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Enhancing **Energy Efficiency** to Increase Affordability:

Evidence from Residential Lighting Retrofit in Peru

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Executive summary

Energy efficiency initiatives can be used to reduce expenditure on energy by consumers, for the same products or services. It is vital for reducing the effects of greenhouse gases in the long term. These initiatives, such as the replacement of domestic appliances and equipment, and the improvement of dwelling characteristics, are often straightforward and deliver concrete results. In Latin America and the Caribbean, households have replaced traditional incandescent light bulbs with energy-saving or light-emitting diode (LED) light bulbs. Given that the energy demand is expected to double by 2040, programs like this are particularly relevant in the region (Yepez-Garcia et al., 2018).

The expected results of energy efficiency initiatives in the developing world differ from those in more advanced economies. In developed countries, initiatives aimed at improving energy efficiency will be successful if energy consumption is reduced. In developing countries, the use of energy efficient technologies can lead to a higher consumption of energy, which is seen as a sign of improved *affordability* of energy services. Thus, households, such as poorer households, cannot have access to all the energy services they need, because they cannot afford it. As consumer awareness on energy efficiency measures increases and technology becomes cheaper, there is a rise in the use of energy efficiency appliances.

In this paper, we discuss the Peruvian retrofit lighting program that was part of the National Energy Plan 2014-2025. Using data from the Residential Survey on Consumption and Uses of Energy or *Encuesta Residencial de Consumo y Usos de Energía* (ERCUE) for the waves 2014–2015, 2016, and 2018, we find that households have greatly benefited by replacing incandescent light bulbs with energy-saving and LED bulbs between the year of implementation of the program, and 2018. Based on this data, we see that surveyed households have reduced their expenditure on electricity. Furthermore, compared to 2014-2015, since 2018, the poorest households (in the survey) have become less sensitive to changes in their monthly electricity expenditure. They have been able to meet their energy needs with higher consumption, and use energy-saving light bulbs due to the wide implementation of the program.

These findings may help policy makers understand the impact of successful energy efficiency programs on households. In the context of developing countries, where affordability of services is a challenge, this work gives a novel perspective on the expectations of energy efficiency as a means to overcome this challenge.

Introduction

DATA

+5.7 %

Average annual GDP growth 2004-16.

+37 %

Total primary energy supply increase 2005-15.

Having achieved significant progress in its macroeconomic indicators in the past ten years, Peru is seen as an example of economic transformation in Latin America. The poverty headcount ratio, measured as a percentage of the population below the national poverty line, has decreased from 58.7% in 2004 to 20.7% in 2016. From 2004–2016, the country has experienced an average annual Gross Domestic Product (GDP) growth of 5.7% (World Bank, 2019). Although Peru has seen considerable progress in economic growth and poverty reduction over the years, the indicators of the energy sector still need improvement in order to meet energy efficiency targets.

In 2005, to improve its energy indicators, Peru first implemented the National Energy Plan (NEP) which, defined comprehensive measures to improve energy efficiency and the affordability of energy services. Thus, the total primary energy supply increased by 37% between 2005 and 2015, due to a significant increase in the supply of natural gas. During the same period, the average annual electricity consumption per capita increased from 0.84 MWh to 1.37 MWh (International Energy Agency, 2018), whereas the annual average residential tariff increased from 0.10(USD/kWh) to 0.14(USD/kWh)[1]. Access to electricity jumped from 77.71% in 2005 to 95.2% in 2018 (World Bank, 2020).

To continue promoting energy efficiency in Peru, it is useful to analyze the manner and determinants of electricity consumption. Over the past four years, the Peruvian Ministry of Energy and Mines developed the National Energy Plan 2014-2025 with the objective of improving energy indicators by 2025. The plan included the replacement of traditional energy bulbs in households. The estimated savings in energy costs for the replacement of 2.5 million and 1.5 million incandescent light bulbs, with energy-saving and light-emitting diode (LED) light bulbs, respectively, amounted to $80 million. The program was also implemented in government and public buildings. Furthermore, Peru is also a part of the Global Efficient Lighting Strategy[2]. The National Efficient Lighting Strategy of Peru is a Global Environmental Facility (GEF)-funded project titled "Lighting Market Transformation in Peru," implemented by the United Nations Environment Program (UNEP) and executed by the Peruvian Ministry of Energy and Mines (MEM).

1 The tariff data is from the online database of Peru's energy regulatory body (i.e., Osinergmin) and corresponds to the residential electricity tariff for a consumption of 125kWh in the fourth quarter of each year. It can be accessed online via: http://www.osinergmin.gob.pe/seccion/institucional/regulacion-tarifaria/pliegos-tarifarios/electricidad. These figures are not subject to the government law FOSE (*Fondo de Compensación Social Eléctrica* – in Spanish). Under FOSE, residential customers who consume less than 100kWh/month pay 20% of the actual tariff, while those who consume more, are charged a special tax.

2 Part of United Nations Sustainable Development Goals Partnership Platform. Please refer to https://sustainabledevelopment.un.org/partnership/?p=7345

Using data collected from the energy regulatory body in Peru (Osinergmin[3]), we conducted an econometric analysis to understand the energy consumption patterns of Peruvian households, and studied whether the adoption of more efficient light bulbs had an impact on these patterns. The information used in this study comes from the Residential Survey on Consumption and Uses of Energy (ERCUE[4]). While data are available from 2003 to 2018, in this study, we use data on variable household consumption from 2014–2015, 2016, and 2018.

Using regression analysis, we analyze two dimensions of the data on energy consumption, namely affordability and energy efficiency. We seek to answer the following questions: How sensitive is the electricity consumption of households with respect to their monthly electricity bills? How do Peruvian households respond to energy efficiency programs? Does replacing incandescent light bulbs by energy-saving or LED light bulbs help to save some of the electricity expenditure? We rely on different econometric techniques to estimate the parameters to answer these questions.

First, to assess whether resources are affordable for families, we estimate consumption-expenditures elasticities to show the sensitivity of consumption with respect to the overall monthly expenditure and the electricity bill. We then estimate the demand functions of electricity expenditure at constant prices[5], in order to measure how the distribution of household expenditures changes when we include a member with specific household characteristics in the sample (e.g., age, sex, etc.). This helps us understand the determinants of energy expenditure. In the model, we also include a dummy variable, to capture whether the household belongs to a poor income category, labeled "poor" (e.g., earns an income below the poverty line) versus "non-poor"[6]. Second, using data from the 2018 residential consumption surveys administered by the energy investments supervisory body in Peru, we estimate the effect of replacing incandescent bulbs with energy-saving and LED light bulbs on household expenditure, and use a count data model to understand how poor households responded to the program.

