Modeling energy consumption to measure energy poverty in households in Buenos Aires (Argentina), 2017–2018

Federico Dubois
Escuela de Ciencia y Tecnología (ECyT)
Universidad Nacional de San Martín (UNSAM),
Argentina

María Florencia Zabaloy
(corresponding author)
Departamento de Economía,
Universidad Nacional del Sur (UNS),
Instituto de Investigaciones Económicas y Sociales del Sur (IIESS) (UNS-CONICET),
Argentina
Email: florencia.zabaloy@uns.edu.ar,
florenciazabaloy@gmail.com

María María Ibáñez Martín
Departamento de Economía,
Universidad Nacional del Sur (UNS),
Instituto de Investigaciones Económicas y Sociales del Sur (IIESS) (UNS-CONICET,
Argentina

Keywords:
energy consumption,
energy poverty,
residential sector,
Argentina

Energy poverty is a complex, multidimensional problem that affects people's quality of life. Its study has become an important pillar of the public policy agenda and the literature in Latin America. Using the 10% indicator, this paper aimed to model the energy consumption of households in Argentina to estimate the energy expenditure of each and thus determine which households are in a situation of energy poverty. For the empirical analysis The authors used the 2017–2018 National Household Expenditure Survey of Argentina, and urban households in the interior of the province of Buenos Aires were selected as a case study. After characterizing the main energy consumption habits of the sample, energy poverty was assessed. The analysis shows that for the study period (2017–2018), a significant number of households suffered from energy poverty; that is, they spent more than 10% of their income on energy expenditures. The findings indicate that the Demand Model is consistent, as the degree of adjustment is 0.1% in the demand for electricity and natural gas and 0.3% in the demand for liquefied petroleum gas. In addition, 462,143 households (28.3% of the sample analyzed) in the interior of the province of Buenos Aires experienced energy deprivation when considering the 10% indicator. On the other hand, by means of the 2M indicator, the results show that 518,686 households were in energy poverty (31.8% of the sample analyzed).

Introduction

With the influence of Mahbubul-Haq and Amartya Sen, in 1990, the United Nations Development Program (UNDP) suggested changing the way of assessing the growth of countries. The focus of the new proposal shifted from national income to life expectancy and literacy, using the Human Development Index (HDI) as a tool. This way of measuring the welfare of the population conceptually revolutionized the idea of development, modifying the triggering question of *how much*? to *how?* (UNDP 2010). The HDI is an indicator that can take values between 0 and 1 and is built with pillars associated with health, such as life expectancy, education, average years of schooling, school life expectancy, and economic situation, for instance, gross domestic product (GDP).

In his analysis of the social dimension of energy uses, García Ochoa (2014) highlighted the link between the level of human development and the per capita energy consumption of a country. The researcher stated that an economy with a very low HDI consumes 40 times less energy per inhabitant than a country with a very high HDI does. Therefore, to achieve high levels of welfare in a society, it is necessary to increase energy consumption. The relationship noted draws attention in the field of international public policies, and this is reflected in one of the 17 Sustainable Development Goals (SDGs) defined at the United Nations General Assembly in 2015. These goals incorporate new challenges compared to the previous Millennium Development Goals (MDGs). For instance, SDG 7 is specifically aimed at ensuring access to affordable, reliable, sustainable, and modern energy [10].

For its part, Argentina is making efforts to respond to the aforementioned goals. Specifically, with regard to access and affordability, a program called the Renewable Energy Project in Rural Markets (PERMER, as per its initials in Spanish) aims at increasing access to electricity in rural sectors isolated from the network. On the other hand, since 2003 and as a consequence of the social and economic crisis unleashed in 2001, the universal subsidy for energy demand began to be implemented, with the objective of guaranteeing its affordability. During the government administration in the period 2003–2015, poverty decreased from 60% to 30%, although excessive public spending began to be questioned by specialists (Gasparini et al. 2019). In 2014, the proportion of funds allocated to the energy subsidy was 3.5% of GDP, focusing criticism on the allocation mechanisms, which, at that time, did not discriminate between low- and high-income households (Secretaría de Energía 2019).

In 2016, due to a change in political management, new political guidelines were outlined. After a scenario of social tension resulting from the sudden increase in gas and electricity rates, which ranged between 1,000% and 2,700%, a path was opened for the progressive removal of the subsidy through public hearings (Wyczykier 2018). This made it possible to reduce the share of public funds to 1.4% of GDP in 2019, destined to subsidize energy demand (Secretaría de Energía 2019). However, poverty levels for that period increased and exceeded (once again) the 35% threshold. This highlighted the relationship between the increase in energy prices and a context of greater social vulnerability, which led to the discussion of energy poverty (EP) on the public agenda.

EP is a concept that originated in the United Kingdom, initially considered *fuel poverty*, and began to appear in the academic field after the 1973 oil crisis (García Ochoa 2014). Since then, the term has been conceptualized in different ways, broadening the spectrum of dimensions involved and expressing the complexity of its approach. García Ochoa was a pioneer in addressing this subject; however, in recent years, research on its notion for the region has intensified, seeking to transpose the concept to the cultural, geographic, social, economic, and environmental reality of Latin America.

In this context, the objective of this paper was to model the energy consumption of households in Argentina to estimate the energy expenditure of each and thus determine which households are deprived of energy. For the empirical analysis, the 2017–2018 Argentine Household Expenditure Survey (ENGHo, as per its initials in Spanish) was used, and urban households in the interior of the province of Buenos Aires (PBA) were selected as a case study. The following research questions guided this analysis: How much do households expend on energy in the PBA? Does such expenditure make them energy poor households? What is the EP rate in the PBA?

The paper is organized as follows: literature review of the definition and measurement of EP, methodology and data applied in the analysis, the estimates of the energy model and EP, and concluding remarks of the investigation.

A review of energy poverty

There is a consensus that the lack of access to energy is a serious problem that leads to EP, which is usually caused by high energy expenditure, low income, and poor building efficiency (Kashour 2023). However, the concept of EP has evolved considerably since its origins. For this reason, a brief review of the concept is presented. The first approaches toward a formal definition of the EP concept developed in the United Kingdom, when the authors Isherwood and Hancock, in 1979, proposed studying *fuel poverty* (Koh et al. 2012). Boardman (1991) characterized a household as fuel poor if it spends more than 10% of its income on adequate heating. Additionally, the author introduced the equipment dimension, giving relevance to the role that technology plays in improving energy efficiency to achieve greater thermal comfort benefits (García Ochoa 2014).

This subsistence approach was questioned by several authors (Whyley, Callender, Clinch, Healy and García Ochoa, among others), mainly due to the methodological difficulty of obtaining accurate data on the indoor comfort temperature in dwellings, the occupation time of the people who inhabit them, and the type of household income considered.

