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Original scientific paper

Economics of Deforestation: Poverty, Inequality and Socio-Environmental Impacts of the Consumption of Firewood in Ecuador

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This article continues the line of research that began with the publication by Maribel Caicedo, María Cristina Vallejo, and Fernando Carrasco (2019). The most important contributions of the present article include the following. First, it is an unpublished study of the impacts on health and the environment associated with the use of firewood in Ecuador. We construct indicators of health conditions through the presence of respiratory illnesses, and we calculate deforestation, the emission of CO_2 and CO into the atmosphere through the burning of firewood, elements that in a multiple correspondence model enable us to identify the statistical significance of the associations between respiratory problems and the exposure to contamination stemming from the consumption of this energy source. Second, to our knowledge this is the first time that the concept of territorial inequality has been introduced into the study of the connections between poverty and deforestation originated in firewood consumption. Third, figures for the year 2018 are included, enabling the recent period to be identified with a situation of inequality that has a negative and growing impact on the economy of deforestation through the use of firewood in Ecuador.

Summary: We take the concept of the economics of deforestation to analyse the consumption of firewood in Ecuador during 2018. We identify poor rural populations as being at risk, since the incomplete burning of firewood generates emissions of CO_2 that can reach levels that are harmful to their health. We calculate that 95% of the impacts associated with the consumption of firewood are concentrated in rural areas, most of them in poverty conditions: the deforestation of 5,935 hectares, the emission of 1,317.38 Gg of CO_2 and 94.58 Gg of CO due to the consumption of 782.08 Gg of firewood. We suggest an energy policy based on solidarity to reduce health risks for these communities, which in turn will enable other impacts to be mitigated. However, it will be necessary to include specific policies for commercial, industrial and productive uses of firewood, where about 65% of firewood consumption and its impacts are concentrated.

Key words: Economics of deforestation, Inequity, Poverty, Consumption of firewood, Socio-environmental impacts, Ecuador.

JEL: D63, Q57, R21.

The economy of deforestation is a term that has previously been used to analyse the connections between deforestation and economic activity in Ecuador (Sven Wunder 2000). In this article we take up this concept in order to analyse the social and environmental effects of deforestation associated with the consumption of firewood.

At the present time more than 2,400 million people, about one third of the world's population, depend on the traditional use of wood-burning for cooking (Food and Agriculture Organization of the United Nations - FAO 2017). Some descriptive statistics are presented below in order to analyse connexions between firewood consumption, poverty and deforestation.

Table 1 Descriptive Statistics on Firewood Consumption, Poverty and Deforestation

Region	Woodfuel consumption[1]			Per capita woodfuel consumption[1]			Poverty[2]		Forest land[1]		
	2000	2018	CGR	2000	2018	CGR	2000	2018	2000	2017	Deforestation
	10^6 m³			m³/person			% population		10^3 ha		
North America	49	72	47% ↑	0,16	0,20	26% ↑	0,65	1,21 ↑	651.342	657.168	0,89% ↓
Central America	76	82	8% ↑	0,56	0,47	-16% ↓	10,37	3,07 ↓	91.304	86.290	-5,49% ↑
South America	185	181	-2% ↓	0,53	0,43	-20% ↓	12,71	4,04 ↓	890.817	842.011	-5,48% ↑
Ecuador	5	5	-6% ↓	0,42	0,29	-30% ↓	28,20	3,40 ↓	13.729	12.548	-8,60% ↑
Europe	107	173	61% ↑	0,15	0,23	56% ↑	1,63	0,57 ↓	1.002.302	1.015.482	1,32% ↓
Asia	808	719	-11% ↓	0,22	0,16	-27% ↓	36,00	2,39 ↓	565.912	593.362	4,85% ↓
Africa	551	700	27% ↑	0,68	0,55	-19% ↓	45,10	33,23 ↓	670.372	624.103	-6,90% ↑
World	1.794	1.941	8% ↑	0,29	0,25	-13% ↓	28,60	10,00 ↓	4.055.602	3.999.134	-1,39% ↑

Notes: CGR - cumulative growth rate. In order to make the data comparable, some figures are estimated based on region composition reported by FAO.

Source: FAO (2019)[1], World Bank (2019)[2].

Literature on the relationship between firewood consumption and poverty is developed according to the "energy ladder" hypothesis (Richard H. Hosier and Jeffrey Dowd 1987; Gerald Leach 1992; Douglas F. Barnes and Willem M. Floor 1996). This concept is "used to describe the way in which households will move to more sophisticated fuels as their economic status improves" (Satya Reddy, Narasa G. V. Reddy, and Maddula R. Reddy 1994). In other words, households do move away from wood (an inferior fuel source) to kerosene and electricity (superior fuel sources) as their economic status improves (Sudhakara B. Reddy 1995). However, beyond income, a large number of other factors determine household energy choices. These aspects are studied as energy transition processes and different policy approaches have been evaluated (some of the most relevant analysis are Glenn G. Stevenson 1989; Omar R. Masera, Barbara D. Saatkamp, and Daniel M. Kammen 2000; Bruce Morgan Campbell et al. 2003; Rasmus Heltberg 2004; John H. Y. Edwards and Christian Langpap 2005; Mehdi Farsi, Massimo Filippini, and Shonali Pachauri 2007; Greg Hiemstra-van der Horst and Alice J. Hovorka 2008; Alemu Mekonnen and Gunnar Kohlin 2008; Nicolai Schlag and Fiona Zuzarte 2008; Luukvan Kempen et al. 2009; Sylvie Démurger and Martin Fournier 2011; Tone Marie Ektvedt 2011; Iñaki Iriarte-Goñi 2013).

Another focus in the specialized literature assesses social and environmental impacts of firewood consumption. Different methodological approaches have been applied (Kedar N. Baidya 1984; Erick Boy et al. 2000; Fabio Emiro Sierra Vargas, Fabiola Mejía B., and Carlos A. Guerrero F. 2011; René Reyes et al. 2015; Julieta Krapovickas, Laura Valeria Sacchi, and Robert Hafner 2016; Alejandra Schueftan, Jorge Sommerhoff, and Alejandro D. González 2016; Luz Moreira Coelho Jr., Kalyne de Lourdes da Costa Martins, and Monica Carvalho 2018).

As a general trend, firewood consumption is expected to decrease over time as a result of poverty alleviation but also due to progressive substitution of this energy source for superior ones. Both of these factors should translate into less deforestation.

[1] **Food and Agriculture Organization of the United Nations.** 2019. Data. http://www.fao.org/faostat/es/#data (accessed September 26, 2019).

[2] **World Bank.** 2019. World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (accessed February 26, 2019).

However, from descriptive statistics at the regional level, it is possible to determine that these patterns are only evident for Asia. In Central America, South America, Africa and globally, despite the fact that *per capita* consumption of wood fuels and poverty decrease, deforestation grows. On the contrary, in Europe there is a decline in poverty and deforestation, although *per capita* consumption of wood fuel increases. How to understand such differences? We argue that only general trends should be considered from international data sources. Information collected locally will be a more accurate and reliable base for the analysis[3].

In the Ecuadorian territory, although the consumption of firewood has been decreasing with its substitution by other sources of energy, for example liquefied petroleum gas (LPG), its use remains significant. According to population and housing censuses, in the last three and a half decades the incidence of the use of firewood has undergone an important change: whereas in 1982 43.7% of households in the country used firewood, in 2018 only 5% did so.

Within the Andean region consumption in Ecuador is only higher than in Bolivia, whereas Colombia and Peru use more than four times as much. For example in 2017 the consumption of firewood as energy in the Andean countries was calculated at 22kg in Bolivia, 33kg in Ecuador, 140kg in Colombia and 158kg in Peru (Latin American Energy Organization 2018). According to the Latin American Energy Organization (locally OLADE) Statistics Manual (Fabio García, Marco Yujato, and Adiela Arenas 2017), information on domestic consumption is given for urban and rural areas and its end uses are for lighting, cooking, boiling water and heating, amongst others. In the case of Ecuador, in addition to the residential use of firewood, it provides information on industrial use, which includes the consumption of energy to transform raw materials into end products. However, commercial and service sector use[4] of this fuel are not reported in the energy balance sheets. In other words, there must be an undisclosed use of wood in restaurants, brickworks, bakers and poultry farms, amongst others.