We observe that compared to 2018, for the period 2014–2015, households are more sensitive to changes in electricity expenditures. Furthermore, when we classify households into "poor" and "non-poor," we see that poor households relatively consume more energy than non-poor households, reflecting increased affordability in poor households. Policy interventions also reduce energy consumption and promote energy efficiency. The 2014-5 National Energy Plan implemented in Peru that replaced incandescent light bulbs with energy-saving or LED light bulbs reduced the electricity expenditure of households.

These findings help us understand the energy consumption behavior of households. They inform policy makers about the effectiveness of adopting energy-efficient technology and suggest ways to tailor policies based on the characteristics of the household. The remaining paper is organized as follows. Section 2 presents a brief literature review and explains the determinants of household energy consumption, with a discussion on affordability. Section 3 presents the data, while Section 4 describes the different methods used in the empirical analysis. We present our results in Section 5 and conclude with some policy recommendations.

3 *Organismo Supervisor de la Inversion en Energia y Minería* in Spanish.
4 *Encuesta Residencial de Consumo y Usos de Energía* in Spanish.
5 The Engel curve, as explained in the methodology section, is a demand function set at constant prices.
6 The categorization of "poor" and "non-poor" households is set according to the departmental poverty line published with the data by Osingermin, based on data from the Peruvian National Statistics Bureau.

1. Literature review

1.1 Technology adoption and affordability

There is considerable evidence that shows that technology adoption leads to better energy efficiency, as it reduces energy consumption (either in total or only fossil fuel consumption) (Marin & Palma, 2015; Linn, 2006; Akinwale, 2018). In the case of light bulb replacement, evidence suggests that replacing light bulbs in households has helped reduce electricity consumption (United States Energy Information Administration, 2019; Kamunda, 2014; Mahlia et al., 2005). Kamunda (2014) estimated that replacing incandescent light bulbs by energy-saving bulbs could reduce the share of the electricity consumption on light bulbs by 90% in Malaysian households, while Trifunovic (2009) found that there is a 27% potential energy saving for Serbian households when incandescent bulbs are replaced by compact fluorescent lamps (CFLs).

However, studies on other developing countries (e.g., Ethiopia and Pakistan) estimated that energy savings from the replacement of light bulbs in households were less than initially expected, due to a "rebound effect" (Costolanski, 2013; Chun & Jiang, 2012). The rebound effect, also known as the "Khazzoom-Brookes postulate" (Saunders, 1992), supports the idea that having a higher disposable income encourages spending and consuming, thereby reversing the initial intended effect of reducing energy consumption. While there is some empirical evidence on the existence of the rebound effect (Jin et al., 2018; Herring and Roy, 2007), the interpretation of this effect in the present work is different, owing to the differences in Peruvian households compared to developed countries.

Poor Peruvian households face the issue of affordability, once the problem of accessibility is overcome, as they cannot afford basic energy consumption (Barnes et al., 2018). Replacing incandescent light bulbs with energy-saving ones will first enable these households to reduce their electricity bills, and then allow them to spend more on using electricity. There is evidence of a rebound effect, which is not perceived as undesirable in the developing world.

Countries in Latin America and the Caribbean consume four times less energy per capita than the Organisation for Economic Co-operation and Development (OECD) countries (Sanchez et al., 2017). In such case, instead of replacing equipment and allowing households to consume more for the same price, the role of energy efficiency is to expand the level of services to satisfy unmet needs. Households, offices, public buildings, and spaces in developing countries do not have the same level of comfort as developed countries, in terms of building insulation, air conditioning (AC), public lighting, etc. Thus, the role of energy efficiency is not to save energy costs, but to improve access to energy services and increase their affordability for households.

It may be noted that the two studies on Ethiopia and Pakistan mentioned above assessed the impact of CFLs, and not LED lights on energy efficiency. Costolanski (2013) looked at income groups and had light bulb replacement as a part of their national program, while Chun & Jiang (2012) looked only at CFL adoption amongst households. We can assess the rebound effect better by focusing on income groups, as there are systematic differences in expenditure patterns at different levels of income, e.g. Engel's law. We used this in our analysis.

1.2 Household consumption patterns

Previous literature examines the economic behavior of individuals and families. The methodological aspects of modelling energy consumption are related to the field of general household consumption. In the 1980s, Engel noted that per capita food expenditures decreased with household size. Later, Deaton and Paxson (1998) showed that larger households spent less per capita on necessities than smaller households, although larger households exhibit many forms of sharing and can afford to consume more. Most studies considered the household as a single unit to determine the allocation among members, in accordance with the methodological baseline developed by Bourguignon and Chiappori (1992). It may be noted that important econometric literature on the demand for electricity focused on residential demand (Azlina, 2016; Kim, 2018; Druckman & Jackson, 2008; Ugarte et al., 2016; Bhattacharjee & Richard, 2011; to cite a few examples).

Regarding the identification of determinants of household energy consumption, "the link between household characteristics and household energy consumption is long established and the literature recognizes that household characteristics will give rise to different load profiles and subsequent demand on the electricity supply network" (Anderson, 2017).

Based on existing literature, there are two important household characteristics that explain household energy consumption. One is the household size, the other is the income level, often classified as "poor" versus "non-poor" households (sometimes also separated into quintiles). With respect to the household size, as the household gets bigger, energy consumption increases (Azlina, 2016; Kim, 2018; Druckman & Jackson, 2008), though not always proportionally (Ugarte et al., 2016). However, energy consumption per capita decreases, due to the sharing of consumer items by household members (Bhattacharjee & Reichard, 2011).

Regarding income levels, elasticities vary depending on the time frame and income growth. The extant literature argues that in the short-term, the impact of income on energy consumption is at best weak or not statistically significant (Frontier Economics, 2016). In the long run, as poor households become middle class, they will demand more energy because they use more appliances and vehicles. Therefore, households experiencing an increase in income will demand more appliances and consume more energy, leading to an increase in overall energy

PERU

96.4 %

of the population had access to electricity in 2017.

21.7 %

of the population still lived below the national poverty line.

expenditure (Frontier Economics, 2016; Wolfram, Shelef & Gertler, 2012; Azlina, 2016; Kim, 2018). In the very long-term, when households have reached high income levels, they will "satiate" and show the net savings effects, and the energy demand will stop growing (Jimenez & Yepez-Garcia, 2016). Potentially, higher income households are most likely to purchase more modern and energy-efficient technologies, and invest in energy saving features (Frontier Economics, 2016). Thus, the income elasticity of household energy demand is an inverted U-shaped curve (Jimenez & Yepez-Garcia, 2016).