Later, it was suggested to expand the range of energy services taken into account in the diagnosis, and consequently, the term changed from *fuel poverty* to *energy poverty*. Moreover, in addition to the impossibility of paying for energy, the new approaches analyze other dimensions, such as access to reliable sources and/or adequate equipment to satisfy energy services.

This broad conception is summarized in various methodological proposals, among which are the methods of the Multidimensional Energy Poverty Index (MEPI), developed by Nussbaumer et al. (2011), and the Satisfaction of Absolute Energy Needs (NAEs, as per its initials in Spanish) elaborated by García Ochoa (2011, 2014). The latter methodology includes energy services for cooking and refrigerating food, heating water for personal hygiene, adequate lighting, and entertainment activities and employs economic assets as a measurement instrument to identify whether a household is in EP. In this sense, if a household does not have the economic assets to satisfy the NAEs, it will be in an EP situation. The proposal notes the need to characterize the weather of the study region to adapt the economic goods required to achieve thermal comfort.

On the other hand, the MEPI focuses on the deprivation of a series of key energy services for people's standard of living. This method seeks to capture, both in quantity and quality, the access to energy services considered and offers a greater analysis of the elements that determine the energy demand. Consequently, dimensions are defined, in particular energy services for cooking, lighting, food preservation, entertainment, education, and telecommunications. Then, the methodology assigns dichotomous variables for each dimension that inquire about possession of the necessary equipment, access to electricity, and access to reliable energy sources for cooking. Finally, it establishes a weighting for each variable and mathematically calculates the incidence – number of households in EP – and intensity – how deprived of energy they are (Nussbaumer et al. 2011).

At the end of 2016, the European Union (EU) created the Energy Poverty Observatory (EPOV). This institution does not formally define EP; however, its characterization accounts for a multidimensional approach. Regarding the measurement of the phenomenon, the indicators used are intended to capture a large number of sources of the problem and are divided into primary and secondary. There are four primary indicators: two of livelihood – twice the median (2M) and half the median (M/2) – and two consensual – delay in utility bills and inability to keep the dwelling heated. The suggested livelihood indicators complement each other. 2M indicates those households in which the energy expenditure-income ratio is more than twice the national median. On the other hand, M/2 indicates those who spend less than half the national median. The latter could be innovative since it takes into account those households that may be saving energy to be able to pay for the service. The secondary indicators aim at explaining the origin of deprivation, that is, why households are in EP. To do this, they consider the prices of the different types of energy used to generate electricity (oil derivatives, mineral coal, solid biomass) and the final prices of electricity and natural gas paid by users. Aspects of the household are also analyzed, such as the number of people who live in it, its surface area, the presence of leaks or humidity, its energy efficiency label, and access to equipment. Finally, other macro indicators are taken into account, such as the economic poverty rate, deaths in the winter period, and population density.

The Latin American context is very different from that of the European Union regarding the approach to EP by countries. No one has established an official definition of the EP concept, much less a strategy focused on its eradication. Despite the absence of national strategies, there is a growing number of contributions from the academic field to provide greater clarity in adapting the concept to the regional reality and define appropriate indicators to capture the problem in households.

In addition to the aforementioned investigation by García Ochoa (2014), Romero Pérez (2015) took as a reference access to electricity in households and the type of energy source used to cook food and/or heat the rooms. These data are supplemented with macro indicators, such as per capita energy consumption, energy intensity, population size, growth rate, HDI, and poverty rate.

Another set of studies estimated EP through some of the livelihood indicators mentioned above (10%, 2M, M/2). For instance, Durán (2018) assessed them for Argentina and highlighted the figures obtained for the level of EP in the last two decades in the country, also using the 10% indicator. Likewise, this author (2018) complemented this assessment by studying the existing relationship between households in an EP situation with their characteristics and the people who inhabit them (the constructive quality of the dwelling, the level of overcrowding, the unemployment rate, etc.) and energy prices.

In another line of academic research in the country, a study was carried out by Ibáñez Martín et al. (2019). Researchers have analyzed the degree of the relationship between energy deprivation and other factors that hinder human development. They first classified households based on whether they are (or not) in EP, according to the type of fuel used for cooking.[1] The definition of EP provided by these authors is the one adopted in the framework of this research:

Energy poverty can be considered as the lack of satisfaction of essential energy services for human life, induced by the lack of access, quantity, and quality not only of energy but also of equipment, which is caused by various factors, such as socioeconomic (insufficient level of income, education, etc.), geographical (disconnection from the network), buildings (type of construction, insulation in openings, etc.) and cultural (preferences for certain energy sources), which ultimately affects the level of well-being of household members (Ibáñez Martín et al. 2019: p. 7).

[1] Kerosene, firewood, coal, garbage burning, among others, and those that use other elements (gas, gas cylinder, or electricity).

Methodology

The previous sections presented the state of the art, gathering the necessary elements to address the main objective of this research. After having approximated a conceptualization of EP and analyzing how to measure this phenomenon, this section describes the sources of information and the methodology used to characterize the sample of households chosen, estimate their energy consumption, build their energy expenditure, and finally determine what proportion of households in the sample is in an EP situation.

Data and sample

The first step involves answering the following questions: How much energy do households consume? What are energy services used for? Through what equipment do households satisfy these services? For this, the ENGHo for the years 2017–2018 was the main source of information. It is a survey carried out by the Argentine Institute of Statistics and Censuses (INDEC, for its initials in Spanish) with a variable frequency. The first edition was in 1985–1986 and was succeeded by those of 1996–1997, 2004–2005, 2012–2013 and 2017–2018.[2] The ENGHo is conducted in urban centers with a population of 2,000 or more. It is a wide source of information that allows us to know the living conditions of urban households, especially in terms of access to goods and services and income [5].

Based on a technical cooperation agreement between the Argentine Department of Energy and INDEC in 2017, the 2017–2018 edition of the ENGHo incorporated a special energy module, which aimed to expand and update the equipment section of the 2012–2013 ENGHo. In addition to ownership, it includes questions about the use of equipment, its age, the energy efficiency label if applicable, and other questions related to energy use [4].

To reduce the volume of data and the climatic heterogeneity that the Argentine territory presents, a determining aspect in energy consumption (OLADE 2017), the sample was limited to those households that are part of the interior of the PBA. The 2017–2018 ENGHo contains a sample of 1,725 urban households in this region, whose representativeness reaches the value of 1,633,388 households. Within the considered subregion, there are two different bioclimatic zones according to the bioenvironmental characterization specified in the IRAM 11603 standard.[3] These are the warm temperate zone (III) and the cold temperate zone (IV). A brief description of each is provided below in Table 1.

