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# Which cooking and heating fuels are more likely to be used in energy-poor households? Exploring energy and fuel poverty in Argentina

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ABSTRACT

Energy poverty in emerging countries has mainly been analysed in the literature as a problem of energy supply accessibility. However, this analysis is too simple, as in many of these countries there can be a problem of energy accessibility that is not necessarily linked to an insufficiency of energy supply but is related to the use of certain types of fuels or facilities to meet the energy needs of the household. Moreover, what can explain the choice of these fuels can also be an affordability energy problem, and this has been scarcely treated on energy poverty papers focused on developing countries. This work aims to shed light on this literature, analysing both the affordability and the accessibility energy problem of Argentine households. To do so, we use micro-data from an expenditure-survey. First, we measure the energy affordability problem by calculating the Boardman indicator. Second, we estimate two logit models to show how likely it is that the affordability energy problem explains the choice of facilities for cooking and heating that can indicate an energy accessibility problem. Third, to refine the results of our estimations, we calculate the ROC curves to measure the levels in which energy-poor and non-energy-poor household are better identified than with the standard identification of logit models. The results show that it is more probable that households characterized by monetary energy poverty use facilities that indicate an energy accessibility problem than households that are not energy poor.

## 1. Introduction

Energy is essential for the development of any economic activity but is also crucial for the quality of life in homes. Access to basic services, including energy, is important for people's quality of life from the point of view of both their health and their socio-economic situation [1,2]. A lack of good access to energy services generates a situation that has come to be called energy poverty and is a consequence of low household incomes, low energy efficiency of dwellings and home appliances and high energy prices. Energy poverty has negative impacts on health, and these in turn have an indirect negative impact on the economic growth capacity of different countries. Therefore, energy poverty has negative economic and social consequences at both microeconomic and macroeconomic levels, which in turn affect the well-being of individuals and society as a whole.

The concept of energy poverty emerged from the seminal work of Boardman [3], which applied to the UK. Later, academic research was undertaken in other European countries and on other continents [4,5,1,6,7,8]. From an institutional point of view, the UK, Ireland, France [9,10] and, more recently, Spain[1] are among the few countries that have officially acknowledged the existence of fuel poverty and systematically monitored its occurrence over time. However, there is growing awareness of the importance of the energy poverty problem wherever it occurs. Thus, summits and conferences have begun to be held, promoted especially by international organizations, from which specific objectives and goals are emerging to deal with and give shape to this issue. For example, one of the goals of Agenda 2030 is to ensure access to affordable, reliable and modern energy for all by 2030. Therefore, the issue of energy poverty is currently a challenge for public policies in different countries due to issues of both equity (linked to poverty) and economic efficiency (the health consequences of this problem reduce the possibilities for economic growth of different economies). To overcome this challenge, it is necessary to measure and characterize energy poverty in each specific case, and more academic

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and research works are necessary.

To characterize energy poverty, first it must be measured. As explained for example by [6] and [9], the methodology applied to measure it usually differs according to whether the study intends to analyse a developed or a developing country. Generally, in developing countries, the focus is more on "accessibility", that is, on the presence of infrastructure networks, viewing the problem mainly as one of insufficient supply. On the other hand, in developed countries, the problem is focused more on "affordability", and thus fuel poverty is defined as the difficulty that households experience in coping with the costs of domestic energy, considering the problem as being the difficulty in meeting the demand. However, Zhang et al. [11] emphasized that, in reality, the problem of energy poverty in developing countries is one of both accessibility and affordability. Thus, they designed an indicator that measures both issues. Besides, they underlined that, in many emerging countries, the accessibility problem is not a problem of infrastructure supply because, in countries such as China, electricity is 100% accessible. Therefore, the problem of energy accessibility in such countries is not necessarily linked to an insufficiency of energy but is related to the use of certain types of energy sources, which are considered non-modern, to meet the energy needs of households.

The concept of non-modern energy sources is based on the energy ladder theory, which supposes that, in general, as average household income levels rise, fuel sources such as biomass tend to be replaced with sources such as kerosene, oil and, ultimately, electricity, which is the cleanest (as renewable energy sources are distributed through electricity) and most versatile energy source of all [12]. Thus, fuels that are abandoned when incomes rise are technologically less advanced and versatile than their substitutes. In that sense, a fuel that is abandoned is always less modern than its substitute. This permits us to classify fuels as non-modern with a logic similar to the economic theory that allows us to classify goods as inferior; in any case, this categorization is relative and not absolute.[2] The IEA considers firewood, charcoal and kerosene to be non-modern fuels [13,14]. These fuels are almost never consumed in developed countries. However, in developing economies (or rural regions in emerging countries), where, in many cases, there are still energy supply problems, a significant percentage of households are still using what are classified as primitive[3] and transition fuels[4] [15] and therefore non-modern fuels following the IEA classification.