When we look at how income affects energy consumption, we should also note the dichotomy between energy consumption and energy expenditures. A poorer household might consume less energy due to a lack of electrical appliances in the household, but pay more for electricity, relative to its earnings. For instance, in a study on households in the United Kingdom (UK), Druckman and Jackson (2008) found that on average, the poorest 10% of the households used only 43% of the energy used by the richest 10%, but spent nearly eight times as much as the richest 10% in terms of the proportion of their disposable income. If the poorest 10% consumed less than half of the electricity that the richest 10% consumed, this is most likely because they cannot afford to use more energy, and not because they are more energy conservation-oriented or because they use more efficient appliances.

Thus, we should be aware which income group is taken into consideration when we measure energy consumption and energy expenditure, and understand what is expected from an energy efficiency program for each income group. A low-income group might react differently to an energy efficiency initiative, compared to a high-income group, especially if the former is already using less energy than it needs to meet basic living requirements, because it cannot afford more. Subsection 2.1 has already discussed the growing attention to energy affordability (Bartl, 2010; Dubois & Meier, 2016; Flues & van Dender, 2017). Energy affordability is defined as "a household's ability to pay for necessary levels of energy use within normal spending patterns" (Flues & van Dender, 2017). This is particularly relevant for Peru, where, in 2017, on an average, only 96.4% of the population had access to electricity, 21.7% of the population still lived below the national poverty line, and the Gini index stood at 43.3[7]. (World Bank Indicators, 2017).

Energy consumption also depends on the location of the household (i.e., in a rural or an urban area). In the UK and South Korea, findings showed that urban households consume more energy than rural ones (Druckman & Jackson, 2008; Kim, 2018). In a review of existing papers on the socio-economic determinants of household energy consumption in the United States (US), Bhattacharjee and Reichard (2011) found that rapid urbanization led to an increase in energy consumption per capita. Furthermore, higher energy consumption in urban households is attributed to the fact that rural areas have lower access to electricity compared to urban areas, as highlighted by Jimenez (2016) in a study on Latin American countries.

7 The Gini Index is defined as the statistical dispersion to represent income inequality.

There is mixed evidence on the impact of other characteristics on energy consumption. In a study on the European Union (EU), Mills and Schleich (2013) found that having a higher level of education implies more (less) energy conservation or a more (less) environment-friendly attitude. However, this could be offset by changes in generational preferences across Europe, as the present generation seems to consume more electricity than the previous one (Bardazzi & Pazienzia, 2017; McLoughlin et al., 2012). These results are in contrast to Kim's (2018) findings from South Korea, where households in the fifth quintile of power consumption (which is also the one where the mean value of electricity consumption is the highest) have a high ratio of middle-aged and highly-educated members. Other studies find no significance of household characteristics once controls for building characteristics, such as building size, are included (Huebner et al., 2015; Jones & Lomas, 2015). The dataset used in our empirical analysis allows us to control for some household characteristics and some household appliances.

2. Data from the Residential Survey on Consumption and Uses of Energy

Since 2003, the electricity regulatory body of Peru publishes the Residential Consumption and Uses of Energy Survey that measures energy consumption at the household level. The survey is representative at the departmental level, and has the following levels of inference: regional, urban-rural areas, and Metropolitan Lima (Osinergmin, 2014, 2016, & 2018). The database includes socio-economic characteristics of the household members such as education, age, and gender, among others. The variable electricity consumption is present only in the recent waves of the survey, starting in 2014. This dataset collects information on electricity consumption, the consumption of other fuels, and the expenditure by fuel type, and on income from an individual, overall expenditure, fuel expenditure, and electricity expenditure at the household level.

In 2014, the ERCUE was carried out between August and October, interviewing 12,025 households, which account for a total of 44,161 individuals (Osinergmin, 2014). In 2016, the ERCUE was carried out between March and April across 13,734 homes, adding up to 49,516 individuals located in different concession areas of the electricity distributors in Peru

(Osinergmin, 2016). The 2018 survey covered 14,127 homes. It is important to point out that the ERCUE does not investigate those households located in areas without an operating utility. For the 2018 survey round, this means that the results of the survey are only representative of 92% of the population (Osinergmin, 2018). Nonetheless, a question was included in the survey to learn if the household generates its own electricity.

The survey is available every year. However, electricity consumption has been reported only since 2014. The survey includes household data and personal data that can be grouped under categories as described in Table 1.

Table 1. Information available in ERCUE

Economic information	Socio-demographic variables	Dwelling attributes
Total household expenditure	Rural/urban location	Construction type
Expenditure on electricity bill, balloons of liquefied petroleum gas (LPG), and natural gas	Department and district data	Dwelling type
Income, secondary income, and income transfers of all individuals	Age	Services
Energy consumption (monthly electricity measured in kWh)	Level of education	
Uses of energy and other services	Gender	
	Number of household members	

Source: ERCUE Surveys, 2014 and 2018

2.1 Disparities between urban and rural areas

The ERCUE has gathered significant data with respect to consumption and the public service use of electricity, in addition to information on the consumption and energy needs covered by electricity. Based on the results of the survey, we deduce considerable differences exist in the access to public provision of electricity between urban and rural areas. This is consistent with the existing literature described earlier.

Regions with a higher percentage share of access are dominantly urban. In Arequipa, Moquegua, Lambayeque, Madre de Dios, Tumbes, Lima, and Callao, the percentage share of access to electricity is more than 99%. In contrast, the rural regions of Huancavelica, Pasco, and Loreto show lower percentage shares of access to electricity. The significant difference in access to electricity between urban areas (99.6%) and rural areas (91.8%) is attributed to the lack of redistributive networks in rural areas—a consequence of their high investment costs and low population density.