[2] Although the survey does not have a fixed frequency, it is generally carried out every ten years. Therefore, the data for 2017–2018 is the most recent. In addition, the article focuses on the equipment and habits of households, which are variables that do not usually change in the short term (Castells 2012).

[3] IRAM standards are certified in Argentina by the Argentine Institute for Standardization and Certification. For details, refer to [8].

Table 1

Characterization of bioclimatic zones in the province of Buenos Aires

Denomination	Zone III	Zone IV[a)]
Classification	Warm temperate zone	Cold temperate zone
Summer	Average temperatures between 20 °C and 26 °C, and average maximum temperatures above 30 °C	Summers are not harsh and have average maximum temperatures that rarely exceed 30 °C
Winter	Average temperatures between 8 °C and 12 °C, and minimum values that are rarely less than 0 °C	Winters are cold, with average values between 4 °C and 8 °C, and average minimum temperatures are often below 0 °C
Subzones	IIIa: thermal amplitudes greater than 14 °C IIIb: thermal amplitudes lower than 14 °C	IVa, IVb, IVc, and IVd, by means of the thermal amplitude lines of 14 °C and 18 °C[b)]

a) It is divided from Zone III by the isoline of 1,170 heating degree days (HDD18), and as a lower limit with Zone V, by the isoline of 1,950 HDD18.

b) Within the considered area, there are only subzones IVc, of transition, and IVd, maritime.

Energy demand model methodology

The 2017–2018 ENGHo contains, among its questions, the amount of energy consumed for the different energy sources. However, this information was not used for the following reasons. First, although there are data for the quarter in which the household was surveyed, it would be necessary to have at least one year of consumption to avoid biases corresponding to winter and summer periods. Second, households with informal or illegal access would not be captured, and therefore, it is not possible to quantify their consumption. As Jaber (2023) mentioned, national surveys should include more questions related to EP, such as information regarding utility bills and indoor temperatures during the different seasons.

Therefore, household energy consumption was estimated through the *bottom-up* methodology, also called *prospective by analytical methods*. It consists of characterizing the demand of a particular sector based on the theoretical construction of demand for individual cases called homogeneous modules (OLADE 2017). In the analysis, hereinafter called the Demand Model, the homogeneous modules are the equipment included in the special energy module of the 2017–2018 ENGHo. Then, these results were grouped to describe the demand by end use, and thus, following this logic, the demand for each household was determined by energy source. In short, the function of the Demand Model is to transform the statements of the surveyed households into amounts of energy.

The energy sources considered in the model are electricity, natural gas, and liquefied petroleum gas (LPG) due to their representation in residential consumption. According to the 2020 Argentine Energy Balance, these sources represent 98% of the total energy consumption of the sector. Likewise, the 43 appliances revealed by the survey were grouped according to each end use, as highlighted in Table 2.

Table 2

Grouping of the equipment surveyed in the 2017–2018 ENGHo according to end use

Energy use	Appliance
Cooking	Gas stove, Electric stove, Gas oven, Electric oven, Microwave
Food preservation	Freezer, Refrigerator with freezer, Refrigerator without freezer
Cooling	Split of up to 2,600 frigories, Split of more than 2,600 frigories, Compact Window type, Fan, Electric centralized refrigeration system
Heating	Split up to 2,600 calories, Split over 2,600 calories, Electric stove, Gas cylinder stove, Gas central heating, Underfloor heating, Water radiator heating, Balanced-flue gas heater, Nonbalanced-flue gas heater
Lighting	Incandescent, Halogen, Compact fluorescent lamp (CFL), Led, Fluorescent tube
Sanitary Hot Water	Gas tankless water heater with autopilot, Gas tankless water heater without autopilot, Electric tankless water heater, Gas tank water heater, Electric tank water heater, Hot water by individual boiler, Hot water by central boiler, Electric shower
Laundry	Semiautomatic washing machine, Automatic washing machine
Others	Well pump or cistern, LED or LCD TV, Tube TV, Desktop computer, Iron

Source: Own elaboration based on information published by [4–6].

Among the gas equipment, the variable 'ch15' from the survey was applied to determine which ones use natural gas and which ones use LPG. This question asks about the main fuel for cooking. LPG was assigned to all households that stated using cylinder gas, tank gas, and bulk gas.

To estimate the annual amounts of energy consumed by each piece of equipment, different variables contained in the survey were applied:

- **Use:** to establish if the equipment was used (or not) in the household.
- **Frequency of use and number of hours:** number of times per week and hours per day that the equipment was used.
- **Age and efficiency:** the age and/or efficiency of the equipment, if applicable.
- **Number of members:** the number of people living in the household.
- **Number of rooms:** the number of rooms in the household.

Once the variables were identified, it was observed that it was necessary to incorporate complementary parameters to calculate the energy consumed by each piece of equipment. The parameters created, and detailed below, are related to the information contained in the survey variables, either due to the characteristics of the equipment, the household, or the bioenvironmental determinants.

- **Specific consumption or power of the equipment:** For electrical equipment, the specific consumption published by the Argentine Electricity Regulatory Entity (ENRE, as per its initials in Spanish) was taken as a reference

[1]. For gas equipment, the database published by the Argentine Gas Regulatory Entity (ENARGAS, as per its initials in Spanish) was used (ENARGAS 2022).

- **Consumption by efficiency and age:** the household statement on the efficiency class and/or the age of the equipment was used to determine its specific consumption. For those devices that have an energy efficiency label, the value established in the respective IRAM/NAG Standards was used, complementing it with academic tests on measurements in real use conditions. If the energy efficiency label was not known, the age data were used, determining the specific consumption from the average of the available efficiency classes according to the stated age.
- **Number of weeks of air conditioning:** for those units that were used only in winter and/or summer, the number of weeks of use was limited based on bioenvironmental determinants. In other words, the number of weeks that the heating and cooling equipment was used was determined based on the temperature. This point is developed later.
- **Number of sunlight hours:** This was applied for the use of lighting to complement the statement of use.
- **Load factor:** a dimensionless value to represent a fraction of the nominal power of the equipment.
- **Simultaneity factor:** a dimensionless magnitude to indicate what proportion of the lamps in the household were on at the same time.

Bioenvironmental determinants:

The bioenvironmental determinants that directly affect the theoretical estimate of energy consumption are temperature (minimum, maximum, and average) and the number of hours of sunlight. Likewise, the end uses these determinants are supposed to influence are cooking, sanitary hot water, cooling and heating of rooms, and lighting. The first four were assessed as a function of temperature while lighting was based on the number of hours of sunlight.