The fact is that the literature tackling the ladder theory and the problems of consuming primitive and transition fuels has mainly focused on developing economies, to which the IEA classification of non-modern fuels is well adapted. However, the former classification of non-modern energy sources does not fit developed economies. In that sense, bottled gas is considered to be a modern energy source in developing countries, where many regions experience energy supply problems. In such regions, when incomes rise, transition fuels are usually substituted with bottled gas, which is, from a local polluting point of view, cleaner than firewood, kerosene and so on. Therefore, bottled gas provides a better quality of cooking and heating than solid fuels because it is cleaner and avoids all the negative impacts on health that the combustion of less modern fuels produces. In such economies, bottled gas is the cleanest energy source, and therefore the most modern source, exchanged in many of their fuel markets. It is also a solution to the health problems associated with the use of primitive fuels; its use is thus considered to improve households' socio-economic conditions substantially (see, for example, Andadari et al. [16] for the case of Indonesia, Troncoso et al. [17] for the case of Chiapas, in Mexico, and Khanwilkar et al. [18] for the case of India).

On the contrary, in developed countries, bottled gas is considered to be a traditional fuel that is consumed by the poorest (see, for example, La Vanguardia (2015)[5] and La Información (2021)[6]). In such countries, the consumption of solid fuels, like charcoal, is almost non-existent, and bottled gas is almost the least advanced and versatile energy source exchanged in the market in a ladder scheme and therefore a non-modern energy source. In fact, bottled gas is, following [19], a secondary technological energy facility. Its versatility is low: with bottled gas, one can heat one room, cook or heat water, but one cannot heat all the house space and cook and heat water at the same time with this energy facility. Bottled gas is consequently used as a strategy to save money in the UK's energy-poor households.[7] Therefore, this facility presents limitations in offering the services needed to meet the energy necessities in what, in many countries, can be considered standard modern conditions. Thus, depending on the socioeconomic characteristics of the country analysed and the relative weight of the use of solid fuels, bottled gas can be considered as a modern or a non-modern energy source.

In the case of Argentina, on which this paper focuses, almost 100%[8] of households have access to electricity [20]; moreover, even though the gas network is not present in one Argentinian region (the Northeast) out of six regions and therefore is not available for 100% of households, the possibility of meeting households' energy needs through modern gas exists because of the possibility of installing zeppelin gas containers.[9] Zeppelin gas containers are versatile, permitting a quality of heating and cooking similar to that of gas provided through a network (it is commercialized from a minimum capacity of 940 kg of gas and allows households, with the same installation, to heat the entire house space, to heat water and to cook at the same time). Thus, technologically, gas in zeppelin containers can be considered a primary energy facility. Therefore, in Argentina, all households have the possibility of cooking and heating with electricity or modern gas because there is a supply of both energy sources everywhere. Thus, the energy accessibility problem in Argentina, like that in China, is not a problem of energy supply but a problem of households' choice of non-modern forms of energy sources.

Considering the situation described in the previous paragraph, in this paper, we expand the International Energy Agency's (IEA) definition of non-modern fuels, and, to adapt this classification to the particular socioeconomic situation of Argentina, we include bottled gas as a *non-modern* fuel. In Argentina, bottled gas is sold in two commercial presentations, a cylinder called "tubo" (with a capacity of 30 or 45 kg of gas) and a cylinder called "garrafa" (with a capacity of 15 kg or 10 kg of gas). We categorize bottled gas as a non-modern energy source because the use of what the literature following the ladder theory and focusing on developing countries has considered to be non-modern fuels presents levels of consumption that are considerably lower in Argentina than in other emerging countries. Thus, for example, 30% of households in China still used solid fuels in 2016 [11] and 100% of households in Chiapas (Mexico) continue to use this kind of fuels [17], whereas, in Argentina, in the period analysed in this paper, the percentage of households using primitive or transition fuels is around 16%. Therefore,

[2] When their income rises, consumers or households abandon the consumption of certain goods and substitute them with other more sophisticated ones that satisfy the same economic necessities. The goods for which consumption is abandoned when incomes rise are considered to be inferior goods.

[3] Firewood, animal waste and agricultural waste.

[4] Kerosene, coal and charcoal.