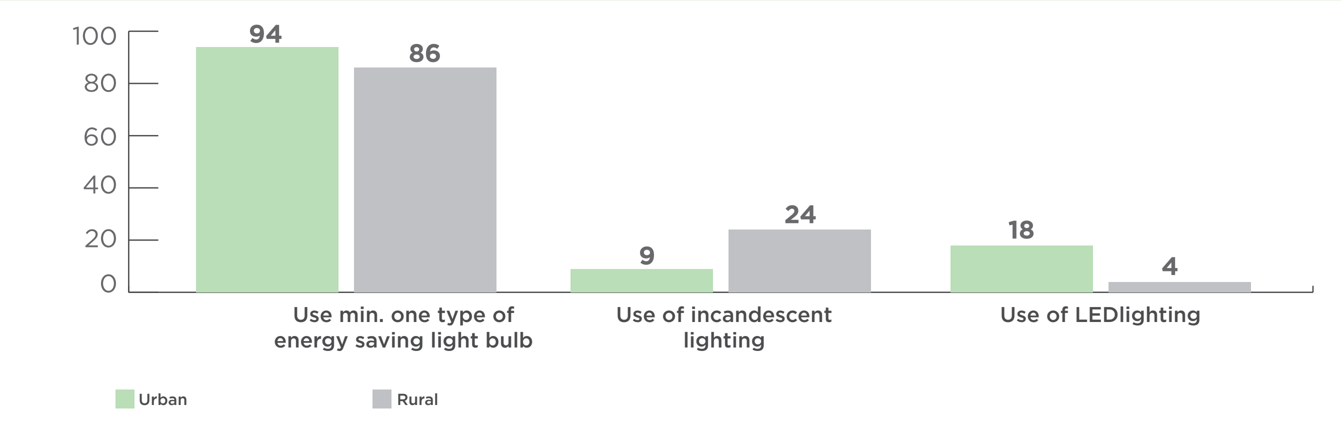
Based on geographical area, there is a noticeable difference in the cost of electricity. The median monthly cost of electricity in urban areas is seven times that of the rural areas (S/11.6). Households located in the rural areas also show a smaller dispersion in their monthly electricity expenditure, compared to urban areas. At the national level, the median monthly electricity expenditure for households is S/56.5.

Electricity is primarily used for lighting and refrigeration in households. Only 3% of the households use electricity to cook food. Out of all households, 5.5% use an independent electricity meter. This number is higher in urban areas (6.2%) and lower in rural areas (1.9%).

Light Bulbs

The type of lighting used in households also varies by geographical area. Overall, 92% of households use at least one type of energy-saving light bulb. This percentage is higher in urban areas (94%) and lower in rural areas (86%), as per Figure 1. Overall, 13% of the households continue to use incandescent lighting. This is because in urban areas, one out of ten households (9%) uses incandescent lighting, while in rural areas it is one out of four households (24%). There is disparity in the share of households that use LED lighting in their homes. In urban and rural areas, 18% and 4% of households, respectively, use this type of lighting.

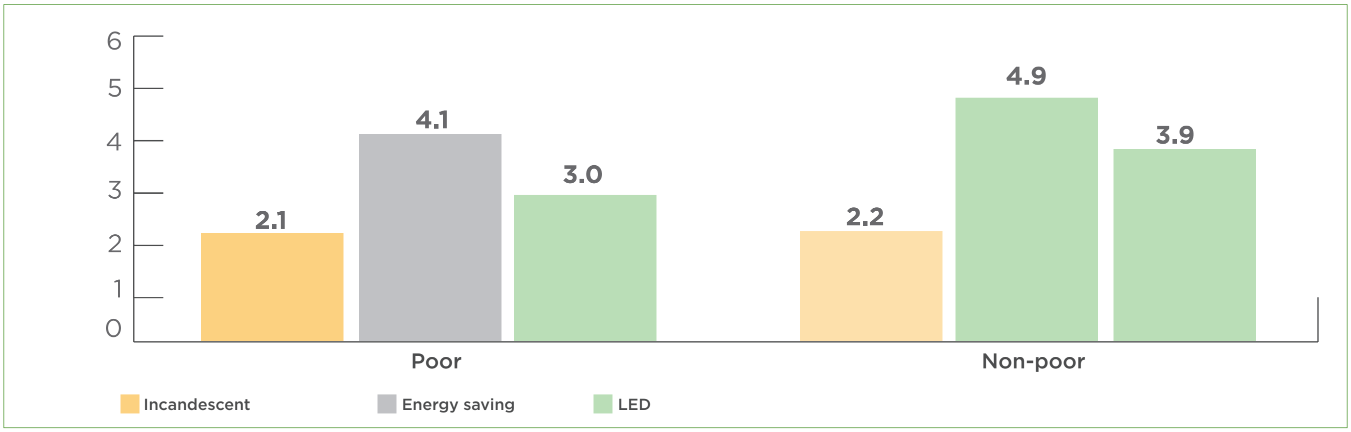
Figure 1. **Use of different lightings in urban vs. rural areas**



Source: Based on data from ERCUE, 2018

Households using some type of incandescent or LED lighting are reported to have one or two bulbs, The "non-poor" households who use energy-saving light bulbs report an average of five light bulbs, compared to an average of four light bulbs for the households characterized as "poor" (Figure 2). This is because poorer households are reluctant to replace their traditional lighting with energy saving ones, as these imply an extra cost.

Figure 2. Average number of light bulbs by type and poverty classification



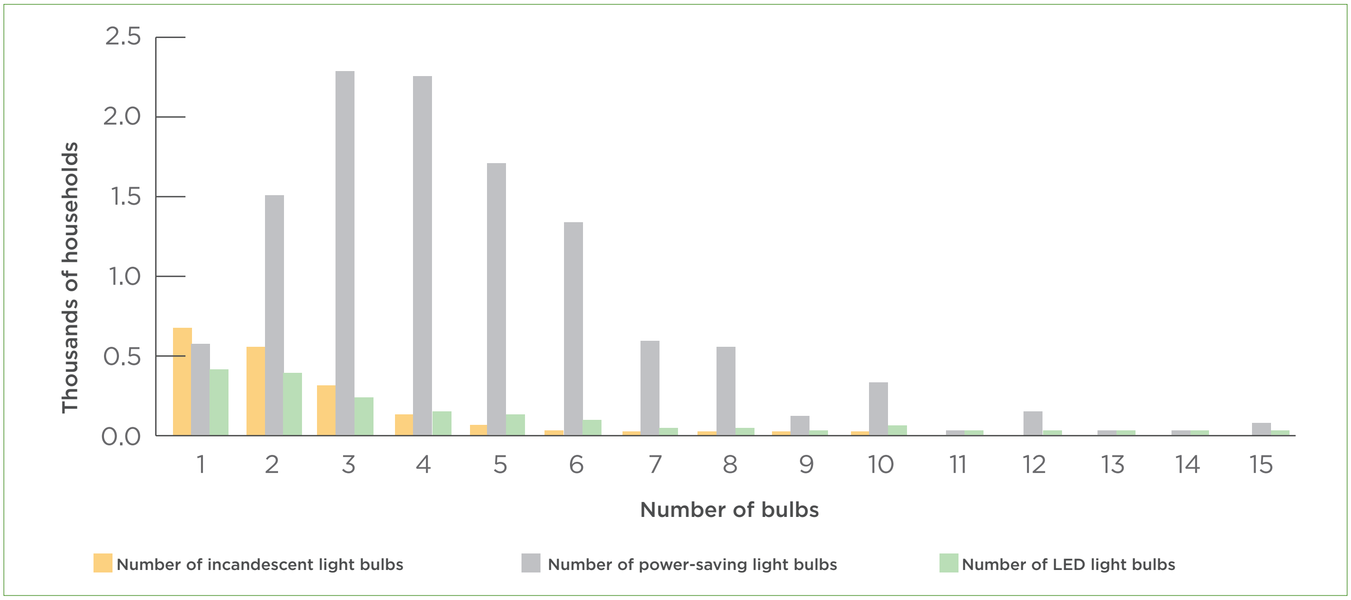
Source: Based on data from ERCUE, 2018, elaborated by Gerencia de Políticas y Análisis Económico (GPAE)-Osinergmin