The territory of the chosen sample of households covers four bioclimatic subzones, according to the Argentine Meteorological Service (SMN, as per its initials in Spanish). This database contains information on the monthly average values of maximum, minimum, and average temperatures for the period 1981–2010 [9]. To more accurately capture the climatic diversity of the four subzones, data from ten weather stations were considered, and a weighted average was calculated based on the number of inhabitants in each subzone. In the Appendix Figure A1 shows the chosen climatic stations and their distribution throughout the territory of the interior of PBA.

Number of weeks of air conditioning:

The number of weeks of air conditioning is a parameter created for the model to estimate the number of weeks per year that cooling and heating equipment were used. For this, the degree days (DG) methodology was applied, which provides information about the thermal requirement inside the house. Once a certain comfort temperature has been chosen inside the household, this methodology allows for the assessment of the difference that exists with the outside temperature (Gil–Prieto 2014).

To determine the number of weeks of heating based on the available database (monthly average of the mentioned temperatures), those months in which the average monthly temperature was less than 18 °C were counted, and the minimum comfort temperature was chosen, according to the World Health Organization (2018). The result is seven months, which implies the use of heating 28 weeks a year on average.

The number of weeks of cooling use was estimated following the method of Moustris et al. (2011), based on the monthly average of maximum temperatures and establishing 26 °C as a threshold. In other words, those months that had an average monthly maximum temperature higher than 26 °C were considered a cooling period. In the sample, three months exceeded this threshold; therefore, the model used 12 weeks per year to calculate the consumption of cooling equipment.

Sunlight hours:

The 2017–2018 ENGHo asked about the use of lamps for lighting based on two questions: 1) How many lamps do you use at home? and 2) How many lamps do you use for more than four hours? However, the number of hours was not considered. Thus, a parameter was created for the number of hours that the household was without sunlight.

For this, data from the Naval Hydrography Service [7] were used, with the town of Azul, located at coordinates 36°47'S 59°51'W, as a reference. Additionally, an active day was assumed, that is, in which household members were awake, which went from 7 a.m. to 11 p.m.

The number of hours of use assigned to the lamps in the household answered in (1) resulted from the number of hours in which the household did not have sunlight and was also within the time slot of the supposed active day. This means that, for example, if for a specific day the sun rose at 8:00 a.m. and set at 6:00 p.m., the number of hours for (1) results in (8–7) + (23-18) = 6 hs. The annual average hours of lighting per day is 4 h 20'. For those lamps that 'are used for more than four hours', the consumption estimated in (1) was considered plus that calculated from the number of lamps stated in (2) multiplied by four hours.

Thermal requirement for sanitary hot water:

To estimate the requirements of the domestic hot water production service, the methodology implemented by Iannelli et al. (2017) was applied, based on the expression:

$$Q = m \cdot c \cdot (T_{confort} - T_{grid}) \quad (1)$$

where Q is the amount of heat required per person, m is the mass of water used by each member of the household, assumed to be 50 liters, c is the specific heat of water, $T_{confort}$ is the hot water use temperature, assumed to be 40 °C, and T_{grid} is the temperature of the water in the network.

The value of T_{grid} throughout the year was estimated by means of the following expression, taken from the methodological notes of the Housing Labeling Program of the Department of Energy (Poggi et al. 2021):

$$T_{grid-n} = T_{average} + \frac{A}{2} \cdot 0{,}6 \left\{ cos \left[\frac{2\pi}{12} \cdot (n-3) \right] \right\} \quad (2)$$

where T_{grid-n} is the temperature of the grid water in month n, $T_{average}$ is the average monthly air temperature, A is the annual thermal amplitude, and n is the number of months considered. Then, the annual average was calculated from the values of T_{grid-n} obtained, which is 15.2 °C. This value was used to complete the calculation of the thermal requirement for the energy service in question.

Monthly end uses:

Although the model performs the theoretical estimate of consumption on an annual basis, due to the methodology applied for its consistency (an aspect developed later) and the need to assess the energy expenditure of households, it was necessary to calculate the estimated consumption monthly. With this, greater precision was obtained in the uses that are supposed to be sensitive to the bioenvironmental determinants considered, and it was also possible to establish the energy expenditure from the corresponding tariff charts.

To this end, an environmental variable was defined for each energy service, as well as different degrees of sensitivity in every case represented as *n* in Equation 3. As seen in Table 3 and based on the work carried out by Gil et al. (2015) and Kang–Reiner (2022), various levels of sensitivity of seasonal consumption of each month to the bioenvironmental variables were assumed for every energy service. These theoretical assumptions were intended to differentiate in a relative way the impact of the variation of the bioenvironmental variable chosen in each case on the seasonal consumption of each month. If the sensitivity is *n*, the model considers the energy service in question as 'totally sensitive', while if the variable is 0.2 (the lowest value assigned), the sensitivity to the variation of the bioenvironmental variable is 'very mild'. Table 3 shows the variables to which end uses were supposed to be sensitive, as well as the degree of sensitivity chosen in each case.

Table 3

Degree of sensitivity of end uses affected by bioenvironmental determinants

End use	Variable	Sensitivity level	
		interpretation	value
Heating	Degree day	total – linear	1
Cooling	Degree day	total – linear	1
Sanitary Hot Water	Average temperature	mild	0.25
Lighting	Sunlight hours	very mild	0.2
Cooking	Average temperature	very mild	0.2

To estimate the seasonal sensitivity of every end use, the equation below was used, in which the proportion of annual consumption corresponding to each month of the year is:

$$Value_{mon-i} = \frac{\sqrt[-n]{X_i}}{\sum_{j=1}^{12} \sqrt[n]{X_j}} \quad (3)$$

where $Value_{mon-i}$ is the portion of the annual consumption corresponding to month i, n is the degree of sensitivity, and X is the environmental variable for each end use. The numerator considers the sum of the bioenvironmental variable, while the denominator is the variable for a given month i. Additionally, the subscript j indicates the accumulation of months that have elapsed at the time of measurement, so it can take values from 1 to 12.

Theoretical estimate of consumption:

Once the incidence of bioenvironmental determinants on the different end uses was identified, at this stage, the theoretical formulas that allow for the assessment of the annual consumption values for each equipment were developed.

Table 4 shows the formulas used for every group of appliances. Each formula depends on the aforementioned variables – statements of the people – and on the parameters identified as necessary to make the estimates. The results obtained for each appliance are expressed in terms of consumption per year and in the common commercialization units of each energy source: kWh for electricity, m^3 for natural gas, and kg for LPG.