Thus the data on the use of firewood and the associated deforestation are limited. Some figures are now available for recent times, but the study of this aspect of the economy is still in its early days in the case of Ecuador. There are some reports that can be mentioned, covering different time periods and also different levels of analysis, which makes comparison difficult.

The Ecuadorian Headquarters for Agricultural Services (locally CESA) (1992) calculates an annual average of local use of 13.5 m^3 for a family of five. This calculation is based on information collected in a survey carried out in 1991 in three communities in the parish of Pilahuin, province of Tungurahua. However, these figures appear to overestimate the aggregate consumption as it neglects the fact that the structure and characteristics of households determine the levels of use and therefore require a non-

[3] Most of the wood fuel statistics are estimated by FAO because only 10 or 15 percent of the global production reported by FAO is based on figures sent by countries. Estimations are based on constant *per capita* figures, which could result in overestimation of the actual wood fuel consumption (Adrian Whiteman, Jeremy Broadhead, and Jamal Bahdon 2002).

[4] This corresponds to the category of trade and services that includes wholesale and retail activities in the public and private sector, national defence, police, financial institutions, hotels and restaurants, warehousing, airports and seaports, education, health, culture, entertainment, etc. (García, Yujato, and Arenas 2017).

linear treatment. For his part Diego Proaño Egas (2005) studied the contribution of the forest in terms of financial income in wood for burning and established a consumption of 6.4 m^3 per family per year as an average at the national level for 1990.

A recent study analyses the household fuel mixes in peri-urban and rural communities in two Coastal and two Andean provinces in Ecuador (Javier Martínez et al. 2017, p. 1). This article assesses "cooking fuel ownership and use patterns after long-term LPG access and the reach of induction stoves promoted through a recent government program". In the same line, another research has found "prevalent use of biomass (firewood) in conjunction with clean cooking fuels in the northern Ecuadorian province of Carchi" (Carlos F. Gould et al. 2018). Both articles, however, focus on quantifying the number and characteristics of households that consume firewood, as well as determinants of such consumption, but not on the quantity of firewood they use.

Finally, the most recent study is that of Caicedo, Vallejo, and Carrasco (2019), according to which the consumption of firewood at national level in 2017 was assessed at 6.37 m^3 per family per year. The advantage of this information is the statistical consistency of the calculation method used. The assumption of economies of scale in household consumption minimizes possible distortions in estimates which can become commonplace if the different levels that are used to structure household consumption are disregarded. In this article we have applied this same methodology to produce estimates for 2018, while our unit of analysis is households in urban and rural areas. We argue that there are different levels of consumption at the national level, so that the incidence of problems associated with the use of firewood, such as poverty, loss of forest cover, contamination from burning this resource and effects on health, turns out to be more significant in rural areas.

We set out to measure the effects on health, the emission of greenhouse gases (GHG), deforestation and their unequal distribution in urban and rural areas of Ecuador, in order to analyse them through a multiple correspondence factor model, that links these impacts with the quality of life of the communities. With these elements we suggest that there are economies that are contingent on deforestation through the consumption of firewood that become a "poverty trap". It is a trap because this activity forms a basic part of the maintenance of poor families. However, while it may be less feasible to improve their quality of life, this will tend to maintain or increase the consumption of firewood, thereby contributing to environmental degradation in terms of deforestation, atmospheric contaminants through the release of CO_2, CO and other GHG which are the cause of health problems that chiefly affect the most vulnerable communities in rural areas. We consider that measuring these impacts is useful in order to define public policy strategies designed not only to mitigate GHG but mainly to improve the quality of life of these communities with an energy policy based on solidarity. At the core of our proposal is the expansion of subsidies to the substitution of fuelwood by other energy sources, in particular LPG in the most vulnerable communities. Although our argument is solidarity, some other studies also recommend subsidies to promote the consumption and favour the transition to a clean cooking fuel (Karin Troncoso and Agnes Soares da Silva 2017; Ashlinn K. Quinn et al. 2018; Joshua Rosenthal et al. 2018; Gould et al. 2020). However, another line of research points to the opposite (Martínez et al. 2017).

With regard to the health problem, respiratory infections are amongst the main causes of mortality related to the environment, representing 567,000 deaths annually at worldwide (World Health Organization - WHO 2016). A major part of the problem is to be found in developing countries, where households use wood or other biofuels without adequate ventilation and occupants are exposed to high levels of contaminants such as carcinogenic and toxic substances. José Rogelio Pérez-Padilla, Justino Regalado-Pineda, and Angel Onofre Morán-Mendoza (1999) claimed that amongst the causes of acute respiratory infections in children, in addition to chronic bronchitis and bronchial obstruction in adults is exposure to wood smoke, with women specifically at much greater risk compared to people who do not suffer from such exposure.

With regard to the environmental problem, as stated by the FAO (2006) the use of firewood in the rural sector is likely to have the greatest effect on native forests, with the threat to various life forms and the cultural integrity of those who depend directly on the forests, who are usually poor and vulnerable people (the elderly, children and women). The dependence of the poor in rural areas on the services of ecosystems is rarely measured, or else partial or non-comparable statistics are used, as in the case of Ecuador. Therefore, in this article we studied deforestation attributable to the consumption of firewood for families' subsistence activities in keeping with their state of poverty. One important find from this evaluation is the identification of a non-significant impact on native forests. However, a complete understanding of the economics of deforestation due to the use of firewood requires the compilation of reliable statistics on the commercial and industrial uses of this resource, which are not available. There are reasons to believe that most deforestation caused by the use of firewood can be identified with these activities (Caicedo, Vallejo, and Carrasco 2019).

This article is a contribution to understanding and specifying the recent volume of forestry resources that households use for food-cooking. This information serves as a basis for the analysis of the social and environmental impacts that stem from its use, its unequal territorial distribution between urban and rural areas and the poverty trap that reproduces these impacts.

From a methodological point of view, these results will contribute to the material flow cost accounting (European Commission 2001) which is available for Ecuador in the work of Vallejo (2010). We sought the quantification of a biomass flow focused on subsistence, which is generally dismissed from official national accounts because it carries such little economic weight, although it is a basic factor in the living conditions of the households that depend on its use. Here we argue that its appropriate consideration in biophysical accounts can become a central element when defining suitable strategies for the protection of the environment and the improvement in living conditions of the communities who need this energy source (Sierra Vargas, Mejía B., and Guerrero F. 2011), in particular from what we have called an energy policy based on solidarity.

In fact, until now studies of the forestry sector in Ecuador have scarcely been used as a component of the public policy decision making, despite the fact that some of them outline useful elements for structuring an environmental strategy (Merylyn McKenzie 1994; Wunder 2000; Mario Añazco et al. 2010; Sierra Vargas, Mejía B., and Guerrero F. 2011; Riyong Kim Bakkegaard et al. 2012). On the other hand, other studies emphasize a different kind of analysis, which is more descriptive of the forestry situation (CESA 1992; Wunder, Enrique Laso, and Fernando Guerrón 1996; Proaño Egas 2005). However, the point that all these studies have in common is the lack of consistent and up-to-date figures on deforestation. This is a weakness that persists in studies of this kind. In particular, the most recent base figures available on the domestic use of firewood come from the study carried out by the Bakkegaard et al. (2012) whose analysis on other scales can only be carried out on the basis of statistically consistent projections.

1. Methods

This article utilises a two-step methodological strategy. First, we classify the use of firewood by households in accordance with their socio-economic and demographic characteristics. Depending on the size of the household, it is possible to identify economies of scale in the consumption. The study emphasises different performance patterns between urban and rural areas in order to discuss problems of rural inequality, deforestation, and the generation of CO_2 and CO emissions in accordance with the methods that are described further in this section. The second part of the methodological strategy aims to evaluate the social and environmental vulnerability associated with the consumption of firewood. We use a factor analysis model with multiple correspondences to study this aspect.