[5] Firewood and bottled gas households coming back fuels: the crisis and the electricity explain the hike of traditional energies. https://www.lavanguardia.com/economia/20150209/54425911264/butano-lena-regresan-hogares-combustibles-baratos.html, 9 February 2015.

[6] Botted gas hikes and stresses low-income households. https://www.lainformacion.com/economia-negocios-y-finanzas/nos-van-arruinar-todos-gas-pobres-maximos-2018/2838535/, 18 May 2021.

[7] To provide another example for the case of the UK, the work by [54] shows that the percentage of bottled gas use is much higher in energy-poor households than in non-energy-poor households.

[8] In our sample, which excludes towns with fewer than 5000 inhabitants, 99.86% of households have access to electricity through the network.

[9] Moreover, these containers can be installed in single houses and in apartment buildings.

solid fuels, which are highly exchanged in many developing fuel markets, represent a small share of the Argentinian fuel market.[10]

In this context, bottled gas is among the least versatile fuels available and sold in the Argentinian market. Its versatility is similar to that provided by, for example, kerosene in the sense that the possibilities of cooking and heating home spaces with kerosene and bottled gas are similar: one cannot cook and heat with the same installation or heat the entire home space. Therefore, bottled gas provides a lower quality of home energy services than other energy facilities available in the Argentinian market, which are much more versatile. Bottled gas clearly offers access to a lower quality of energy services than electricity and gas supplied through a network or zeppelin container. In fact, contrary to its consideration in other developing economies as being indicative of economic improvement, bottled gas is considered in Argentina, as it is in Spain or the UK, to be the gas of the poor (El Argentino, 2021).[11]

Taking these features into account, along with the fact that bottled gas is a secondary energy facility compared with gas provided through a network or a zeppelin container, in this paper, we consider the following as non-modern energy sources: animal waste, agricultural waste (classified as "other" in the Survey of Household Budgets in Argentina), kerosene, firewood, charcoal and bottled gas. As modern energy sources, we consider electricity, gas supplied through a network and gas from a zeppelin container. This classification is better adapted to the Argentinian situation and characteristics than the usual classification of modern and non-modern fuels in the literature. To avoid creating confusion, in this paper, we will talk about non-modern and modern facilities instead of non-modern and modern fuels.

Concretely, this work aims to measure and characterize energy poverty in Argentinian households, investigating specifically how likely it is that the problem of energy affordability explains the problem of energy accessibility and measuring it through the use of non-modern facilities for both cooking and heating (the survey used in this paper includes data about both heating space and heating water).[12] Our hypothesis is that, in a country where there is a modern energy supply throughout the whole territory, the choice of non-modern facilities for cooking and heating – which are indicative of a technological energy poverty situation – are explained by the energy affordability problem and therefore by monetary energy poverty in households.

The work will be undertaken in three stages. In the first stage, using Boardman's indicator – which is the most frequently used expenditure indicator of energy poverty in the literature – we will measure energy poverty in Argentinian households between November 2017 and November 2018, which is the period for which the data used in our estimations, which come from the Survey of Household Budgets in Argentina, are available. Second, we will estimate two logit models, dealing with endogeneity. In the first one, we will estimate the probability that the use of non-modern energy sources for cooking in Argentinian households is explained by a situation of monetary energy poverty (as measured in the previous stage); in the second one, we will estimate the probability of the use of non-modern energy sources for heating (as measured in the previous stage). We will include control variables in both models. In the third stage, we will use the results of the logit estimates to calculate ROC curves. The main aim of discrete choice models is to build a tool that allows the best discrimination of the cases of the dependent variable. The value of the dependent variable that is usually used to separate cases is 0.5, but this value is arbitrary. In our work this means that it could happen that with this value a high percentage of non-poor households are identified, and thus sensitivity is assessed well, but, with this value a low percentage of poor-households are identified, and specificity is not well assessed. The ROC curves allow us to study and determine graphically which is the best discrimination value, seeking the one that achieves the greatest sensitivity and specificity, which is the point at which the biggest percentage of non-poor and poor households are identified (and that in many cases is not 0.5). In our models, we use this value, which allows us to predict better which are the households that are choosing non-modern facilities to cook and heat.