Table 4

Theoretical formulas for estimating household consumption

Group	Equipment	Theoretical formula
1	Cooking equipment	hours per day * times per week * weeks per year * equipment specific consumption * load factor
2	Refrigerators and Freezers	annual specific consumption
3	Sanitary Hot Water equipment	annual specific consumption per capita * number of household members
4	Individual equipment for HVAC (heating, ventilation and air conditioning)	hours per day * times per week * weeks per year of air conditioning * specific consumption * load factor
5	Centralized air conditioning system	hours per day * times per week * weeks per year of air conditioning * specific consumption * load factor * covered area of the house
6	Lamps	[amount used * specific consumption * hours without sunlight + amount used for more than 4 hours * specific consumption] * 365 * simultaneity factor
7	Washing machine	times per week * weeks per year * specific consumption
8	Others (LED/LCD TV, Tube TV, Desktop computer, Iron)	hours per day * times per week * weeks per year * equipment specific consumption
9	Well pump/cistern	number of weeks per year * specific consumption (if the number of members is greater than 1, multiplied by 0.75)

Source: Own elaboration based on the equipment surveyed by the ENGHo and the Demand Model developed.

Moreover, the model estimated another end use called 'Other non-ENGHo'. This includes electrical equipment that was not considered in the survey but is commonly used in a household, such as a shaver, electric kettle, notebook, hair dryer, etc. To specify the consumption of this category, the model assumed that the greater the number of appliances under 'Other ENGHo' use, the greater the consumption of 'Other non-ENGHo'. Then, the aggregate consumption of this end use was calculated as 50% of the consumption corresponding to 'Other ENGHo'.[4]

After these estimates, the consistency of the model results was tested based on the energy consumption data published by the Department of Energy in the Argentine Energy Balance (BEN, as per its initials in Spanish). The average consumption corresponding to 2017 and 2018 of the residential sector was considered, as the survey was carried out in those two years. It is worth noting that the BEN presents consumption information in aggregate form, that is, annual consumption and for the

[4] The assumption arises from the consistency with the direct data and the estimates on the consumption of 'other uses' of the reference studies mentioned below (Gastiarena et al. 2017, Gil 2021).

entire country. Since the paper focuses on the interior of the PBA, it was necessary to complement these data with those from energy distributors.

The breakdown of the aggregate consumption took as a reference the Annual Statistical Report of the Electricity Sector of the Department of Energy and the public databases of the Argentine Wholesale Electricity Market Clearing Company (CAMMESA, as per its initials in Spanish), ENARGAS, and the Argentine Registry of the LPG Industry.

First, information referring to the monthly consumption of each energy source was gathered. To reduce possible short-term distortions, the average consumption of each month of the year was calculated, taking the period between 2013 and 2018. Second, the proportion of the country's total consumption represented by the households of the selected sample was identified. Since the information is shown by the distributor, a weighted average was used based on the distribution of households[5] between the interior of PBA and Greater Buenos Aires (GBA) to estimate the amount corresponding to the study region.

In the case of electricity, data from the EDENOR and EDESUR distributors were considered, which comprise 9.8% and 4.9%, respectively, of households in the interior of PBA within their area. Regarding natural gas, the Metrogas and Naturgy BAN distributors were taken into account, representing 3.4% and 19.1%, respectively. For LPG, the weighting was applied according to the number of households that stated using LPG in the 2017–2018 ENGHo, with 22.4% of the households surveyed.

The previously detailed procedure allowed for knowledge of the official monthly consumption of the three energy sources, which served to compare the results of the model. In addition, the ENGHo was conducted only in urban households; thus, to weight the direct data, it was necessary to use the information on urban and rural populations from the 2010 Population Census [3].

Energy poverty and energy expenditure

After estimating the energy consumption of each household, it was necessary to determine the energy expenditure and then EP based on the former. For EP, the consistency indicators already mentioned in this work were used: 10% and the relative 2M (2Mr). The 2M indicator was also adjusted to capture the fact that the attributes and consumption of a household did not change proportionally but rather depended on its size. This modification gave rise to the 2Mr. Both indicators relate energy spending to household income. The 10% one considers EP as a household that allocates more than said proportion of its income to paying for energy (Boardman

[5] To learn the distribution of households, the 2010 Population Census and the population growth projections estimated by INDEC were used [3].

1991). For its part, 2Mr determines EP based on whether a household has an 'energy expenditure-income' ratio that exceeds twice the median of this ratio of the sample [2].

The total household income to calculate the previous indicators was taken from the 2017–2018 ENGHo. This information can be associated with the consumption obtained by the Demand Model using the ID of each household. However, a treatment was applied because the survey was conducted during a full year, and the Salary Index increased 28% in this period [6]. Then, the income was deflated based on the quarter to which the statements of each household correspond. For this, the last quarter (September-October-November) was considered as the reference period, deflating the income of the statements taken in the other quarters.

On the other hand, the energy expenditure was estimated using the tariff charts in force for November 2018 for electricity and natural gas and the maximum reference price for the 10 kg gas cylinder, set by the Department of Energy. Concerning electricity prices, the values of the EDEN distributor were considered and, for natural gas, those of the Camuzzi Gas Pampeana distributor were considered. The main taxes, VAT and provincial taxes[6] were taken into account, resulting in 32% for the electricity rate and 25% for natural gas.

In relation to the effect of the social tariff[7] on household spending, since the 2017–2018 ENGHo did not report whether the household had been assigned this subsidy, it was analyzed whether it met the necessary conditions to apply to this program, and if so, the discount indicated in the tariff charts was adjusted. This mechanism aimed to avoid an overestimation of households with excessive spending.

For the abovementioned analysis, the variables available in the survey were used and involve whether the household received retirement or pension income, Universal Child Allowance, Pregnancy Allowance, or unemployment insurance. Under these conditions, the social tariff was applied to the household as long as the income did not exceed twice the adjustable minimum living wage. Moreover, households that owned a car less than 15 years old were not considered, in accordance with specifications of the Electric Power Control Agency of PBA (OCEBA, as per its initials in Spanish). The same occurred with households that were neither owners nor tenants of the dwelling. This latter is not part of the requirements but was included as one of the deficiencies of the program in terms of its actual applicability.

According to the International Bank for Reconstruction and Development (2019), there is a significant number of vulnerable populations that do not receive subsidies from the social tariff since gas and electricity services are not registered in their name. Therefore, households that have stated that they live in dwellings with a tenancy

[6] Information from OCEBA and ENARGAS.

[7] The social tariff in Argentina applies to electricity and natural gas services. In the latter case, it depends on the national government, while in the former, it has been the responsibility of the provinces since 2018. This type of subsidy seeks to protect vulnerable households from energy deprivation.

regime declared as 'occupation' were excluded from the estimation of the social tariff. The results of this analysis are presented in Table 5.

It is possible to observe that the number of potential social tariff beneficiaries decreases for the highest household income quintiles, which is in line with the objective of targeting vulnerable populations. According to the estimate, the proportion of households in the sample that received or could have received the social tariff is 22%, a figure similar to that of the World Bank.

