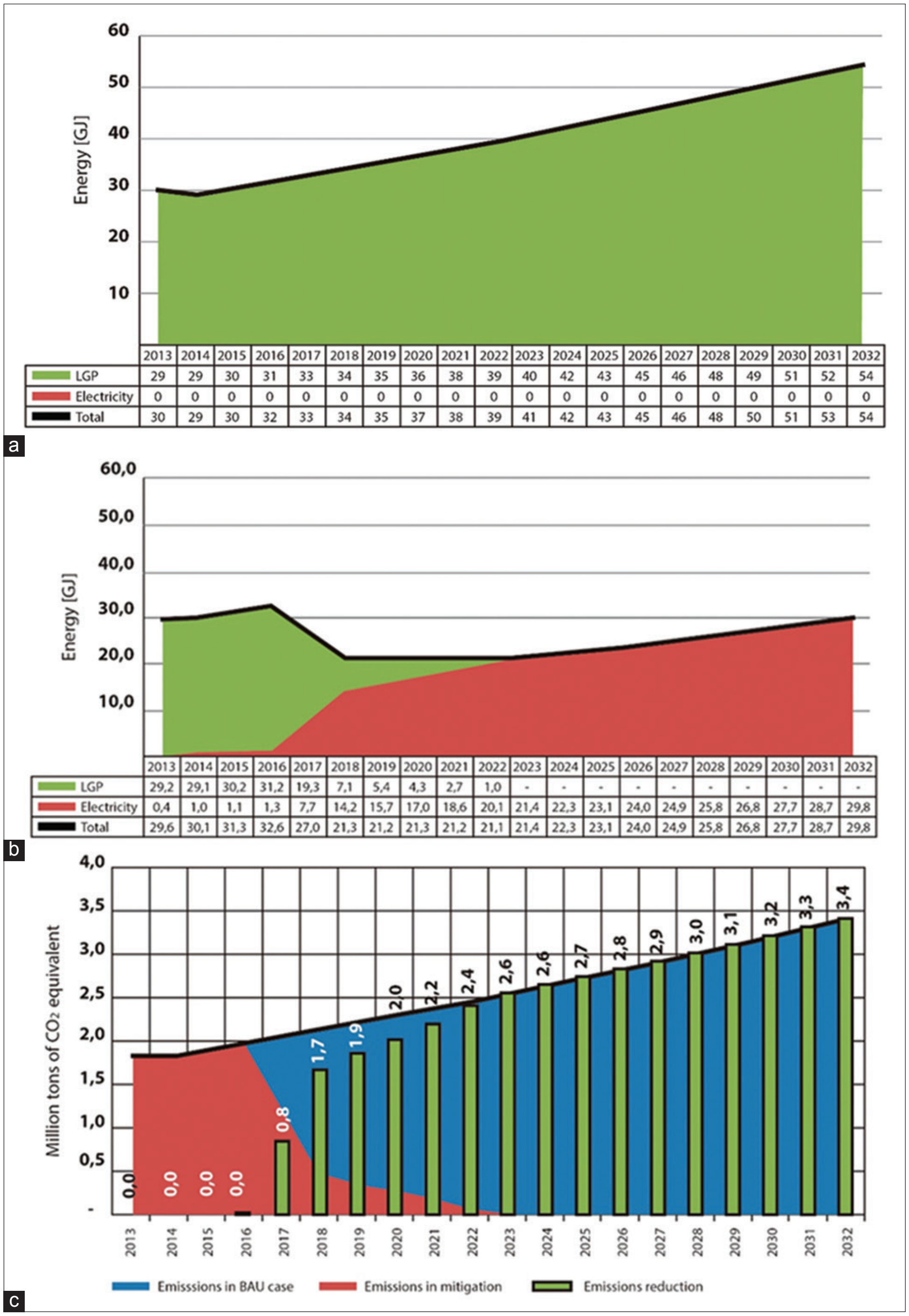
The energy demand in the mitigation scenario is shown in Figure 8b. The mitigation scenario changes the LPG stoves by inductions stoves according to the planned introduction of induction stoves in Figure 3. The results show an increment in the electricity use, which replaces the LPG consumption. This tendency is abrupt during the introduction of the induction stoves through the NECP, between 2016 and 2018. It is expected that the consumption of LPG will be almost cero in 2024. In addition, it is expected that the energy demand of LPG varies from 30 million GJ in 2013 to O GJ in 2032. While the energy demand of electricity increases until 30 million GJ of electricity in 2032.

The CO_2 equivalent emissions in BAU and Mitigation scenario through the implantation of NECP are shown in Figure 8c. The emission of greenhouse gases in the BAU scenario between 2013 and 2032 are about 50.9 million tons of CO_2. When the induction stoves are introduced in 2016 until 2023, the reduction of greenhouse gas emissions is about 40.8 million tons of CO_2 equivalent to 10.1 million tons of CO_2.