The contribution of this work to the literature is threefold. First, this work is an addition to the scarce literature on the subject of energy poverty in Latin America; furthermore, as far as we know, it is the first study of this type to be carried out in the case of Argentina. Second, to the best of our knowledge, this is the first work to explain how, for an emerging country, the energy affordability problem determines the probability of a household having an energy accessibility problem, specifically a lack of accessibility of modern facilities for cooking and heating the house space and water. In this sense, the previously mentioned work by Zhang et al. [11] highlighted for the first time that, in many developing or emerging countries, the problem of energy poverty is incompletely analysed if only accessibility is considered and thus designed an indicator to measure both dimensions. However, Zhang et al. [11] did not measure the relationship between energy affordability and energy accessibility, as our work does. Besides, an abundant literature has investigated the determinants of the choice of different energy sources for cooking and heating at the household level ([21] presents a review of these papers); however, as far as we know, this is the first time that an indicator of monetary energy poverty is used as an explanatory variable in such an analysis. Third, this paper introduces ROC curves to determine the best threshold for the results of discrete choice models, which are common in this kind of literature. Therefore, we will be able to assess the sensitivity and specificity produced by each probability and obtain the best cut-off point to identify with the greatest accuracy the energy-poor households that use energy facilities for cooking and heating to explain the problem of energy accessibility. This calculation, which is not commonly used in the energy poverty literature based on discrete choice models (as logit models), should be used regularly in such literature to enable better identification of energy-poor households and therefore better implementation of public policies against energy poverty.

The paper is structured as follows. The next section will provide a review of the existing literature on the measurement of energy poverty. Section 3 will present the database, a description of the situation of Argentinian households regarding the use of different facilities for cooking and heating and the results of the monetary energy poverty Boardman indicator applied to Argentinian households. Section 4 will discuss the methodology, Section 5 will explain the results obtained and finally Section 6 will conclude the paper.

## 2. Related literature

In this section, we present the literature related to the two issues analysed in this paper. Then, we review the works that have measured energy poverty and, subsequently, the works that have analysed the determinants of the use of different energy sources in households.

### 2.1. Review of works measuring energy poverty

The literature measuring energy poverty has mainly focused on two different approaches: a unidimensional expenditure approach and a

[10] Argentina is in an intermediate situation between emerging countries and developed countries considering the percentage of households using different kinds of energy sources. In that sense, in Spain, for example, only 4.65% of households bought solid fuels in 2020 (data from the Spanish Households Expenditure Survey). As for bottled gas, 17.58% of Spanish households bought it, but this percentage in Argentina is double.

[11] https://www.diarioelargentino.com.ar/opinion/editorial/457, editorial of 13 September 2021, which explains that bottled gas in Argentina is considered to be the gas of the poor.

[12] Space heating is necessary throughout the whole of the territory for a minimum of 2 months to reach the minimum level of thermal comfort in households. Heating water is obviously necessary during the whole year in the entire territory.

multidimensional consensual approach. The expenditure approach, which was introduced in the UK in the 1980s by authors such as Lewis [22], defined a household as being in fuel poverty when it cannot afford the fuel necessary to maintain the heat or temperature that provides thermal comfort in the living place. Therefore, following this approach, energy poverty is understood as a problem of income insufficiency to meet the energy needs of the household, and the indicators provide objective measures of energy poverty. The consensual approach was developed by Healy and Clinch [23] and was first applied to Ireland with data from the European Household Panel Data. This approach proposes an index that considers various quantitative and qualitative indicators and provides a subjective measure of energy poverty. The quantitative indicators measure homes' infrastructure related to thermal comfort, while the qualitative indicators estimate people's relative feelings of satisfaction or deprivation with respect to their energy situation. The literature using one or other approach is abundant. In this paper, we will focus on works using the expenditure approach, as this is the approach that we follow to measure energy poverty.

The indicators used to measure energy poverty through the expenditure approach are numerous. The most well-known are the indicators developed for application in the UK; this is surely because the UK pioneered the recognition and institutionalization of energy poverty. Among these indicators, the most relevant are the following:

1- The indicator developed by Boardman [3], which has been widely used in the literature and is the best known among the indicators that measure the affordability of energy. It was the official indicator of energy poverty in the United Kingdom between 2001 and 2013. Initially, this indicator defined a household as being in fuel poverty if it spent more than 10% of its income on maintaining a comfortable level of warmth at home. Later, Boardman [24] extended the definition to the ability to maintain a minimum level of all house-related energy services and not only space heating (electricity, space heating and water heating).
2- The indicator proposed by Moore [4], which is based on the Minimum Income Standard (MIS). A household is defined as energy poor if its disposable income after expenditure on all energy services falls below the minimum income standard.
3- The indicator proposed by Hills [25] for the UK in a report commissioned by the Department of Energy and Climate Change, which is called Low Income/High Cost (LIHC) and defines a household as energy poor if its expenditure on all energy services is above the median expenditure of all households and if it falls below the official income poverty line after expenditure on all energy services. This is the current indicator used to measure energy poverty in the UK.