Table 5

Estimate of households in the sample with feasibility of applying the social tariff

Income quintile	Households with the social tariff					
	1	2	3	4	5	Total
Number of households	127,081	116,394	79,435	27,849	7,055	357,814

Finally, based on the income and energy expenditure estimated according to the previous steps, how EP was measured with the two indicators proposed above is explained. Under the 10% indicator, all households whose ratio between total deflated family income and energy expenditure (both annual) exceeds said proportion were counted.

For 2Mr, a 'Modified Equivalence Scale' proposed by the Organisation for Economic Co-operation and Development (OECD) was used, which is based on the assumption (empirically validated) that certain economic variables of the household do not increase in the same proportion depending on the number of household members and distinguishing between adults and minors (Mancero 2001). Thus, this equivalence expresses that both income and energy consumption, and consequently energy expenditure, do not increase equally according to the number of household members. The equivalence was applied using the following equation:

$$y = \frac{Y}{1 + 0{,}7\,(A - 1) + 0{,}5K} \tag{4}$$

where y is the number of equivalent household members, Y is the number of members stated in the survey, A is the number of adults, and K is the number of children under 14 years of age. Given the characteristics of the 2Mr indicator, using this equivalence allowed less distortion in calculating the median.

The estimate was also corrected as suggested by EPOV, with the M/2 indicator, to identify those households in a 'low-expenditure' condition, that is, to add to the measurement those households that consume less energy than necessary. To do this, the variable of equivalent energy consumption (not expenditure) was considered to avoid the distortions generated by households benefiting from the social tariff.

Results

Energy demand model

In this paper, the annual energy consumption of households was estimated for electricity, natural gas, and LPG. Then, the consistency of the model results was tested using the energy consumption data published by the Department of Energy in the BEN, as mentioned in the methodology section. This consistency for each energy source resulted from comparing the consumption per household per year reported by official sources (direct data) versus those obtained by the model. This can be observed in Figure A2 and A3, where the different colored curves indicate the estimated consumption for each end use, while the red curve with white dots represents what was reported by the distributors. This consistency test allowed adjustments to the model to reduce the difference between the modeled and the direct data. In this sense, the load factor parameters for the cooking and air conditioning equipment were adjusted, resulting in 0.8 and 0.85, respectively. The simultaneity factor, initially assumed at 0.5, was also changed to 0.4, and finally, the parameter concerning the number of weeks of use of the cooling equipment was modified from 12 to 15.

The results showed evidence of a difference with respect to annual consumption of 0.1% for electricity and natural gas and 0.3% for LPG. The consistency adjustment for the LPG case is worse in relative terms because the database of the Argentine Registry of the LPG Industry does not discriminate by type of end user, so it was assumed that households consume LPG cylinders of up to 45 kg. Additionally, the database does not distinguish between households in the interior of the PBA and GBA, for which the 2017–2018 ENGHo was used, as previously mentioned (Appendix Figures A2 and A3).

After performing the consistency evaluation, the average distribution of household consumption by end use was estimated. Figure A4 shows the average relative participation of each end use in the energy consumption of households in the interior of the PBA, based on the Demand Model. The aggregate consumption of the three energy sources analyzed is 13,873 kWh/home-year (1.19 tons of oil equivalent). The largest consumption corresponds to thermal uses – heating, sanitary hot water, and cooking – (considering the pilot flame) with 87% of the total. The rest of the consumption is divided into exclusively electrical uses: 4% for food preservation (26% of electrical consumption), 2% for cooling, 1% for lighting and laundry, and the remaining 5% for other electrical uses (Appendix Figure A4).

The results obtained were contrasted with other studies in the literature. On the one hand, Gil (2021) worked with a sample of 96 households from the Autonomous City of Buenos Aires (CABA, as per its initials in Spanish) and GBA. On the other hand, Gastiarena et al. (2017) performed a top-down analysis for households in the Buenos Aires Metropolitan Area (AMBA, as per its initials in Spanish). The most significant difference between these studies and the present paper is found in heating consumption, where the aforementioned studies assigned it 36% and 42% of total consumption, respectively, while the Demand Model estimated 53%. These variations could be explained by three factors. First, those studies did not consider passive consumption within the end use in question; they estimated it separately. Second, the households analyzed by Gil (2021) had higher electricity consumption than those in the interior of the PBA (4.2 MWh/household according to the sample, while that reported by the distributors for the interior of PBA was 2.4 MWh/home). Third, the sample of households in the Demand Model includes bioenvironmental zones IVc and IIIa, which are regarded as 'colder'. As a reference, according to the data published in the IRAM 11.603 standard, 852 degree days (DG_{18}[8]) were estimated for CABA and 968 DG_{18} for San Fernando – GBA – (both from zone IIIb), while 1215 DG_{18} were estimated for Junín (IIIa), and 1477 DG_{18} for Bahía Blanca (IVc), which shows a higher energy requirement for heating.

Energy poverty and energy expenditure

With the estimate of the amount of energy consumed by the households in the sample and the subsequent treatment of the data, it was possible to determine which households showed energy deprivation, that is, which were in EP.

Figure A5 shows the results obtained with the two indicators mentioned above, taking November 2018 as the reference period. According to the 10% indicator, 462,143 households in the interior of the PBA lived in EP conditions due to excessive spending (28.3% of the sample), while this proportion rises to 518,686 households (31.8% of the sample) when applying the 2M indicator. In the case of the 2Mr, a higher incidence of EP is observed in the lowest quintiles, possibly explained by the correction of the indicator to capture those with low expenditure (M/2) (Appendix Figure A5).

The results were contrasted with an estimate of households in EP conditions made by ENARGAS (2021) for the period 2015–2019 using the 10% indicator. The comparison shows similarities between the findings of this paper and those published by the agency (20% in 2018 and 30% in 2019), taking into account that this work considered data from November 2018. Additionally, this study calculated the indicator at the national level; therefore, different energy prices were assigned to the regions (for example, AMBA has lower prices), which could account for the variations found (Economía & Energía 2019). In turn, the significant proportion of households estimated to be in EP for the study period can be explained by the rate increase and an inefficient allocation of the social tariff, also combined with a complex macroeconomic scenario in 2018. For instance, depreciation of the US dollar by

[8] DG_{18} refers to the degree-day requirement for heating, taking a comfort temperature of 18 °C as a reference.

114%, inflation of 47.6% while the Adjustable Minimum Living Wage grew 25%, and a decline in GDP of 2.6%, among others (ENARGAS 2021).