1.1 Sources of Information and Scale of Analysis

This research uses official figures which come from five main sources: the FAO (2012) for data on the consumption of firewood; the Ministry of the Environment in Ecuador (MAE 2019b) for the administrative register of forest-covered territory (native and deíforested) during the period 2014-2016; the National Institute of Statistics and Censuses (locally INEC) to determine the territorial distribution of firewood use and of deforestation, the characteristics of the people, their sociodemographic, socioeconomic and housing situation, as well as the health conditions of the families; finally, the Intergovernmental Panel on Climate Change (IPCC 1996, 2006), García, Yujato, and Arenas (2017) and OLADE (2018) for guidelines and information on emissions of carbon dioxide (CO_2) and carbon monoxide (CO) that come from the burning of fuels.

The study of Bakkegaard et al. (2012) carried out in the Amazonian province of Sucumbíos, covers a total of 673 people in 417 households are involved, which enables different types of users to be classified because depending on the size of the household it is possible to identify economies of scale in the consumption of firewood. These groups have been proposed on the basis of the latest national employment survey available from the INEC for 2018, and the results have been statistically validated for a total of 11,454 households in the urban sector and 221,186 households in the rural sector. This information can be cross-checked with data on health from the quality of life survey of 2014.

1.2 Methods of Analysis

Projections of Firewood Consumption

In this study we use the levels of consumption by size of household established by Caicedo, Vallejo, and Carrasco (2019) based on the Bakkegaard et al. (2012) study in the province of Sucumbíos, which have been identified as statistically significant based on the coefficient of variation[5], homogeneity of variances test (ANOVA)[6] and the Levene's statistic.

These figures provide a non-linear distribution of the consumption of firewood and charcoal at the household level measured by weight (kg). The figures for volume (m^3) of firewood used by each type of household are obtained by applying specific forest densities taken from the World Agroforestry Centre (ICRAF 2019)[7] for each type of tree reported as harvested or cut over one year per household, according to the forest resources assessment of Bakkegaard et al. (2012). This distribution of firewood consumption is statistically significant in order to establish projections on a national, urban and rural scale in accordance with the sociodemographic structure of the households in 2018.

Deforestation Associated with the Consumption of Firewood and Its Territorial Distribution

We calculated the loss of forest associated with the consumption of firewood on the basis of the most recent historical data for deforestation, which correspond to the period 2014-2016 (MAE 2019b). For this purpose, we considered the volume of firewood or charcoal consumption corresponding to registered households in urban and rural areas in each province of Ecuador in 2018, according to the reports of the latest employment survey of the INEC.

The consumption of firewood measured by volume is used to quantify the hectares taken up by this activity. To this end we used as a conversion factor the inverse of the volume of wood in each hectare of residual native forest, in other words 241.68 m^3/hectare with figures from MAE (2019a), which translates into 0.0041 hectares per m^3 of firewood used. In this way we can also calculate the incidence of forestry loss that stems from the consumption of firewood as a percentage of total deforestation:

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[5] The coefficient of variation is defined by the quotient between the standard deviation and the mean, whose relationship measures the size of the data dispersion, in this case applied to the strata identified and the global population. A stratum is a homogeneous group of elements and heterogeneous compared to any other stratum, so that in the case of the sociodemographic strata, homogeneity is a desirable characteristic. A commonly applied criterion defines a community as homogeneous if this statistic is less than 20%, otherwise it is heterogeneous.

[6] The main objective of this model is to establish whether there are any differences between consumer groups, in other words to verify the heterogeneity of the index of sociodemographic conditions between strata. To that end the probability of statistical significance has to show statistically significant differences (*p*-value < 0.05 for 95% reliability).

[7] **World Agroforestry Center (ICRAF).** 2019. Worldwide Open Access Tree Functional Attributes and Ecological Database: Global Wood Density. http://db.worldagroforestry.org//wd (accessed October 01, 2019).

$$Deforestation_{Firewood} = \frac{1}{241.68\,\frac{m^3}{ha}} = 0.004138\,\frac{ha}{m^3}. \quad (1)$$

Main GHG Generated from Firewood Burning: CO_2 and CO

Emissions of CO_2

We produced these estimates based on the IPCC guidelines (1996), according to which the amount of CO_2 emitted into the atmosphere depends fundamentally on two factors: the quantity of fuel used and the carbon content of each fuel.

(a) The apparent consumption of the fuel, measured in units of energy, in this case terajoules (TJ) or 10^{12} joules, represents the amount of an energy source that is needed to cover the internal needs of a given territory. It is calculated as:

$$AC = P + M - X - B - ENU + VI + TR, \quad (2)$$

in which,

AC - apparent consumption;
M - total import of energy;
ENU - energy not used;
TR - transfers;
P - primary energy production;
X - total export of energy;
VI - variation of inventories;
B - fuels sold to ships and aircraft on international voyages (Bunker).

These data can be taken from the national energy balance sheet. In this case we calculated AC as corresponding to a tonne of firewood. For this purpose, first the caloric content of each tonne of firewood has to be identified. Using figures from García, Yujato, and Arenas (2017) we know this to be 2.59 boe. In order to get information in comparable units, a conversion factor of 172.22 boe/TJ is used (García, Yujato, and Arenas 2017).

$$AC_{t\ Firewood} = 2.59\,\frac{boe}{t\ Firewood} \times \frac{1}{172.22\frac{boe}{TJ}} = 0.02\,\frac{TJ}{t\ Firewood}. \quad (3)$$

(b) The carbon content of the fuels is measured on the basis of a carbon emission factor for each fuel. However, in order to calculate the emissions this heading has to be adjusted by the proportion of carbon that is not oxidised and the amount of carbon that is stored.

The carbon content (CC) which the IPCC guide (2006) suggests should be used as a default is 30.50 tC/TJ for the case of wood, a factor which when multiplied by the apparent consumption produces a carbon content of 0.46 t C/t firewood. This figure coincides with the carbon content suggested by García, Yujato, and Arenas (2017) for firewood in the range of 45% to 50%. In our assessment we do not consider carbon storage for firewood as non-energy uses are not recorded for this fuel; and the oxidised carbon factor is taken as 1, following the default values recommended in the IPCC guidelines (2006). In this way the emission of carbon is not adjusted for storage and the incomplete oxidation of carbon. It is calculated at 0.46 tC.

$$CC_{t\ FIREWOOD} = 0.02\frac{TJ}{t\ Firewood} \times 30.50\frac{tC}{TJ} = 0.46\frac{t\ C}{t\ Firewood}. \tag{4}$$

In order to translate this calculation into CO_2 emissions the molecular mass (*MM*) of the CO_2 in each unit of carbon needs to be considered. In the case of carbon dioxide (CO_2), consisting of one molecule of carbon (C) and two of oxygen (O), one molecule of C weighs 12 grams and each molecule of O weight 16 grams, in other words the molecular mass of CO_2 is: 12 + (2 x 16) = 44 grams. Therefore, each gram of C will contain 3.67 grams of CO_2 (44/12). This value enables the emissions of CO_2 to be calculated from the burning of this fuel:

$$MM_{CO_2} = \frac{44\ g\ CO_2}{12\ g\ C} = 3.67\frac{g\ CO_2}{g\ C} = 3.67\frac{t\ CO_2}{t\ C}. \tag{5}$$

$$Q_{CO_2 t\ Firewood} = 0.46\frac{t\ C}{t\ Firewood} \times \frac{44\ t\ CO_2}{12\ t\ C} = 1.68\ \frac{t\ CO_2}{t\ Firewood}. \tag{6}$$

Our results show that the combustion of every tonne of firewood generates emissions into the atmosphere of 1,684.46 kg of CO_2. This figure is very similar to the estimates suggested as a default in the IPCC guide (2006) for wood, that is 112,000 kg/TJ, which converted to comparable units means 1,686.97 CO_2/t firewood[8]. However, there are wider differences with the coefficients of emissions suggested by OLADE, which in the case of consumption in the residential sector gives a factor of 92,893 kg/TJ which is equivalent to almost 1,400 kg CO_2/t firewood. It is important to note that the calculations of OLADE are lower because they are adjusted to a lower carbon content (29.9 tC/TJ) and an oxidised carbon coefficient of 70%.