All these indicators present limitations or disadvantages.[13] It cannot be said, therefore, that one index is better than another, and their adequacy depends on the aspects to be prioritized in a specific analysis or on the data available. In this sense, the academic literature contains a large number of case studies conducted in different countries that have measured energy poverty using one of these indicators. As we know, the seminal works appeared in the UK; therefore, their definitions were appropriate for the reality of that country and for the surveys available there.[14] For other countries, the indicators have been adapted using the surveys available for each case; see, for example, Heindl [26] for the case of Germany, Lawson et al. [27] for the case of New Zealand, Imbert et al. [10] for the case of France and Zhang et al. [11] for the case of China. For the specific case of Argentina, two studies of energy poverty measurement have used the Boardman indicator: one of them focused on the Metropolitan Region of Buenos Aires [28] and the other one considered the entire country [29].

Besides, the academic literature about energy poverty has in most cases measured it to analyse its determinants: in other words, the factors of vulnerability to energy poverty (see, for example, Romero et al. [30]). The literature is quite abundant, especially for developed countries, due to surveys' availability. However, there is a relative scarcity of works investigating what energy poverty explains. Most of these works have focused on establishing how energy poverty explains health status or well-being, for example Thomson et al. [31], Rodriguez-Alvarez et al. [32] and Llorca et al. [33]. Our paper is a contribution to this scarce literature as its aim is to determine how objective energy poverty (measured with an expenditure approach) explains the use of different energy sources in households. Therefore, our paper tackles an analysis that is quite novel in the literature. In the next subsection, we present a review of works that have analysed the determinants of households' choice of different energy sources, even though, as far as we know, none of these works has introduced energy poverty as an explanatory variable.

### *2.2. Review of works analysing the determinants of households' choice of different energy sources*

The literature analysing households' choice of different energy sources has mainly focused on developing countries. In these countries, solid fuels (charcoal, firewood and kerosene) are quite frequently used for cooking and heating. These kinds of fuels are very polluting and have important negative effects on health; therefore, they can be considered as a characteristic of underdevelopment. For this reason, extensive literature has analysed the variables that explain the choice of solid fuels for cooking or heating in many developing countries. As we have already explained in the introduction, following the ladder theory, it is considered that an energy transition from non-modern to modern fuels takes place when the level of well-being of these economies, and in particular of its households, increases. Muller and Yan [21] presented a review of this kind of papers, highlighting that some studies have been based on simple descriptive statistics while others have used econometric methods to quantify the patterns and factors of households' fuel use. Among the studies applying econometric measures to determine the characteristics of households that use different kinds of fuels, we can mention the works by Hou et al. [34], Wang et al. [35] and Chen [36] for the case of China, all of which applied multinomial logit regression models and the last of which also used an alternative-specific conditional logit model. Furthermore, the work by Acharya and Marhold [37] for the case of Nepal adopted a multiple discrete continuous extreme value model, and the study by Çelik and Oktay [15] for the case of Turkey used both ordered and unordered discrete choice models.

The literature on developed countries is scarcer as the energy transition, understood as the substitution – at the societal level – of solid

[13] The limitations and disadvantages of the different indicators are mentioned, for example, in [12] and [30].

[14] The works conducted in the UK used modelled energy bills (energy requirements to attain convenient thermal comfort) rather than real expenditure. This is possible because an instructional survey, the English Housing Survey, was developed to monitor the occurrence of fuel poverty in that country. This is not the case for other countries, like Spain, where the only surveys available to measure energy poverty with the expenditure approach are expenditure surveys, and thus real expenditure is used.

fuels for other kinds of fuels took place a long time ago.[15] However, there are also works focusing on developed countries that have explained the determinants of households' choice of different kinds of fuels; for example, Sardianou [38] estimated OLS, tobit and probit models for the case of Greece; Couture et al. [39] used a multinomial logit choice model for the case of France; Laureti and Secondi [40] estimated a multinomial logit model for the case of Italy; and Michelsen and Madlener [41] estimated a multinomial logit model for the case of Germany.

To sum up, most of these works estimated discrete choice models. Following Çelik and Oktay [15], we can state that, among the characteristics that explain households' fuel choice, most works have found some sociodemographic and socioeconomic variables, such as the educational level, age and gender of the main breadwinner, household size, annual income, total annual expenditure and so on, some dwelling characteristics, like the type of dwelling, the dwelling's size, the housing tenure, the year of construction and so on, and some spatial characteristics, like the urban or rural location of the households, to be significant.