Note: the number of households surveyed for incandescent light bulbs are 1,703, those for energy-saving light bulbs are 12,664, and those for LED light bulbs are 1,723. The corresponding enlarged number of households are 932,499, 7,166,051, and 1,099,138, respectively.

Figure 3 below shows the distribution of the three different types of light bulbs reported in the survey (incandescent, energy-saving, and LED) across all households, based on the number of light bulbs they have at home. Energy-saving light bulbs are most commonly used, while households that use very few light bulbs have a higher number of incandescent and LED light bulbs. This number reduces as households have more light bulbs.

Figure 3.

Distribution of lighting sources



Source: Based on data from ERCUE 2018

Measures taken to save electricity consumption

According to the survey, households saved energy by turning off the lights, when not in use (either because there was no one, or when they were leaving the house). In urban (rural) areas, 91% (78%) of the households report that they turn off the lights. Second, to reduce energy consumption, they unplug electric devices. Almost half the households in urban areas report that they unplug devices (46%), while only 23% of the rural households, which is half the share of urban ones, take the same measure.

In terms of electricity consumption by type of electric device, refrigerators are the most demanding, as they cover 40% of the total electricity demand, measured in kWh. This is followed by lighting (incandescent, LED, and energy saving light bulbs), contributing roughly 17% of the total demand, followed by televisions and computers at 10% and 7%, respectively.

2.2 Socio-demographic characteristics of households

On average, households have about four members, and poor households make up approximately 28% of the samples in 2014 and 2018 (see Table A1 in the Appendix). While the age distribution does not show large differences between the years, the number of members under 21 years of age in 2014 is higher than in 2018. The age of the household head partner is the same for both years, at an average of 52 years. We note that household heads are seen to have slightly more years of education in 2018 than in 2014. Approximately 10% of the heads of the households surveyed held at least a bachelor's degree, while 12% of them had technical education (see Table A1 in the Appendix).

Monthly electricity expenditure averaged S/60 in 2014 and S/71 in 2018. The energy expenditures in 2018 is an average of 7% of the total expenditure, and the share for poor households tends to be larger than that for the non-poor households, at 7.8%, compared to 6.8 %. Therefore, in poor households, we see that the various expenses have a great share of the total expenses, a fact that is consistent with Engel's method, which suggests considering the share of expenditure on necessities as an inverse indicator of welfare (e.g., the larger the proportion of electricity expenditure, the lower the level of welfare). This method is explained in the next section.

While electricity expenditures have gone up during the two years, electricity consumption has gone down by 15% (from 117.35 kWh in 2014 to 73.07 kWh in 2018[8]). Households also report that they have increased access to a landline phone, electricity, their own vehicle, natural gas, water, and have a higher number of energy-saving light bulbs, in accordance with the national energy efficiency strategy.

8 This drop might be over-estimated by the fact that the information collected for 2014 only represents 69% of households that have access to this service, according to the annual ERCUE report for 2014. Please refer to the report for more information: http://www.osinergmin.gob.pe/seccion/centro_documental/Institucional/Estudios_Economicos/ERCUE/Reporte-ERCUE-2014-2015.pdf

3. Methodology

3.1 Estimating Engels' curves

We estimate Engel's curves to arrive at the overall allocation of electricity and energy goods among household members, when consumption at the household level, and not individual level is observed. It is difficult to collect data at the individual level due to the high cost of acquiring information and the difficulty of splitting energy consumption between household members. Therefore, we use Engel's curves as an indirect method, to infer the behavior of different individuals, involved in resource allocation[9] in the household.

The United Nation's Economic Commission for Latin America (CEPAL) determines the equivalence scales for the allocation of expenditures inside households[10]. The equivalence scales are used to make interpersonal comparisons of well-being for purposes such as indexing social transfers and measuring poverty, inequality, and social welfare. The estimation of Engel's curves is based on the fact that different individuals within the household have different characteristics. These characteristics can be associated with demographic conditions, such as gender or age range, and the differences between individuals are reflected in consumption patterns (i.e., the distribution of expenditure among different goods). When we compare a household with children, with another household without children, we notice a difference in the expenditure levels for necessity goods, such as food or electricity, in households with children, as consumption with children is thought to be more intensive.

We use the traditional indirect utility derivation of a representative household and define the utility function of the household, which depends on the goods consumed inside the household (q) and the household characteristics (z):

$$u = u(q,z) \quad (1)$$

9 Gibson, 2002.
10 Medina, 2002.

Let us assume that this utility function is used by the head of the household to maximize the overall well-being of the household members. Engel's method is based on the observation that, for any given household composition, the share of good (i) expenditures on the total expenditures is inversely related to total household income. From the utility function, we obtain an expenditure function[11] that indicates the minimum expenditure on goods that the household with characteristics (z) needs to spend in order to reach its utility level (u) when prices (p) are constant:

$$e(u,p,z) = w \quad (2)$$

The scales of equivalence are obtained by dividing the function of the household expenditure (p) for the representative household expenditure function (e^0), for the same price level (p) and for the same utility level (u). The scales of equivalence are factors that allow for the adjustment of household consumption, based on its size and composition, with the objective of comparing them. This way, new income or expenditure variables, in terms of the household equivalence, can be generated. This scale of equivalence cannot be estimated because the level of utility (u) of a household is not observable. Nonetheless, from the microeconomic characteristics of the utility function, we estimate the indirect utility function (v); $v(w,p,z)$. Given that (v) is a function of expenditures, we obtain an expenditure function. The goods and services demand functions will depend on the observable variables and can be estimated empirically[12].