Emissions of CO

We have estimated the emissions of this GHG because in countries like Ecuador firewood and other solid fuels like agricultural waste and charcoal are usually burnt in open fires that are fed with firewood, which causes an incomplete combustion process. An ideal complete combustion of firewood provides heat, light and low levels of gases and water vapour. However, in the majority of cases the opposite occurs, since in practice there is an incomplete combustion producing a large quantity of gases, particles and chemical compounds similar to those produced by cigarette smoke, attacking somatic cells especially in prolonged exposures, where there is an interaction and mixture of contaminants forty times more dangerous than those generated by tobacco smoke. The human response in the presence of contaminants in the air is very varied and can go from slight symptoms such as dizziness, headaches and drowsiness to serious respiratory or bronchial problems or even death (María José Berenguer and Félix Bernal 2000). In this section we analyse the releasing of CO that results from the incomplete combustion of firewood (Kirk R. Smith 2006).

For this estimation we considered the emission factors reported by García, Yujato, and Arenas (2017), according to which the consumption of firewood in the residential sector generates CO emissions at 8,029 kg/TJ.

We proceeded in a similar way to the estimation for the emissions of CO_2. We considered the *AC* corresponding to a tonne of firewood, which we calculated in the

[8] Applied as conversion factor 0.0151 TJ/t firewood.

previous section with a caloric content of firewood of 2.59 boe/t and the conversion factor of 172.22 boe/TJ (OLADE 2017). By applying the emissions factor of CO we calculate that 120.94 kg of CO is emitted per tonne of firewood consumed:

$$Q_{CO} = 0.02 \frac{TJ}{t\ Firewood} \times 8{,}029 \frac{kg\ CO}{TJ} = 120.94 \frac{kg\ CO}{t\ Firewood}. \quad (7)$$

Different emission factors are reported in other sources. A study for Africa (FAO 1999) calculated 69 kg CO/t firewood. The IPCC (1997) suggested 80 kg CO/t firewood, a default factor for the case of uncontrolled emission in the burning of fuels in the residential sector. We consider that our calculations based on the figures reported by OLADE correspond better to Latin American reality. However, to confirm the validity of these results we carried out a sensitivity analysis in section 2.5 so as to establish whether there continues to be a connection between the CO emissions and possible harm to the health of the people who use firewood for cooking.

A Factor Model of Multiple Correspondence in Order to Study the Determinants of Firewood Consumption

For this analysis we first calculated a poverty index for 2018 using the method of unsatisfied basic needs (locally NBI) introduced by the Economic Commission for Latin America and the Caribbean (locally CEPAL) at the beginning of the 1980s (CEPAL 1995). The people can be classified into different poverty levels according to satisfaction or deprivation in five conditions (access to housing, access to basic services, economic capacity, access to primary education and overcrowding). This index can take the values of 0 to 5, and the poverty line has a value of 1, so that those who have no unsatisfied needs are classified as "non-poor", those who are deprived of a need in any one of the five dimensions are classified as "non-destitute poor", while those with more than one unsatisfied need are classed as "destitute poor".

In addition, we calculated the average emission values of CO per household for each level of consumption. These figures contrast with the health data on account of the presence of respiratory illnesses, poverty, sex, age, smoking habits and low birth weight. The interactions between levels of the consumption of firewood and this group of variables were evaluated based on a factor model of multiple correspondence, applied in the most recent quality of life survey (National Institute of Statistics and Censuses - INEC 2014) which makes it possible to analyse the information on health conditions. The object of the factor analysis models of correspondences is to analyse and describe in graphic form and by means of a Cartesian plane which categories of a variable *X* are associated or correlate with (or are independent of) the categories of another variable *Y*. In this way we can establish types or groups of individuals: if two categories of variables (qualitative variables or variables of attributes) are related we refer to this as simple correspondence and if more than two it is referred to as multiple correspondence analysis.

From Firewood to LPG: A Clean Conversion?

The last indicator that we set up in our analysis was emissions of CO_2 caused by the burning of LPG. This estimate was for comparative purposes, with the aim of analysing the advantage in terms of emissions of an energy conversion aimed at promoting the use of LPG instead of firewood as a fuel for domestic activities.

This calculation follows a process similar to that described in the case of the emissions from the burning of firewood, adjusted for conversion factors. Our starting point is the figures for the use of LPG in energy units, in this case joules (J). Based on the reports of García, Yujato, and Arenas (2017) we calculated that the energy associated with each tonne of LPG amounts to 0.0443 TJ, using a conversion factor of 22,571.31 kg of LPG/TJ. In addition, we assumed a default emission factor of carbon of 17.20 t C/TJ (IPCC 2006), which produces a carbon content of 0.76 tC. In this case we have not included figures for carbon storage[9] because in the Ecuadorian energy balance sheets there is no record of any non-energy use of LPG which is required for this calculation. In addition, a carbon oxidation factor of 99% is included (García, Yujato, and Arenas 2017) and the relationship of the molecular masses of CO_2 and C in order to obtain an emissions factor of 2.77 t CO_2/t LPG.

$$CC_{t\,LPG} = 0.04\,TJ \times 17.20\frac{t\,C}{TJ} = 0.76\,t\,C. \quad (8)$$

$$Q_{CO_2 t\,LPG} = 0.76\,\frac{t\,C}{t\,LPG} \times 0.99 \times \frac{44\,t\,CO_2}{12\,t\,C} = 2.77\,\frac{t\,CO_2}{t\,LPG}. \quad (9)$$

This figure is similar to the default value that was given in the IPPC guide (2006), which is 63.100 kg CO_2/TJ, equivalent to 2.80 t CO_2/t GLP. Another source of contrast is the work of Carlos Samaniego-Ojeda, Orlando H. Álvarez Hernández, and Jorge Maldonado Correa (2016, p. 63) who produced estimates of emissions associated with the use of water heaters that use LPG as a fuel for the city of Loja in the Interandean highlands of Ecuador. These authors calculated that each cylinder generates 43,224.8 grams of CO_2. This figure is equivalent to 2.88 t CO_2/t LPG for a 15kg cylinder[10].

In this case we did not calculate the CO emissions because these would be below the standards defined as dangerous to health by the WHO (2005). This aspect is confirmed by Samaniego-Ojeda, Álvarez Hernández, and Maldonado Correa (2016), who estimate an emission of CO per gas cylinder of 7.6 grams for the city of Loja, equivalent to 0.507 kg CO/t LPG.

[9] With the inclusion of this factor a storage figure of 80% could be considered in the case of LPG, as per the OLADE methodological guide (García, Yujato, and Arenas 2017).

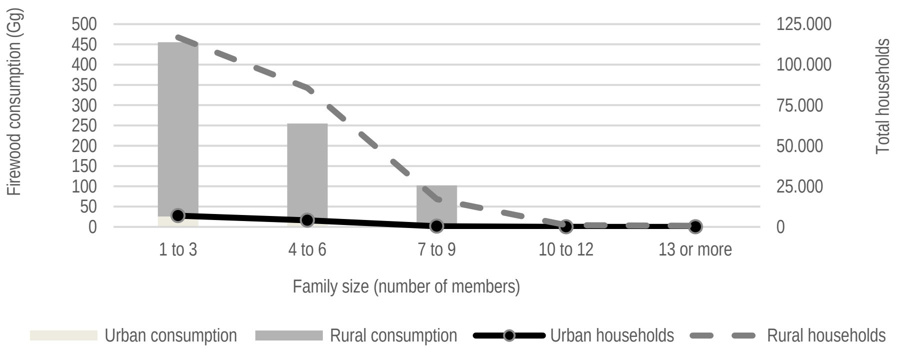
[10] This figure can be adjusted for the unusable part of each cylinder. Cristhian Wilfrido Aguilar Romero (2012) calculates that only 13.64kg of each cylinder is used.