4. DISCUSSION

The decade of sustainable energy that has been declared by the United Nations, between 2014 and 2024 (Smith, 2014). The goals among this declaration include providing universal access to electricity and clean cooking facilities (Smith, 2014). Sometimes though, it is ignored that electricity is part of the solution for a clean cooking environment. In the rich world, electric cooking devices include a wide range of appliances that are starting to appear in poor areas, such as rice cookers, water pots, microwaves, and specialized devices often tailored to local foods (Banerjee et al., 2016). In this sense, the Ecuadorian government has developed a change in its energy mix to achieve energy sovereignty based on renewable energies, and it has improved the access to electricity for all the population of the country. For this purpose Ecuador is replacing the use of fossil fuels to renewable energies based on hydroelectric power plants. Along to the energy mix change operates the NECP, which is a clean cooking program, to migrate from around three million LPG stoves to induction stoves across the country by 2018 (Martínez-Gómez et al., 2016).

Figure 8: (a) Energy demand in the BAU scenario, (b) energy demand in the mitigation scenario, (c) CO_2 emissions in BAU and mitigation scenario through the implantation of National Efficient Cooking Program



Induction stoves seem to have advantages related with safety and energy efficiency compared to LPG based stoves, which stimulate users to change from LPG to induction stoves in the energy ladder (Wong and Fong, 2013). This fact is validated with the collected data in the Plan Fronteras study that took place in the rural area of the Carchi province in Ecuador. The program consisted in the addition of electricity in the fuel mix of the houses taking part of the program, removing the use of LPG and firewood. Until the implementation of the Plan Fronteras started, 92.4% of the households used the LPG cylinder and 6.69% used firewood. After the implementation of the program, the households shifted to electricity as the primary cooking fuel resource. In this way the Plan Fronteras shows a similar result as the one obtained in the program in rural Himachal Pradesh (Banerjee et al., 2016), even though the results of the studies indicate a very small fraction of shift to a clean cooking fuel.

The foremost criterion to introduce the NECP is the availability of reliable power supply, or at least some supply during cooking time (Banerjee et al., 2016). At the level of the electrical network distribution the implementation of induction cookers during the Plan Fronteras increased the energy demand. For this reason, the government is investing 11619 MUS$ in a new hydroelectric power station, a new electric transmission grid and distribution infrastructure, the NECP and a program for electric heaters (CONELEC, 2015). As a consequence of this energetic strategy, a reduction in the energy production costs through hydroelectric power plants is expected, which would allow a decreasing price of electricity. In addition, the electric grid has not presented problems in its operation regarding the behavior of the main parameters such as voltage, power factor and harmonics. The results of electric grid parameters were within the permitted levels by regulation (04/01) CONELEC, which regulates the proper functioning of the electrical network in Ecuador (CONELEC, 2015).

The insertion of recurring loads as through induction stoves with the same constant maximum power affects the entire electrical net system, so it is necessary to make readjustments to the entire transmission grid system. For that reason, it is important to analyze the C_F, as it will provide better and accurately expansion planning data for the electrical grid. As a consequence, some problems could be avoided such as the existence of transformer losses due to low charge ability, or reduction in their lifespan due to excessive load. The C_F has been calculated based on measurements considering breakfast, lunch and dinner time energy consumption in a four member family.

The CEDENAR model has been used to analyze the case study of the massive migration to induction stoves by the NECP. In the obtained analysis of Ecuador three peaks are spotted in the demand curve, caused by the recurring loads in the demand profile. In the demand response curves can also be appreciated that the demand peaks behavior differs between the highland and the coastal regions. When analyzing the highland and coastal region electrical demand at the same time, it can be determined that the maximum demand peak occurs at 19:00, which requires an additional power of 660 MW (from 1.0 base power in 2014 to 1.3 base power in 2017). Similar energy demand analysis have been performed with induction stoves in Kerala states that reveal a peak demand in electricity during the morning hours, due to the use of induction stoves (Government of Kerala, 2014).

In addition, it is necessary to compare and mention the energy expenditure in the case of maintain LPG stoves and the introduction of induction stoves in Ecuador. The results showed that energy demand will be reduced by the introduction of induction stoves by NECP between 2016 and 2018.

Furthermore, the access to the clean cooking program based on clean electricity could bring a reduction on the greenhouse gas emissions. The results showed a reduction of greenhouse gas emissions of 19.8 % tons of CO_2 between 2016 and 2032, when implementing the NECP.

5. CONCLUSIONS AND POLICY IMPLICATIONS

In this research the implementation of the Plan de Fronteras, in order to measure the social, economic and technical impact that would change LPG to electricity for cooking food has been studied. This program is previous to the technological migration from LPG stoves to induction stoves by the NECP polices.

With the implementation of the Plan Fronteras, it could be estimated the coincidence factor operating of induction stoves. This value has been used to estimate the electric demand when the NECP will be implemented.

After the addition of induction stoves the Plan Fronteras program has reduced the consumption of LPG and firewood for cooking purposes. For this reason, induction stoves can be considered as cooking technology to address the challenges of energy access and clean cooking. However, it should be taken into account that the viability of the massively introduction of induction stoves depends largely on the necessary corrections to be made to the structures of relative prices LPG and electric power.

Therefore, the policy that Ecuador is implementing to reach a clean cooking scenario by the introduction of induction stoves, that is provided with new local hydropower facilities, and replaces in this manner LPG stoves and the import of fossil fuel which is currently subsidized. It would lead to a better performance in savings on energy demand, LPG consumption and reduction on the greenhouse emissions, improving energy sovereignty, security and health benefits for families.

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