## 3. Data and descriptive statistics

### 3.1. Database on household expenditures in Argentina

The data source is the National Household Expenditure Survey. This database is compiled by the National Institute of Statistics and Censuses of Argentina (INDEC), which provides information on the nature and destination of consumption expenditure as well as on various characteristics relating to the living conditions of households. The survey is carried out throughout the country approximately every 5 years.[16] The last survey was conducted between November 2017 and November 2018.

The total number of households in the sample is 21,053, and these are located in towns with 5000 or more inhabitants. This sample represents 86.7% of the total population. Therefore, the survey does not cover 13.3% of the total population, specifically the population located in rural areas, where presumably many of the households facing the most problems consuming energy services in good conditions are located. This limits our research as it in fact cannot cover all Argentinian households, so the results of our estimations and descriptive statistics have to be understood as outcomes concerning only the population represented by the sample available. We must point out that, when we talk about Argentinian households, we refer to urban households, as these are the households covered by the database used in this work. In that sense, the descriptive statistics and results on energy affordability and accessibility problems presented in this paper underestimate the real Argentinian situation.

### 3.2. Description of the energy accessibility problem in Argentinian households

In this section, to provide a description of the energy accessibility problem in the country, we present descriptive statistics on the use of different energy sources in Argentinian urban households in general and the household characteristics analysed in our estimations. In that sense, we understand, as explained in the introduction, that households have an energy accessibility problem when they cook and heat with what we call non-modern facilities, that is, animal waste, agricultural waste, kerosene, firewood, charcoal and bottled gas.

Table 1 presents data on the distribution of the use of different energy sources in Argentinian urban households. As can be observed, 64% of Argentinian households use modern facilities (electricity, gas supplied through a network or gas supplied through a zeppelin gas container) for cooking and 76.60% use them for heating. However, 35.90% of households still use non-modern facilities for cooking and 23.40% do not have modern facilities for heating the dwelling and water. Therefore, we can assert that 35.90% of Argentinian urban households have energy accessibility problems for cooking and 23.40% have energy accessibility problems for heating.

Tables 2 and 3 present descriptive statistics on the types of energy sources that households use, according to the different characteristics of the households analysed in our estimations, respectively for cooking and heating.

Table 2 shows that:

1. Modern energy sources for cooking are used in a higher percentage of urban households that:

- Are not energy poor (67.3%);
- Have five or more members[17] (68.42%);
- Live in a standard or modern dwelling[18] (64.68%);
- Have a breadwinner aged 50 years or older (73.47%);

**Table 1**
Percentage of the use of energy sources for cooking and heating in Argentine urban households.

| Variable | | Percentage |
|---|---|---|
| Access to energy for cooking | Households that mainly use gas from a network for cooking | 62,5% |
| | Households that mainly use zeppelin gas container for cooking | 0,1% |
| | Households that mainly use gas cylinder for cooking | 35,7% |
| | Households that mainly use electricity for cooking | 1,4% |
| | Households that mainly use kerosene/ firewood/charcoal for cooking | 0,1% |
| | Households that mainly use other fuels for cooking | 0,1% |
| Access to energy for heating | Households that mainly use gas from a network for heating | 51,1% |
| | Households that mainly use zeppelin gas container for heating | 0,1% |
| | Households that mainly use gas cylinder for heating | 7,4% |
| | Households that mainly use electricity for heating | 25,4% |
| | Households that mainly use kerosene/ firewood/charcoal for heating | 5,4% |
| | Households that mainly use other fuels for heating | 10,6% |

Source: own elaboration from data from the National Households Expenditure Nov. 2017–Nov. 2018.

[15] However, in such countries, the energy transition concerns the substitution of carbon fuels with renewable energy sources.

[16] It is a cross-sectional survey. Prior to the last one, three surveys were carried out in the following periods: February 1996 to March 1997, October 2004 to December 2005 and March 2012 to March 2013. The lack of more regular conducting and close continuity of the survey is another limitation for research based on this kind of data.

[17] To indicate the household size, we build a dichotomous variable grouping households with one to four members on the one hand and with five or more members on the other, in accordance with the results of contingency tables and the behavior of the standardized residuals.