2. Results

2.1 Consumption of Firewood Projections: A Non-Linear Model of Economies of Scale within the Household

Our estimate of the consumption of firewood for 2018 confirms the results previously produced by Caicedo, Vallejo, and Carrasco (2019) between 1982 and 2017, in relation to a non-linear structure, with decreasing returns according to the size of the household and where usage predominates among households in conditions of poverty. What is original in this study is that we identify this same structure of firewood consumption not only in the national context but also in urban and rural areas and therefore similar conditions are projected for CO_2 and CO emissions as well as deforestation.

The levels of consumption that are used in this document and their statistical significance are stated in Figure 1.



Notes: Coefficient of variation for levels of use < 0.20. ANOVA test statistical significance $p = 0.037$ and Levene's test statistical significance $p = 0.001$* for the average consumption per level of household.

Source: Caicedo, Vallejo, and Carrasco (2019), INEC (2019), ICRAF (2019).

Figure 1 Consumption of Firewood according to the Size of the Household in Urban and Rural Areas

2.2 Deforestation Associated with Firewood Consumption and Territorial Distribution

In Table 2 we show the extent of deforestation arising from the consumption of firewood, according to which in 2018 6,235 ha, 95% of which is to be found in rural areas, can be attributed to the use of this resource. For an annual average deforestation of 94,353 ha (MAE 2019b) it can be calculated that the incidence of firewood consumption is 6.61% of deforested territory and rural areas accounted for 6.29%. Our estimates can be examined in Table 2 consistent with the levels of consumption per household. Deforestation in rural areas by consumption of firewood is estimated at 3,279 ha due to consumption in households with up to three members. Another nucleus of consumption is to be found in 102,617 rural households with 4 to 9 members in conditions of overcrowding (with the number of people per household higher than three), where consumption reached 623,813 m^3 in 2018 and 2,581 ha/year were deforested. Finally, there are 1,777 households with extreme overcrowding (with the number of people per household higher than nine), which are only to be found in rural areas, where consumption of firewood represents in terms of deforestation a loss of 75 ha in total. Deforestation arising from its consumption at all levels of urban households barely reached 300 ha in 2018.

Table 2 Deforestation in accordance with the Consumption of Firewood in Urban and Rural Areas

Family size	Number of households cooking with firewood and charcoal			Firewood consumption	Aggregate firewood consumption			Firewood consumption deforestation*		
	National	Urban	Rural	Mean m^3/household	National m^3	Urban m^3	Rural m^3	National ha	Urban ha	Rural ha
Caicedo, Vallejo and Carrasco (2019)	INEC (2019)	INEC (2019)	INEC (2019)	Caicedo, Vallejo and Carrasco (2019)	Authors' estimate	Authors' estimate	Authors' estimate	Authors' estimate	Authors' estimate	Authors' estimate
1 to 3	123,766	6,974	116,792	6.78	839,715	47,317	792,398	3,474	196	3,279
4 to 6	89,649	4,076	85,573	5.12	459,350	20,885	438,465	1,901	86	1,814
7 to 9	17,448	404	17,044	10.87	189,745	4,398	185,348	785	18	767
10 to 12	1,087	0	1,087	14.22	15,469	0	15,469	64	0	64
13 or more	690	0	690	3.93	2,714	0	2,714	11	0	11
Total	232,640	11,454	221,186	6.48	1,506,994	72,599	1,434,395	6,235	300	5,935

Notes: * calculated with a deforestation factor of 0.004138 ha/m^3 firewood.

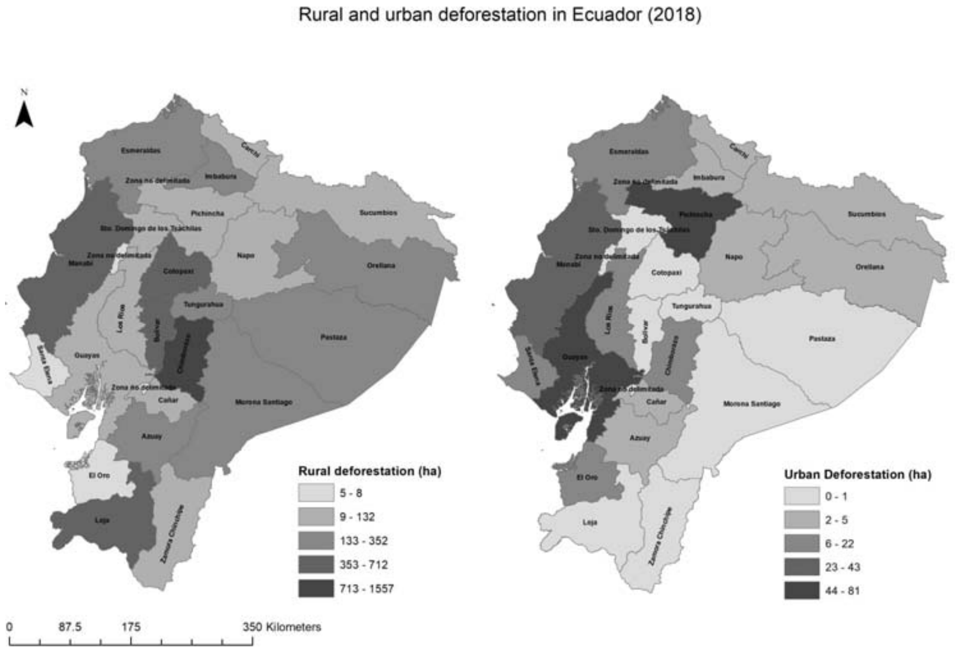
Source: Authors' compilation.

The territorial distribution of deforestation associated with the consumption of this energy source during 2018 is shown in Figure 2. The provinces where the loss of forest is greatest are found in the Interandean region with 3,933 ha, 97% of which are located in rural areas. The provinces of Chimborazo (40%), Cotopaxi (14%) and Loja (13%) account for 67% of deforestation in this region. In the Coastal region 1,379 ha were lost in 2018 to these activities, mainly in the rural areas (87%). The provinces with the highest consumption and deforestation in this region are Manabí (55%), Esmeraldas (16%) and Guayas (15%). Finally, the loss of forest in the Amazonian region reached 917 ha, of which 99% occurred in rural areas. Their highest concentration was in Morona Santiago (38%), Orellana (21%) and Pastaza (18%).

In the urban areas Pichincha (27%), Guayas (24%) and Manabí (14%) were the provinces with the highest level of deforestation.

These results seem to be consistent in the sense that the Amazonian region has rains during most of the year, so that the available firewood is damp or soaking and therefore burns badly or does not heat up. On the other hand, in the Interandean region people endure low temperatures and use the firewood not only for cooking but also for heating.

Furthermore, based on data for the consumption of firewood and the felling of trees, it is possible to claim that a total of 4,332,701 m^3 of wood would be used as firewood (MAE 2019a). Of this total MAE reports that the use for production or commercial purposes was 2,825,708 m^3; in other words, 35% of the firewood was for domestic consumption and 65% for commercial, industrial or productive use (by restaurants selling grilled chicken, rotisseries, brickworks, bakers and chicken breeders, among others). It is worth noting that the level of firewood consumption in informal establishments will certainly be higher, although official figures do not take no account of this information.



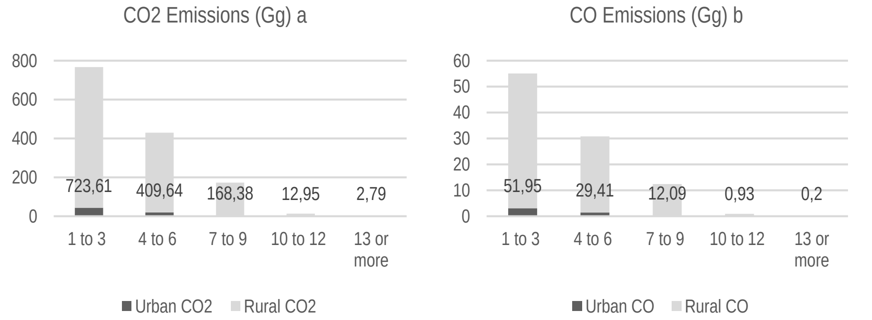
Source: INEC (2019), MAE (2019a).