We hypothesize the functional form of the utility function as follows, in order to carry out these derivative functions:

$$u^h = \frac{(e^h\ (u,p,z^h)}{(e^0\ (u,p,z^0)} \quad (3)$$

The expenditure on the good , electricity (in the case of this paper), is obtained using the following expression:

$$p_i \cdot q_i = \frac{\partial e(v(w,p,z),p,z)}{\partial \ln p_i} \quad (4)$$

Equation (4) represents the expenditure on the left-hand side and the marginal cost in relation to prices on the right-hand side. This is the general method used to estimate Engel's curves and scales of equivalence. Thus, we interpret equation (4) as many different empirical ways of estimating the demand functions.

We estimate the empirical demand curves, in a manner similar to what determines the scales of equivalence in previous studies. However, in our empirical approach, we account for non-linearities that are present in the demand curves, and for the dependent variable bound between 0 and 1. This allows us to estimate fractional nonlinear demand curves[13]. In this paper, we estimate the demand function for the good for the years 2014, 2016, and 2018, where the sub-index represents the selected good, e.g., food and education. We later use its linear estimation, for the sake of simplicity. This equation can be estimated better using non-parametric methods, as per the following equation:

$$x_i = f\cdot\left(\alpha,\beta,\ln\left(\frac{w_i}{n}\right),\ln\left(\frac{w_i}{n}\right)^2,D,Z,\varepsilon\right), \quad (5)$$

11 See Jehle (2001) for Theorem 1.6 on Roy's identity.
12 Ibid.
13 We used Stata 15 commands for fractional probit estimates.

where is the share of the good or sevice in the total household expenditure, is the natural logarithm of the total expenditure per capita, is the number of members of the household, is a dummy variable that represents the criteria used to categorize households into "poor" and "non-poor" according to the poverty line, and controls for other household characteristics.

The "poor" versus "non-poor" categorization of households is calculated according to the departmental poverty line published with data from Osingermin, based on the Peruvian National Statistics Bureau. Since the poverty line is calculated at the departmental level, we account for the inter-departmental differences in the composition of consumption, due to changes in prices. When takes the value of 1, the total household income is less than of the poverty line income at the departmental level, and when the value of is 0, the total household income is equal or greater.

3.2 Before and after comparison

The replacement of incandescent light bulbs with energy-saving light bulbs shows tendencies in the data, using cross-sections for each year. Based on this, we perform a before and after comparison[14]. The method used is the difference-in-difference, although the survey questions on energy-saving light bulbs are identical every year. For instance, the 2014 survey only has information about the number of energy-saving light bulbs, but not about the number of incandescent light bulbs, while the survey in 2016 has information on both, and that in 2018 has further information on incandescent, energy-saving, and LED light bulbs. We use this treatment if the household uses energy-saving or LED light bulbs. To measure the effect of replacing light bulbs on electricity consumption and expenditures, the following equation is estimated:

$$\ln(y_i) = \beta_0 + \beta_1 D_t + \beta_2 S_i + \beta_3 D_t S_i + \beta_4 Z + u, \quad (6)$$

where is the outcome variable measuring household electricity consumption or expenditure of household , represents a dummy variable for each year, is a binary variable indicating whether the household uses energy-saving light bulbs, and controls for other household characteristics. The coefficient in equation (6) captures the effect of replacing incandescent light bulbs with energy-saving or LED light bulbs, on electricity expenditures and consumption.

14 We do not observe the same household before and after. Survey samples for 2014 and 2018 are not a panel.

4. Results

4.1 Effect of electricity expenditure on total expenditure

Table 2 shows the results from the Engels estimations. They show how the proportion of expenditures towards electricity varies when the expenditure varies per se. These estimations reveal that there is an improvement in the share of electricity expenditure for the year 2018, compared to the total expenditure in 2014 and 2016, as the share has gone down. The coefficient for the expenditure logarithm is less in 2018 compared to all quintiles of income for the two previous years (except for the “poor” category between 2016 and 2018, due to their electricity demand that is less elastic).

Consistent with prior literature, households have a higher share of electricity expenditure over total expenditure, if they belong to the “poor” category. This is valid when we consider all quantiles together. There is no need to consider the estimates of being “poor” for households that are amongst the richest, or look at quintiles separately, as this would capturing the same information twice. Table 2 presents Engel’s estimates.

Table 2.

Engel’s estimates: Share of electricity expenditure over total expenditure

	All quantiles	Poor	Middle quintile	Rich
2018				
Log of electricity expenditure per capita	1.133***	1.111***	1.050***	1.216***
	(0.0397)	(0.0634)	(0.0321)	(0.0969)
Binary poverty classification	0.904***	0.763***	-0.004	-0.113*
	(0.0227)	(0.0669)	(0.0187)	(0.0639)
Number of incandescent light bulbs	-0.025	-0.014	0.021	-0.018
	(0.0192)	(0.0485)	(0.0138)	(0.0259)
Number of energy-saving light bulbs	-0.027***	-0.055	0.011	-0.010*
	(0.0065)	(0.0392)	(0.0084)	(0.0061)
Number of LED light bulbs	-0.039***	0.011	0.001	-0.009
	(0.0072)	(0.0661)	(0.0107)	(0.0076)
Observations	4,695	565	1,041	1,138
2016				
Log of electricity expenditure per capita	0.353***	0.310***	0.378***	0.399***
	(0.0137)	(0.0210)	(0.0128)	(0.0404)
Binary poverty classification	0.240***	0.198***	-0.029***	-0.061*
	(0.0063)	(0.0120)	(0.0084)	(0.0347)
Number of incandescent light bulbs	0.005	0.007	-0.004	0.007

	(0.0037)	(0.0182)	(0.0084)	(0.0051)
Number of energy-saving light bulbs	-0.004	-0.007	0.001	-0.005
	(0.0037)	(0.0182)	(0.0084)	(0.0051)
	7,561	1,220	1,591	1,580
2014				
Log of electricity expenditure per capita	0.352***	0.292***	0.345***	0.339***
	(0.0108)	(0.0156)	(0.0113)	(0.0312)
Binary poverty classification	0.221***	0.165***	-0.026***	0.054*
	(0.0068)	(0.0137)	(0.0077)	(0.0314)
Number of energy-saving light bulbs	-0.004***	-0.009	0.002	-0.004*
	(0.0016)	(0.0055)	(0.0019)	(0.0021)
Observations	11,259	2,099	2,269	2,346

Source: Elaboration based on ERCUE-Peru 2014–2015, 2016, and 2018.

*Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors and in parentheses. The control variables for column specifications are the household characteristics described in Table 1, and a squared term for the variable on the log of electricity expenditure per capita. The complete model specification can be made available by the authors on request. Population weights were used in the regressions. The estimated regressions are fractional probit, as the dependent variable varies between 0 and 1. To take into account household characteristics, the use of other fossil fuels, and fixed effects at the regional departmental level, they also include covariables*

4.2 Effect of replacing incandescent light bulbs by energy-saving and LED ones

Replacing incandescent light bulbs by energy-saving or LED light bulbs has an impact on household electricity expenditure. Table 3 compares the effect of different light bulbs on energy savings across income categories in 2018. In 2018, having one additional incandescent light bulb led to a higher electricity expenditure, compared to having one additional LED light bulb, or one additional energy-saving light bulb. This confirms the energy efficiency of using energy-saving light bulb and LED light bulbs. If we hypothetically replaced an incandescent light bulb by an LED light bulb in the same household, electricity expenditure would go down by 2.2%, when everything else is constant. This is the difference between the two coefficients, as shown in Table 3. Based on this finding and data from Figure 2, we see that around 932,499 households (which is the number of "poor" households that have on an average two incandescent light bulbs) could potentially benefit from replacing incandescent light bulbs. This result is important, as households that have fewer light bulbs tend to use more incandescent light bulbs (see Figure 3 above).

Table 3.

The effect of having energy-saving light bulbs on the log of electricity expenditure

Number of incandescent light bulbs	Number of energy-saving light bulbs	Number of LED light bulbs
0.0926**	0.0908***	0.0708***
(0.0464)	(0.0117)	(0.0132)
Number of incandescent light bulbs squared	Number of energy-saving light bulbs squared	Number of LED light bulbs squared
-0.0017***	-0.0049	-0.0021***
(0.0004)	(0.0076)	(0.0006)
Observations:	6,261	
R-squared:	0.431	

Source: ERCUE survey, 2018.

*Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors and in parentheses. The control variables for column specifications are the household characteristics described in Table 1. There is two-stage least squares estimation. The second stage includes other covariates such as regional fixed effects. The first stage regresses the log of income against gender and age of the household, a dummy for children less than five years old, a dummy for members older than five and less than 21 years, education categories, regional fixed effects number of rooms, number of members in the household, poverty, and urban categories. The complete model specification can be made available by the authors on request. Population weights were used in the regressions.*

The first line of results in Table 4 shows that households are more sensitive to changes in electricity expenditures for the years 2014–2015 compared to 2018, as reflected in the sensitivity parameter seen to be negatively higher for 2014–2015, than for 2018. This means that in 2018, the likelihood that a household belonged to the "poor" category with an increase in electricity expenditure is more than in 2014. Another way to interpret these coefficients is to take their absolute value and assess how an increase in the log of last month's electricity expenditure affects the probability of being "non-poor" now. This probability is lower in 2018, meaning that higher electricity expenditure is less common in "non-poor" households. This parameter is a good proxy for the electricity affordability of "poor" households.

Before the national program's intervention in 2014–2015, "poor" households were less likely to use energy-saving light bulbs and were much more sensitive to electricity expenditure. After the intervention, the results change. The sensitivity to the monthly electricity expenditure and the probability of not having energy-saving light bulbs decreases considerably. We see that the coefficient for the number of energy-saving light bulbs in 2014 is much more negative than in 2018. These findings reveal that the Peruvian national program for replacing incandescent light bulbs with energy-saving light bulbs has contributed to the affordability of poor households by allowing them to consume more electricity through the use of efficient lighting. We also find that categorizing households into "poor" and "non-poor" has contributed to understanding the impact of using energy-saving light bulbs.

Table 4.

Probability of using energy-saving light bulbs by year

Dependent variable: Binary poverty categorization		
Variables	2014	2018
Log of the last month's expenditure on electricity	-0.3460***	-0.0701***
	(0.0417)	(0.0084)
Number of energy-saving light bulbs	-0.0568***	-0.0097***
	(0.0152)	(0.0027)
Number of energy-saving light bulbs squared	0.0010**	0.0003***
	(0.0004)	(0.0009)
Observations	7,835	7,856

Source: own elaboration based on ERCUE-Peru 2014-2015 and 2018.

*Note: *p<0.1, **p<0.05, ***p<0.01. Robust standard errors and in parentheses. The control variables for column specifications are the household characteristics described in Table 1. The complete model specification can be made available by the authors on request. Population weights were used in the regressions. The estimated regressions are fractional probit, and include covariables that take into account the household characteristics, the use of other fossil fuels, and fixed effects at the regional departmental level.*

4.3 Limitations

The results reported in this section should be considered as possible tendencies, rather than general conclusions, as they have several limitations. First, although we used cross-sectional sample data, panel data would provide greater data variation, less collinearity, and more degrees of freedom. The survey has improved over the years in content and quality, and we have made every possible effort to filter the data and use consistent variables over the years. Second, in our econometric estimations, as we estimate simple equations for the demand functions, results could be biased towards the equation for the included and non-included variables in the model. Third, it is possible that there is endogeneity in the program, wherein electricity consumption influences the adoption of energy-saving light bulbs. Finally, the household survey does not include information on the number of domestic appliances, which if less could justify why there is less energy consumption in some households.

Information on the prices and availability of LED and energy-saving light bulbs is also excluded in the present analysis. However, we see that their prices have decreased, their availability has increased, and that on average, LED light bulbs have a life that is 25 times that of incandescent light bulbs.

This exercise has allowed us to gain a deeper understanding of how households consume energy, and whether policies implemented by the government are actually helping Peruvian households access and afford energy, especially in the case of different income groups, i.e., the low-income group, who, compared to higher-income groups, spend much more on their basic needs.

5. Concluding remarks and policy recommendations

Using newly available data from 2018, and older data from 2014-2015 and 2016, this paper first identified the determinants of electricity consumption and expenditure amongst Peruvian households. Second, it evaluated the impact of replacing incandescent light bulbs with energy-saving and LED bulbs. Furthermore, it assesses the impact of replacing traditional energy bulbs with energy-saving and LED light bulbs in households as per the National Energy Plan 2014-2025. To the best of our knowledge, this is the first paper that focuses on the determinants of household electricity consumption and expenditure in Peru based on ERCUE data.