[18] According to the survey, 69.48% of households live in a standard or modern dwelling and 30.52% live in a substandard dwelling. A standard dwelling is a house or an apartment, and a substandard dwelling comprises different kinds of housing that are not modern and are precarious. Definitions of all these kinds of substandard houses can be found at https://www.santafe.gob.ar/index.php/web/content/download/248592/1307297/version/2/file/Manual+del+Encuestador_ENGHo+2017-2018_Operativo+Final.pdf.

**Table 2**
Percentage of the use of different energy sources for cooking, according to households characteristics.

| | Index energy poor household | | Gender of the breadwinner | | Age of the breadwinner | | Household size | | Education level of the breadwinner | | Type of dwelling | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Household energy poor | Household not energy poor | Women | Men | 50 or more years | 49 or less years | 1 to 4 members | 5 or more members | Non-high education | High education | Sub-standard housing | Standard housing |
| Households that mainly use gas from the network for cooking | 55.08 | 65.34 | 61.62 | 63.14 | 72.41 | 58.9 | 45.73 | 66.63 | 54.6 | 80.99 | 17.38 | 63.09 |
| Households that mainly use zeppelin gas container for cooking | 0.14 | 0.16 | 0.08 | 0.2 | 0.13 | 0.19 | 0.09 | 0.16 | 0.16 | 0.12 | 0 | 0.15 |
| Households that mainly use electricity for cooking | 0.44 | 1.8 | 1.48 | 1.38 | 0.93 | 1.79 | 0.57 | 1.63 | 0.64 | 3.25 | 0.21 | 1.44 |
| *Subtotal - sources of modern energy for cooking* | 55.66 | 67.3 | 63.18 | 64.72 | 73.47 | 60.88 | 46.39 | 68.42 | 55.4 | 84.36 | 17.59 | 64.68 |
| Households that mainly use gas cylinder for cooking | 44.09 | 32.45 | 36.58 | 35.02 | 26.34 | 38.94 | 53.13 | 31.39 | 44.28 | 15.53 | 81.14 | 35.09 |
| Households that mainly use kerosene/ firewood/charcoal for cooking | 0.2 | 0.17 | 0.15 | 0.2 | 0.1 | 0.15 | 0.37 | 0.13 | 0.25 | 0.03 | 0.65 | 0.17 |
| Households that mainly use other fuels for cooking | 0.05 | 0.07 | 0.09 | 0.05 | 0.09 | 0.02 | 0.1 | 0.06 | 0.07 | 0.07 | 0.62 | 0.06 |
| *Subtotal - sources of non-modern energy for cooking* | 44.34 | 32.69 | 36.82 | 35.27 | 26.53 | 39.11 | 53.6 | 31.58 | 44.6 | 15.63 | 82.41 | 35.32 |
| Observations | 3,437,785 | 8,951,308 | 5,282,456 | 7,106,637 | 4,426,215 | 5,774,314 | 2,451,215 | 9,937,878 | 8,684,543 | 3,704,550 | 160,355 | 12,228,738 |

Source: own elaboration from data from the National Households Expenditure November 2017–November 2018.

**Table 3**
Percentage of the use of different energy sources for heating, according to households characteristics.

| | Index of energy poor household | | Gender of the breadwinner | | Age of the breadwinner | | Household size | | Education level of the breadwinner | | Type of dwelling | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Household energy poor | Household not energy poor | Women | Men | 50 or more years | 49 or less years | 1 to 4 members | 5 or more members | Non-high education | High education | Sub-standard housing | Standard housing |
| Households that mainly use gas from the network for heating | 46.86 | 52.76 | 50.4 | 51.66 | 60.35 | 47.35 | 36.04 | 54.84 | 45.69 | 63.87 | 7.64 | 51.69 |
| Households that mainly use zeppelin gas container for heating | 0.06 | 0.12 | 0.09 | 0.12 | 0.1 | 0.11 | 0.08 | 0.11 | 0.1 | 0.11 | 0 | 0.11 |
| Households that mainly use electricity for heating | 24.8 | 25.58 | 25.85 | 25.01 | 19.31 | 27.81 | 30.63 | 24.07 | 26.16 | 23.5 | 41.69 | 25.15 |
| *Subtotal - sources of modern energy for heating* | 71.72 | 78.46 | 76.34 | 76.79 | 79.76 | 75.27 | 66.75 | 79.02 | 71.95 | 87.48 | 49.33 | 76.95 |
| Households that mainly use gas cylinder for heating | 9.05 | 6.82 | 7.5 | 7.39 | 6.2 | 8.39 | 9.1 | 7.02 | 9.25 | 3.2 | 10.14 | 7.4 |
| Households that mainly use kerosene/ firewood/charcoal for heating | 6.79 | 4.81 | 5.14 | 5.53 | 5.1 | 5.18 | 7.72 | 4.78 | 6.86 | 1.84 | 10.45 | 5.3 |
| Households that mainly use other fuels for heating | 12.43 | 9.9 | 11.02 | 10.3 | 8.95 | 11.17 | 16.42 | 9.17 | 11.94 | 7.48 | 30.08 | 10.35 |
| *Subtotal - sources of non-modern energy for heating* | 28.27 | 21.53 | 23.66 | 23.22 | 20.25 | 24.74 | 33.24 | 20.97 | 28.05 | 12.52 | 50.67 | 23.05 |
| Observations | 3,437,785 | 8,951,308 | 5,282,456 | 7,106,637 | 4,426,215 | 5,774,314 | 2,451,215 | 9,937,878 | 8,684,543 | 3,704,550 | 160,355 | 12,228,738 |