Figure 2 Territorial Distribution of the Domestic Consumption of Firewood in Ecuador

2.3 Principal GHG Emissions Generated by the Burning of Firewood: CO_2 and CO

With a national average consumption of firewood of 3,532 kg per household per year, a total of 232,640 families generate 66.72 Gg of CO_2 and 4.79 Gg of CO in urban areas, while in the rural areas the figures are 1,317.38 Gg of CO_2 and 94.58 Gg of CO. In other words, the emission of these gases in the rural areas is 19 times higher than in the urban areas. In addition, the emission of CO_2 is almost 14 times higher than that of CO. However, the health problems of the people exposed to these emissions are mainly from CO emissions.

Owing to the non-linear structure of the consumption of firewood in households, the emission of GHG shows a similar pattern, that is, 88% of GHG emissions are concentrated in households with up to 6 members, while the remaining 12% are in households with more than 7 members. These results can be seen in Figure 3.



Notes: [a] Significant ANOVA test (*p* = 0.035) and significant Levene's test (*p* = 0.002*). This is calculated with an emission factor of 1.68 t CO_2/t firewood. [b] Significant ANOVA test (*p* = 0.035) and significant Levene's test (*p* = 0.002*). This is calculated with an emission factor of 0.12 t CO/t firewood.

Figure 3 Definition of the Consumption of Firewood according to the Principal GHG

2.4 Distribution of the Consumption of Firewood, Deforestation and Emission of CO_2 and CO in Conditions of Inequality and Poverty

Total poverty is produced by the sum of the categories of non-destitute poor and destitute poor and is estimated to affect 38% of households in 2018. With a multiple relationship between NBI, the fuel used by households and the property location, it was found that in 2018 of the 232,640 households that used firewood, representing 5% of the total use of fuels in Ecuador, 83% was used by poor families. The majority of households that used firewood in 2018 were in rural areas; i.e., 221,186 households, which used 1,434,395 m^3 of firewood. Of the rural consumption of firewood, 85% was accounted for by poor families, with a total of 1,222,692 m^3 of firewood, a figure almost 40 times greater that urban consumption among poor families (31,007 m^3). Finally, among non-poor households, rural consumption of firewood stood at 14% and urban consumption at 3% of the national total.

These figures show that the consumption of firewood has a mainly rural character and within that rurality it is to be found in households in conditions of poverty. However, from a broader perspective on a national scale, of the 4.6 million households registered in Ecuador in 2018, firewood continues to be the second most used fuel, but is far behind the 92% that used LPG.

From a reading of the deforestation associated with these consumption figures, poor families in rural areas account for 81% of the loss of 5,051 ha of forest which arises from this specific use of wood. By contrast, with regard to total deforestation which comes to 94,353 ha, the incidence of these families is 5.36%, while the non-poor families account for barely 1.11% of this loss, with 1,048 ha affected by the consumption of this energy source.

The structure of the consumption of firewood that we have set out also conditions the distribution of associated GHG emissions. In fact, in the rural areas 1,317 Gg of CO_2 and 95 Gg de CO are generated, of which 75% comes from poor households. On the other hand, only 5% of the total emissions occur in urban areas, that is, 67 Gg of CO_2 and almost 5 Gg of CO. In this case, however, the main responsibility for the emissions falls on the households who are not in conditions of poverty, who emit 57% of the GHG generated in urban areas, that is, 38 Gg of CO_2 and almost 3 Gg of CO. This information is summarized in Table 3.

Table 3 Distribution of Deforestation and Release of GHG in Ecuador Relating to the Consumption of Firewood, in accordance with the Poverty Situation and the Location of the Properties 2018

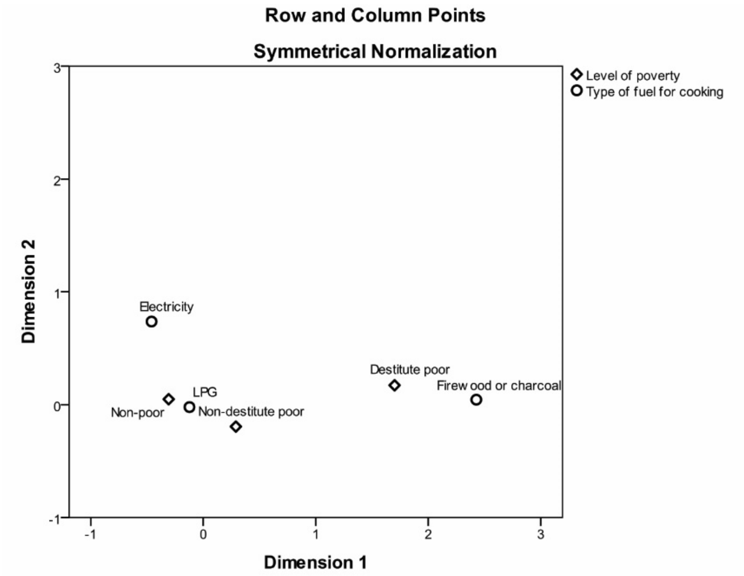
Poverty distribution	Number of households cooking with firewood and charcoal		Firewood consumption by household (m^3/household)		Impacts of firewood consumption					
					Deforestation (ha) [a]		CO_2 emissions (Gg) [b]		CO emissions (Gg) [c]	
	Urban area	Rural area	Urban area	Rural area	Urban area	Rural area	Urban total	Rural total	Urban total	Rural total
	INEC (2019)	INEC (2019)	Bakkegaard et al. (2012)	Bakkegaard et al. (2012)	Authors' estimate					
Non-poor	6.530	33.875	6,37	6,25	172	876	38,24	194,54	2,75	13,97
Non-destitute poor	3.853	91.476	6,22	6,49	99	2.458	22,02	545,30	1,58	39,15
Destitute poor	1.071	95.835	6,59	6,56	29	2.601	6,46	577,55	0,46	41,46
Total	11.454	221.186	6,34	6,49	300	5.935	66,72	1.317,38	4,79	94,58

Notes: [a] A deforestation factor of 0.004138 ha/m^3 firewood is used. [b] An emission factor of 0.919 t CO_2/m^3 of firewood is used. [c] An emission factor of 0.0659 t CO/m^3 of firewood is used.

Source: Authors' compilation.

Another reading of these relationships can be produced through the environmental Kuznets curve (EKC) (Gene Grossman and Alan Krueger 1995; David Stern, Michael Common, and Edward Barbier 1996). The EKC is a representation of the post-materialist thesis (Ronald Inglehart 1990) that seeks to show that environmental quality could be guaranteed on the basis of economic prosperity. According to the EKC the relationship between the level of income and environmental quality has the shape of an inverted-U, with increasing environmental impacts for the poorest households and decreasing impacts once households have sufficient income to invest in environmental protection. Here we connect conditions of poverty and the consumption of firewood and establish that the poorest rural areas could be placed in the upward phase of the EKC. We can deduce that as families' quality of life improves, or specifically their real wealth, households tend to use more LPG, a fuel that is less polluting than firewood. However, here we can see a sort of "poverty trap" among the poorest levels because while it may be less practicable to improve families' quality of life, these families will tend to maintain or increase their consumption of firewood, thereby contributing to environmental degradation in terms of deforestation and atmospheric pollution through the release of CO_2, a situation that can be reversed if these communities manage to convert to other energy sources.

On the other hand, for urban households there is not only a strong correspondence with the consumption of LPG, but also the highest volume of the consumption of firewood is accounted for by non-poor urban communities. With these elements we can reject a Kuznets-type effect that would support a better environmental quality linked to patterns of firewood consumption in these communities, a consumption that moreover does not satisfy basic needs; on the contrary it could refer to social or recreational activities of the non-poor urban households (barbecue preparation, pool heating, etc.). These aspects can be analysed in Figure 4.