Conclusions

A review of the EP concept allowed us to identify that, since its emergence, numerous and different cross-cutting aspects have been recognized. Due to its dimensional nature and gradients (various degrees of deprivation), EP must be addressed from diverse angles to achieve a reduction in the deprivation situation of households. In this sense, the present paper estimated EP for households in the interior of PBA. To this end, it was necessary to determine the energy consumption of households through a Demand Model and ENGHo data. Then, with energy price information, the household energy expenditure was calculated. Based on these constructed data and those from the survey concerning household income, two EP indicators were used: 10% and 2Mr.

The findings show that the Demand Model is consistent, as the degree of adjustment is 0.1% in the demand for electricity and natural gas and 0.3% in the demand for LPG. The results of this model differ from the energy consumption data stated by the people surveyed. For this reason, when working with microdata in the energy area, it is extremely important to use this type of model to obtain more robust statistics that are closer to reality.

In addition, it was found that 462,143 households in the interior of the PBA allocated more than 10% of their income to energy expenditure, which represents 28.3% of the sample analyzed. In the case of the 2Mr indicator, 518,686 households were in energy deprivation (31.8% of the sample analyzed). These results show that a nonnegligible proportion of the population analyzed suffers from an excessive level of energy expenditure and becomes a group feasible to be treated by policies that tend to alleviate the EP situation.

From the public policy perspective, the main mechanism applied to mitigate this situation has been the universal energy subsidy. This policy could be complemented with energy efficiency measures. Indeed, financing lines could be implemented to buy more efficient equipment for the country's vulnerable population. In this sense, there is a close link between the benefits associated with energy efficiency and the SDGs. In addition to SDG 7, which specifically aims at improving the energy efficiency rate, given the social and environmental impact, carrying out energy efficiency actions could help to achieve SDG 1 'No Poverty' and SDG 13 'Climate Action'. Identifying this present link can be of great interest for the feasibility of this type of project, since the initiatives can be very attractive when it comes to requesting support through financing from international organizations and cooperation with other countries. The economic-financial analysis of different energy efficiency policies designed to reduce EP could be a future line of research that emerges from this paper.

However, the analysis has some limitations that should be mentioned. The indicators selected to measure EP do not allow for determining if the energy consumption of the household is enough to fulfill the needs of its members. Moreover, it is not possible to establish whether a household is more energy efficient than others. Therefore, future research could address these issues. On the other hand, the study presented in this paper could be extended to more regions of Argentina or to other Latin American countries, either individually or comparatively. For instance, other nations in the region have similar surveys, such as the Consumer Expenditure Survey (POF, as per its initials in Portuguese) in Brazil, the National Survey of Quality of Life (ENCV, as per its initials in Spanish) in Colombia, and the Continuous Household Survey (ECH, as per its initials in Spanish) in Uruguay (Schimer Soares et al. 2023). This extension of the model to other territories of Argentina and other countries is a line of research originating from this first modeling. Argentina is a country with high territorial disparities; in fact, the provinces of northern Argentina have a lower level of development than their central and southern peers (González 2020). Therefore, studying the level of EP across provinces could be an important contribution to the literature. It is worth noting that the model developed here, its application and the study of its results show its usefulness, and this first analysis is necessary for its generalization to the Latin American region.

Appendix

Figure A1

Distribution of the ten selected climatic stations

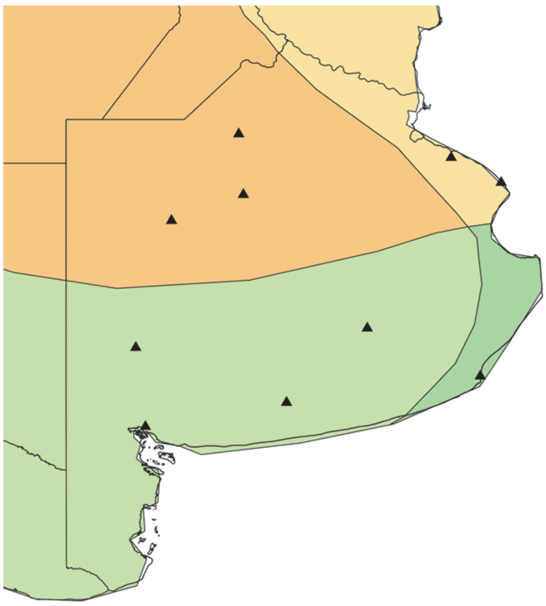


Figure A2

Consistency of electricity consumption with direct data

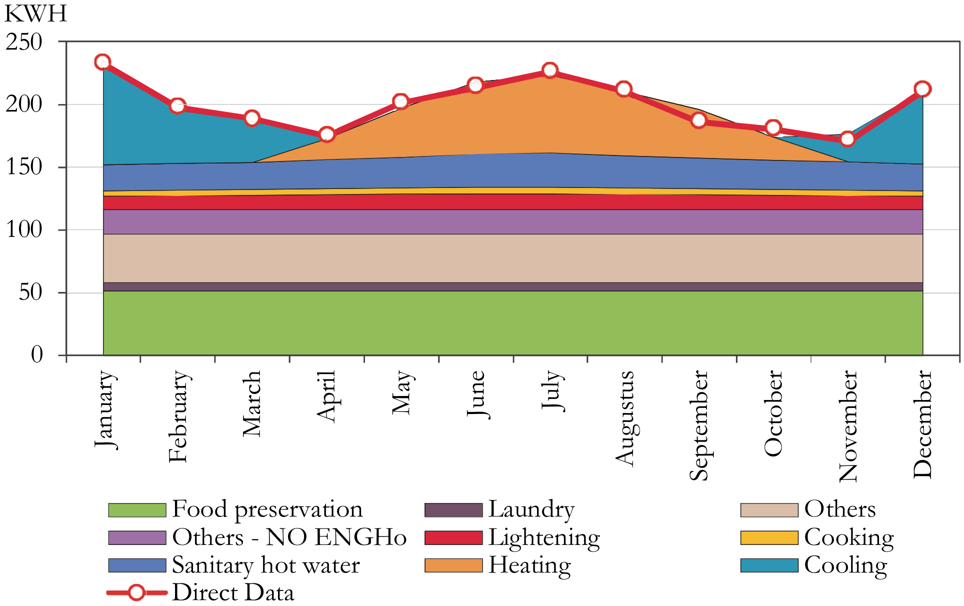
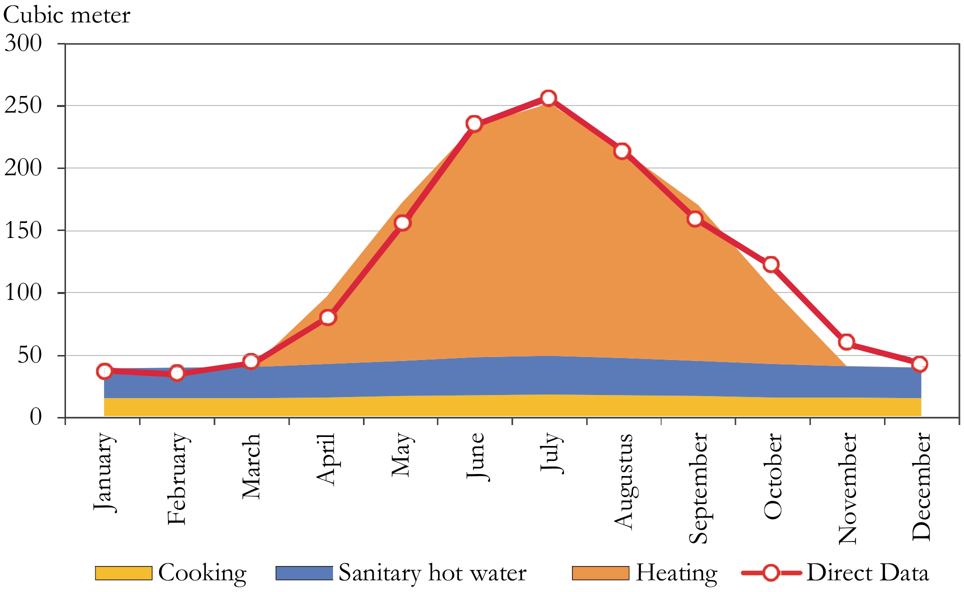