We used a descriptive analysis and two different econometric techniques to arrive at the following findings. First, households in rural areas have less access to electricity. Second, we found that compared to non-poor households, poor households tend to spend more on electricity as a share of their total expenditure, even though urban areas showed higher expenditure on electricity. Overall, the share of expenditure towards electricity reduced between 2014 and 2018. Third, households in urban areas use more energy-saving light bulbs than those in rural areas. Fourth, there is still a high number of households using incandescent light bulbs. One out of ten households and one out of four households in urban and rural areas, respectively, use incandescent lighting. Fifth, replacing incandescent light bulbs by energy-saving or LED light bulbs can reduce household electricity expenditure by 2.2%, ceteris paribus. Last but not least, the national Peruvian program for the replacement of light bulbs has made poor households less sensitive to electricity expenditure and more likely to adopt energy-saving light bulbs.

Our results have some policy recommendations. First, to continue to realize the effects of national programs on energy efficiency, reliable and active legislative, regulatory, and normative frameworks need to be in place. These frameworks support the adoption of efficient technologies through measures that curb the commercialization of low efficiency equipment. Furthermore, they can deliver relevant information about technologies, regarding their efficiency and total operational costs, as seen in the case of refrigerators, the biggest source of energy consumption in Peru.

Second, government initiatives could improve access to electricity in rural areas. This would require investment in infrastructure, and distribution networks, as well as ensuring that households have the correct equipment to access electricity.

Third, the implementation of targeted energy efficiency policies could reduce the electricity expenditure of households and increase affordability. Among other policies are programs on clean cooking stoves. These help in overcoming the problem of affordability in poorer households. Our results showed that poorer households became less sensitive to electricity expenditure, and hence could consume more energy to meet their basic needs. They also became more likely to adopt energy-saving light bulbs after the implementation of the program.

Finally, the response of poor households to the replacement of light bulbs shows the need to stimulate incentives from the demand side. For instance, the government could provide financial support for investments in energy-efficiency equipment, in the form of a subsidy for the equipment or device, a grant, or a tax credit. Another example is the removal of taxes on energy efficiency equipment imported into Peru, such as solar panels. Evidence had shown that it was "virtually impossible for households to afford them" while the tax was in place (Barnes et al., 2018, p. 48).

We believe that our findings are encouraging and promising. Based on these, governments may initiate more energy efficiency programs, such as the light bulb replacement program. On the one hand, programs like this can help overcome the problem of energy affordability affecting poorer households, thereby ensuring universal and affordable access to energy. On the other hand, by promoting long term energy efficiency, they contribute to the global objective of reducing CO2 emissions and fighting climate change.

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Appendix

Table A1. Descriptive statistics and the mean differences test of main variables from the 2014 and 2018 surveys

	Survey 2014		Survey 2018			
	Mean	Obs.	Mean	Obs.	Mean Diff	p-score
Demographic and socio-economic characteristics of the household						
Age of the household head	51.42	12,025	52.90	14,116	(1.47)	0.00
Below the poverty line classification (Yes = 1, No = 0)	0.28	12,025	0.31	13,288	(0.04)	0.00
Urban area (Yes = 1, No = 0)	0.70	12,025	0.72	13,288	(0.02)	0.00
Gender of household head (Male = 1, Female = 0)	0.79	12,025	0.74	14,116	0.05	0.00
Number of kids < = 5	0.20	12,025	0.17	14,116	0.03	0.00
Number of kids >5 and < 21	0.84	12,025	0.72	14,116	0.12	0.00
Number of persons in the household	3.67	12,025	3.56	13,288	0.11	0.00
Education categories for the heads of the households						
Less than primary education (Yes = 1, No = 0)	0.21	12,025	0.20	14,116	0.01	0.03
Only primary education complete (Yes = 1, No = 0)	0.30	12,025	0.27	14,116	0.03	0.00
High school graduate (Yes = 1, No = 0)	0.28	12,025	0.29	14,116	(0.01)	0.10
Some college education (Yes = 1, No = 0)	0.02	12,025	0.03	14,116	(0.01)	0.01
College graduate (Yes = 1, No = 0)	0.09	12,025	0.10	14,116	(0.01)	0.00
Postgraduate education (Yes = 1, No = 0)	0	12,025	0.00	14,116	(0.00)	0.01
Technical education (Yes = 1, No = 0)	0.1	12,025	0.11	14,116	(0.01)	0.01

Income and expenditures						
Expenditures (Local currency unit -LCU - monthly)	20,185.30	12,025	12777.80	13,288	7,407.50	-
Income primary (LCU - monthly)	1,100.87	10,052	4736.92	11,035	(3,636.04)	0.20
Income secondary activity (LCU)	423.13	1,284	134.19	11,033	288.94	0.00
Income received transfers (LCU - monthly)	7,699.39	1,770	149.89	14,116	7,549.50	0.00
Total income (LCU - monthly)	1,723.45	10,052	4931.51	11,033	(3,208.06)	0.91
Energy expenditures and consumption						
Electricity consumption (kwh)	117.35	7,916	73.07	6,787	44.28	0.00
Expenditure on electricity (LCU - monthly)	59.77	11,369	71.45	13,288	(11.68)	0.00
Expenditure on electricity per capita (LCU - monthly)	20.68	11,369	25.49	13,288	(4.81)	0.00
Expenditure per capita (LCU - monthly)	6,546.90	12,025	4336.80	13,288	2,210.10	0.00
Share of electricity expenditure	0	11,369	0.01	13,263	(0.00)	0.00
House characteristics						
Electricity (Yes = 1, No = 0)	0.95	12,025	1.00	12,754	(0.05)	0.00
Has own vehicle (Yes = 1, No = 0)	0.17	12,025	0.18	14,116	(0.01)	0.04
Internet (Yes = 1, No = 0)	0.15	12,025				
Landline phone (Yes = 1, No = 0)	0.21	12,025	1.00	2,387	(0.79)	-
Mobile (Yes = 1, No = 0)	0.81	12,025				
Natural gas (Yes = 1, No = 0)	0.02	12,025	1.00	739	(0.98)	-
Number of energy-saving light bulbs	3.96	11,440	4.38	11,641	(0.42)	0.00
Water (Yes = 1, No = 0)	0.84	12,025	1.00	10,434	(0.16)	-

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