Source: INEC (2019).

Figure 4 Multiple Correspondence Model to Test the Environmental Kuznets Hypothesis: The Relationship between the Type of Fuel Used for Cooking, the Level of Poverty and the Location of the Property

From Firewood to LPG: A Clean Conversion?

We have estimated that each tonne of LPG has an associated emission factor of 2.77 t CO_2. According to figures from INEC (2011), on average a family of 4 uses 1.23 15kg tanks of LPG per month, in other words 18.45kg per month, resulting in 224.48kg of LPG in each household over one year. Equation (10) calculates the average annual emission of CO_2, based on the domestic consumption of LPG as 620.88 kg of CO_2 in each household.

$$Q_{CO_2 LPG} = 18.45 \frac{kg}{month} \times \frac{365\ days}{30\ days} \times 2.77\ \frac{kg\ CO_2}{kg\ LPG} = 620.88 \frac{kg\ CO_2}{household}. \quad (10)$$

Returning to the figures for emissions from firewood consumption in order to contrast them with these results, we can establish that LPG emits almost ten times less CO_2 than firewood (5,866: 621 kg CO_2/household), a condition that results in certain environmental and social advantages. According to the INEC (2019) the total number of households that use LPG is 4,226,601, which generate an annual emission of 2,624.21 Gg of CO_2, compared to 232,640 households that use firewood and charcoal and generate 1,384.10 Gg of CO_2.

2.5 Connexion between Respiratory Illnesses and Exposure to CO

Table 4 shows a sensitivity analysis with emission figures for CO obtained through emissions factors reported by different sources: IPCC (1997), FAO (1999) and García, Yujato, and Arenas (2017). Average emissions per household have been calculated in order to project them onto the quality of life survey of 2014 and evaluate the consistency of the results on people's health through exposure to this pollutant.

Table 4 Sensitivity Analysis of the Average Emissions of CO from the Burning of Firewood

Family size Bakkegaard et al. (2012)	Average people by household Bakkegaard et al. (2012)	Emission of 80 kg CO/t IPCC (1997) [a]		Emission of 69 kg CO/t FAO (1999) [b]		Emission of 121 kg CO/t García, Yujato, and Arenas (2017) [c]	
		t/fam/year	kg/ fam/day	t/fam/year	kg/ fam/day	t/fam/year	kg/ fam/day
1 to 3	2.50	0.29	0.81	0.25	0.70	0.44	1.22
4 to 6	4.89	0.23	0.62	0.20	0.54	0.34	0.94
7 to 9	7.84	0.47	1.29	0.40	1.11	0.71	1.94
10 to 12	10.56	0.57	1.55	0.49	1.34	0.86	2.34
13 or more	13.50	0.19	0.53	0.17	0.45	0.29	0.80
Total	5.02	0.31	0.86	0.27	0.74	0.47	1.30

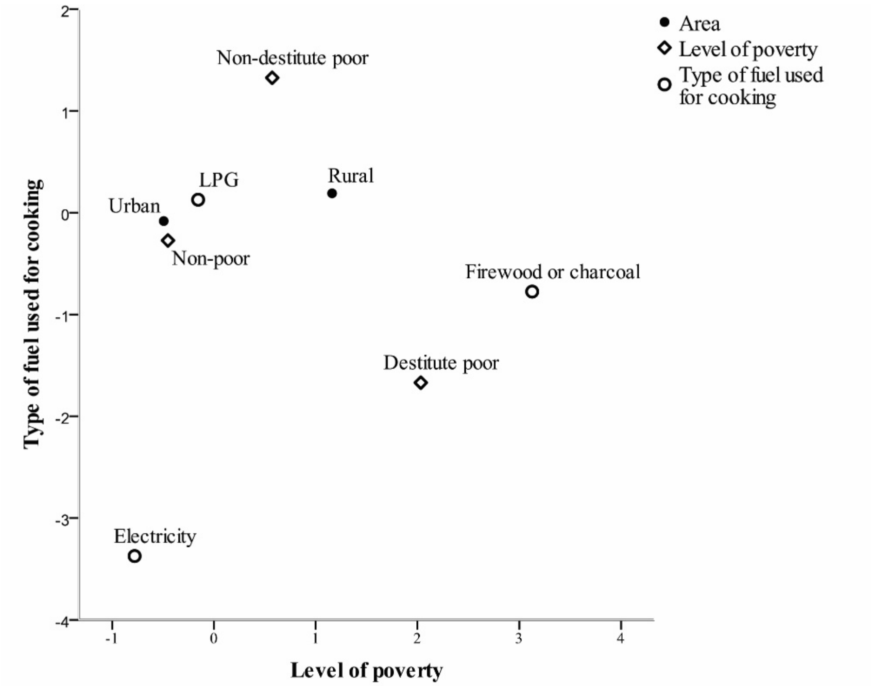
Notes: [a, b, c] The statistical significance of the ANOVA test $p = 0.035$ and the statistical significance of the Levene's test $p = 0.002$*; fam: family.

Source: Authors' compilation.

We analysed three emission factors that turned out to be statistically significant ($p < 0.05$). We chose to use our estimate because it is based on conversion factors proposed for the Latin American region by García, Yujato, and Arenas (2017), which better reflect the national situation. With the information available in national surveys and censuses, however, we cannot carry out cross references which would allow us to establish directly the state of health of communities who use firewood. Consequently, the process that we applied to study these relationships is only indirect *via* the statistics of respiratory illnesses from the quality of life survey 2014 and the socio-demographic conditions of the households that use firewood.

The average emissions per household levels were projected onto the national scale in order to connect them to the prevalence of illnesses linked to the consumption of firewood. Although the results of this evaluation do not provide direct data of the number of people made ill through the inhalation of smoke from burning firewood, they do enable us to define some interesting correlations for analysis. Through the multiple correspondences model in Figure 5 we show a greater prevalence of respiratory illnesses for influenza, sore throat, cough and pneumonia in young women (aged 19 to 26) and older women (aged 60 and over), communities who are closely associated with non-destitute poor households and a structure of 7 to 9 members, where the emissions are estimated at 0.71 tCO/year (see Table 4). Smoking, on the other hand, was not associated with the presence of respiratory illnesses.

As stated in the air quality guide of the World Health Organization (WHO 2005), exposure to 10 mg/m^3 of CO for a period of eight hours can have harmful effects on people's health. According to our calculations, although levels of harmful emissions are not identified in the national average, the situation is different for levels of households. Those with seven or more members show dangerous levels of exposure to CO from the burning of firewood, as well as households in urban areas. In fact emissions from the consumption of firewood is 0.0659 tCO/m^3 or 65,939,214 mg CO/m^3 in a



Source: INEC (2014).

Figure 5 Multiple Correspondence Model; Set Diagram of Category Points: Global Summary of the Association of the Amount of CO with Respiratory Illnesses, Poverty, Age, Sex, Low Birth Weight and Smoking

year and for a total of 232,640 households. This figure is equivalent to 0.7765 mg CO/m^3 per day and per household. This value corresponds to exposure in a household over a period of eight hours per day for cooking, according to estimates by Adolfo León-Taborda and Vergara Juan Fernando Ramírez Quirama (2014) who identified an average use of 7h51’ ± 20’ in traditional firewood stoves used by rural families in Eastern Antioquia in Colombia. We found a relationship of 0.78: 10 mg CO/m^3 between the exposure to CO in Ecuadorian families who use firewood for cooking and tolerable exposure in accordance with WHO standards. Consequently, it would appear that at the national level the consumption of firewood indicates risks for people’s health but in fact it does not affect them. Nevertheless, when this information is analysed by levels of consumption, the effects on those households consisting of seven or more members exceed the WHO standards (up to 293: 10 mg/m^3 of CO in households with more than 13 members), so that these levels of consumption would in fact be affected by the emission of CO from the firewood used in cooking. Similarly, there are households in urban areas exposed to harmful levels of CO. In their case, however, the periods of exposure to firewood smoke are on average likely to be shorter because firewood would be a secondary fuel in the cooking of food. According to the standards of the WHO the maximum admissible exposure for one hour would be up to 30 mg/m^3. This means that in urban areas households with more than three members would be exposed to dangerous emissions of CO from the consumption of firewood (up to 442: 30 mg/m^3 of CO). Households that showed harmful levels of exposure to CO would be those in urban areas in conditions of poverty (47: 30 mg/m^3 of CO) and extreme poverty (168: 30 mg/m^3 of CO). These values can be seen in the following tables:

Table 5 Emissions of CO by Family Size

Family	Emission of CO mg CO/m^3 of firewood/family/day		
	National	Urban	Rural
Bakkegaard et al. (2012)	Authors' estimate		
1 to 3	1.45	25.76	1.54
4 to 6	2.05	45.09**	2.15
7 to 9	10.24*	442.31**	10.48*
10 to 12	151.54*	0.00	151.54*
13 or more	292.91*	0.00	292.91*
Total	0.78	15.78	0.82

Source: Authors' compilation.