Figure A3

Consistency of natural gas and LPG consumption with direct data

Natural gas consumption



LPG consumption

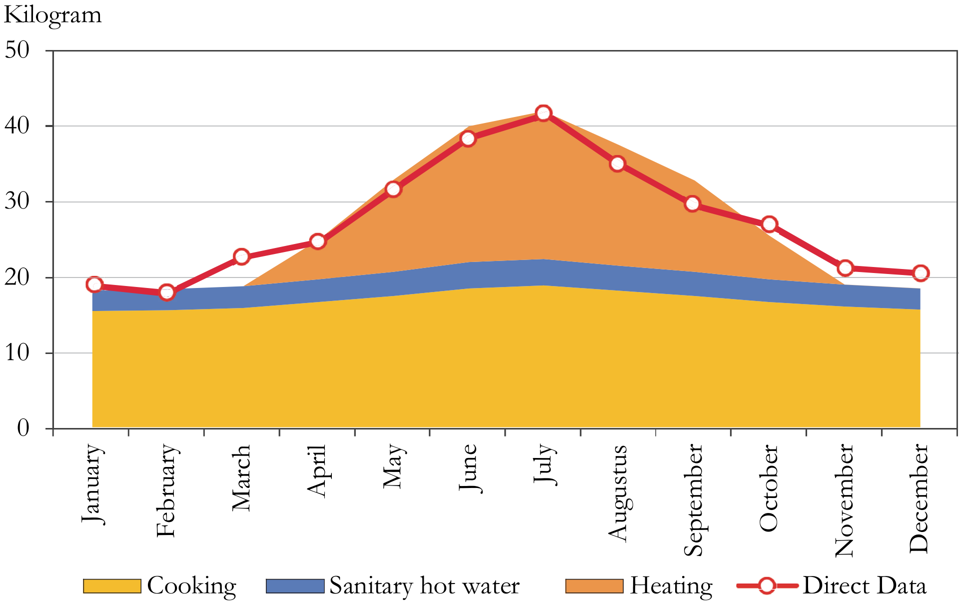


Figure A4

Distribution of energy consumption by end use estimated from the Demand Model

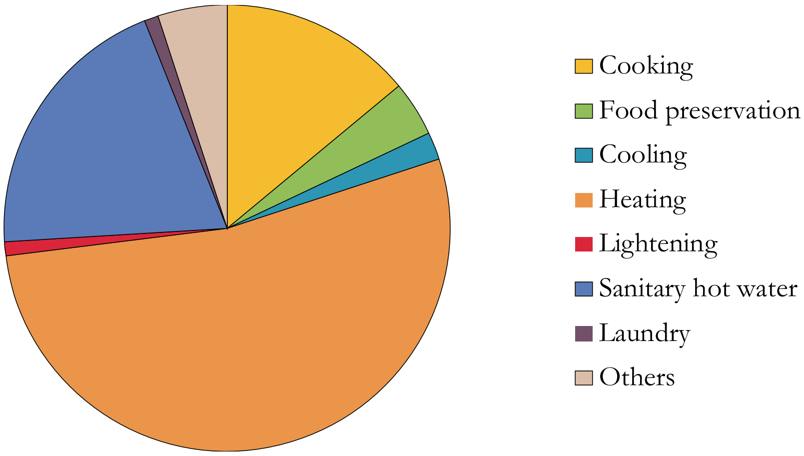
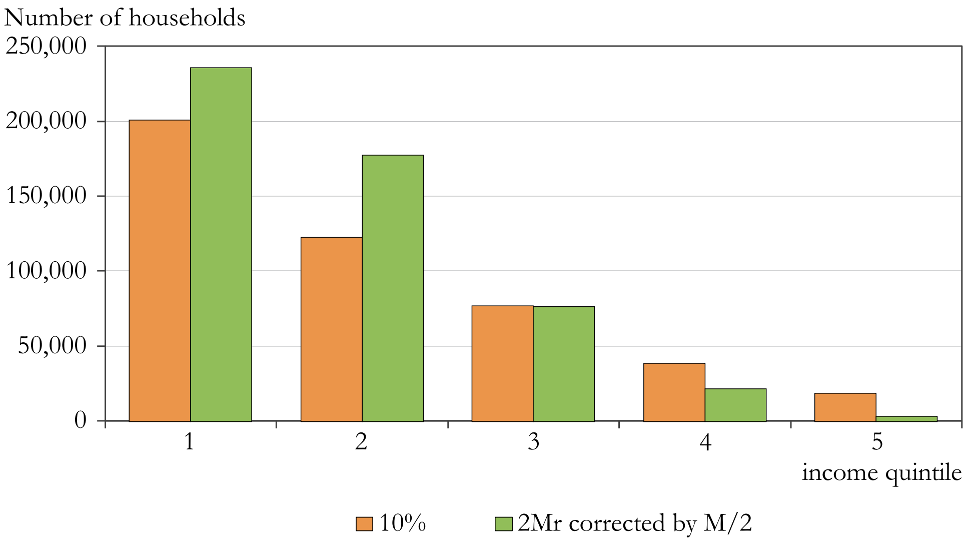


Figure A5

Estimation of households in energy poverty based on the 10% and 2Mr indicators



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