Table 6 Emissions of CO by Poverty Level

Poverty distribution	Emission of CO mg CO/m^3 of firewood/family/day		
	National	Urban	Rural
	Authors' estimate		
Non-poor	4.47	27.70	5.34
Non-destitute poor	1.89	46.93**	1.97
Destitute poor	1.86	168.03**	1.89
Total	0.78	15.78	0.82

Notes: * Exceeds acceptable emissions of 10 mg CO/m^3 of firewood for exposure over 8 hours. ** Exceeds acceptable emissions of 30 mg CO/m^3 of firewood for exposure over 1 hour.

Source: Authors' compilation.

3. Conclusions and Policy Implications

Two key factors explain the economy of deforestation due to the consumption of firewood that occurs in Ecuador: poverty conditions and rurality. Poverty, in the sense of people's unsatisfied basic needs and rurality as understood from the politico-administrative division suggested by censuses and national surveys, as those territories that are not a provincial capital or capital of a canton (INEC 2001). We calculate that 85% of the impacts associated with the use of firewood for cooking occur amongst the poor rural households or those in extreme poverty. This means 5,059 ha of deforestation, 1,123 Gg of CO_2 and 81 Gg of CO. Of particular concern are the emissions of carbon monoxide because they can be the cause of adverse effects on people's health. Deforestation connected with this use in particular constitutes only 6.61% of total deforestation.

Based on WHO standards we identified that the average exposure of families to CO generated by the burning of firewood for cooking does not reach dangerous levels because they are far below the maximum acceptable (0.78:10 mg/m^3). However, when this information is disaggregated according to the levels of households, harmful amounts can be identified for households with more than three members and those located in urban areas and in conditions of poverty or extreme poverty. Therefore, the consumption of firewood can be identified with possibly harmful levels of CO for some groups of the population, and for that reason we suggest that an energy policy based on solidarity should be identified that allows for a reduction in the risks to which these people are exposed on account of the use of this resource, an action that can also contribute towards the mitigation of the deforestation of sensitive areas and the generation of GHG. It should be recognised that the analysis of the connections between the consumption of firewood and associated health problems that we carried out in this document only identifies the problem indirectly, although it enables the risks due to the exposure of these communities to be laid at the door of pollution and to identify women, old people and under-fives as the most vulnerable groups. One of the limiting principles of this kind of study is the lack of systematic and detailed information by which these aspects can be further explored in future research.

We have asked ourselves which elements could define an energy policy based on solidarity. We believe there are two central aspects: the first, to promote conversion towards alternative energy sources for cooking. In particular, in this document we have studied the case of LPG, which has been continuously replaced by other fuels in Ecuador since the 1980s when records were first kept (Caicedo, Vallejo, and Carrasco 2019). In practical terms this means maintaining or even extending existing subsidies to LPG for domestic use, although directed at poor communities who live in both urban and rural areas of the country. This aspect is not a minor debate at the national level, in the context of the serious political and social crisis experienced in the country shortly before this document was written, owing to the polemical decision of the Government to remove subsidies from gasoline and diesel that had been in place for forty-nine years.

It seems strange from an ecological perspective to propose the expansion of subsidies for a fuel that has its origins in a non-renewable source, as is the case with LPG. However, the advantage of LPG over firewood for cooking is not only environmental due to the lower emissions of GHG, but also on account of social and principally health reasons.

Regarding social aspects, we argue that energy conversion is not an easy process. These communities have age-old traditions such as the “minga” (communal unpaid work for the common good) connected to the use of firewood, coal and even dry dung fuel on certain occasions. These are open access resources, whereas LPG is not. For people in these communities obtaining a cylinder of LPG means sacrificing other basic needs such as access to clean water, education or health. Such circumstances result in a poverty trap. To overcome it requires the introduction of incentives that promote an alternative to this energy source. We argue that there is no possible trade-off between the economic situation of these people and wellbeing. It is a matter of subsistence. Without an energy policy based on solidarity these populations are not able to reach the minimal requirements to subsist. Joan Martínez-Alier (2013, p. 20) explains this aspect.

Let us suppose that a mining company like Vedanta, Tata or Birla contaminates the water in a village in India from the mining of bauxite, iron or coal. The families have no option but to obtain water from streams or wells. The rural wage is slightly more than one euro per day, while a litre of water in a plastic bottle costs 10 cents. If the poor have to buy water, their whole wage would simply go on drinking water for them and their families. In addition, if there is no firewood or dry dung fuel, and if they bought butane (LPG) as they would prefer, they would spend the weekly income of one person in order to obtain a 14kg cylinder. The contribution of nature to the human subsistence of the poor is not well represented in monetary terms. The matter is not financial but to do with subsistence. Without water, firewood or dry dung fuel, or fodder for their cattle, poor people simply die. Women are the first to protest. The ecological problem does not present itself in prices, for prices do not include ecological costs nor the necessary jobs for social reproduction (the "caring jobs").

With regard to environmental impacts we have calculated that the relationship between LPG and firewood is 62.44: 111.83 tCO_2/TJ. In relation to CO, which is a direct indicator of the risks to health, the relationship is 0.0114: 8.0290 tCO/TJ. Despite the advantages that we identified when comparing LPG with firewood, these figures show that LPG does not constitute a clean source of energy either and nor is it free from having an impact on the national forests. Consequently, in future research other options could be explored, such as electric induction stoves, the use of which was not widespread at a national level despite the fact that there was a subsidy in Ecuador for the use of electric energy until 2018. It was applied to households that adopted induction stoves. These difficulties in successfully converting energy supplies should be properly assessed, since the consumption of firewood amongst the poorest household levels occurs because it is a traditional, cheap, easily accessible resource and perhaps an even "better satisfier" of needs for heating or cooking, for example.

The second element that can define an energy policy based on solidarity concerns the situation of urban households that use this resource. The problem with its use in this sector is that it is mainly concentrated in non-poor households, where it would not form part of their basic needs. Households in the urban areas with the highest incomes could pay a tax as an equivalent fraction of their use of electricity, with the aim of financing the subsidies suggested above, to urban and rural poor households replacing firewood with LPG. In some other cases, the sale of LPG can be controlled through electricity accounts that can categorize whether a property is urban or rural, while the volume of electricity consumption can give some idea of the level of poverty. Moreover, poor people without an electricity bill should be identified as beneficiaries of the human development bonus, a state conditional cash transfer program that has been operating since 2003.

Finally, there is a part of the consumption of firewood that is not adequately quantified and that concerns the industrial and commercial use of the resource. From the figures for natural resources compiled by the MAE (2019a) we have shown in this study that only 35% of the total volume of different kinds of trees used for firewood are devoted to domestic use, while the remaining 65% are aimed at commercial, industrial or productive use. In this way the social and environmental impacts of the use of this resource are still hidden outside of the domestic sphere. Despite the limitation that follows from the absence of this information, it is possible to state that the poorest households are not the main cause of deforestation due to the consumption of firewood in Ecuador. Therefore, an integral energy and ecological strategy requires the inclusion in the analysis of the commercial, industrial and productive uses of this source of energy and the definition of specific policies.

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