- Have a breadwinner with a high educational level (84.36%).

2. Non-modern energy sources for cooking are used in a higher percentage of urban households that:

- Are energy poor (44.34%);
- Have one to four members (53.6%);
- Live in a sub-standard type of dwelling (82.41%);
- Have a breadwinner aged 49 years or younger (39.11%);
- Have a breadwinner without a high educational level (44.6%).

As shown in Table 3:

1. Modern energy sources for heating are used in a higher percentage of urban households that:

- Are non-energy-poor households (78.46%);
- Have five or more members (79.02%);
- Live in a standard or modern type of dwelling (76.95%);
- Have a breadwinner aged 50 years or older (79.76%);
- Have a breadwinner with a high educational level (87.48%).

2. Non-modern energy sources for heating are used in a higher percentage of urban households that:

- Are energy poor (28.27%);
- Have one to four members (33.24%);
- Live in a sub-standard type of dwelling (50.67%);
- Have a breadwinner aged 49 years or younger (24.74%);
- Have a breadwinner without a high educational level (28.05%).

Regarding the gender of the breadwinner, there are almost no differences between men and women with respect to the use of modern or non-modern energy for cooking (Table 2) and for heating (Table 3).

### 3.3. Measurement of monetary energy poverty in Argentina as an indicator of the energy affordability problem

Definition:

$$EE_h > 0.1 \times TE_h \quad (1)$$

where

- $EE_h$ is the household energy expenditure;
- $TE_h$ is the total household equivalent expenditure.

The proportion of poor households is defined based on the following indicator (or index):

$$H_{pe} = \frac{HPE}{HT} \quad (2)$$

where:

- $H_{pe}$ is the rate of energy-poor households according to the definitions;
- $HPE$ is the number of energy-poor households;
- $HT$ is the total number of households in the survey.

The energy poverty indicator provides the percentage of households that exceed the energy poverty threshold in relation to the total number of households in the population.

Now, taking into account the available information and the definitions of energy poverty, we define the variables taken from the ENGHo from November 2017 to November 2018 for each case.[19]

- *Expenditure on energy*: the item "expenditure on electricity, gas and other fuels" followed Tirado Herrero et al. [42] and was annualized.
- *Equivalent total household expenditure*: the "total household consumption expenditure" was taken from the survey, following the Boardman [3] methodology, and annualized.

Porterba [43] stated that "a household total expenditure may be a more reliable indicator of economic wellbeing than the same household annual income" (p. 6). This is because the income declared in household budget surveys is often lower than the actual income, especially in surveys from countries like Argentina, where there is a high percentage of hidden income (see, for example, La Vanguardia Digital, 2017).[20] Since the work by Poterba was published, it has been usual in the literature (mainly in papers focused on countries where the hidden economy is relatively important), as in this paper, to use household expenditure as a proxy for income [44,45,46]. An additional advantage of using expenditure is that it is a good proxy for permanent income. Besides, in the present study, the modified OECD equivalence scale is used.[21] It is usually recommended that the weighting parameter for economies of scale should be close to 0.5 in developed countries and higher in developing countries since the proportion of spending devoted to food is larger [47].

As a result of calculating the energy poverty indicator, the percentage of energy-poor households in Argentina is 27.7%. This result differs from those of other works applied to Argentina as the database used, the period analysed and the case itself are not the same.[22]

To complete the description of the energy affordability problem in Argentinian households, Table 4 presents data on the distribution of energy expenditure by income decile. It can be observed that the households that spend more than 10% of their income on energy are

[19] The document by [4] presents each of the variables and the implications of using each of them in detail, based on a review of the literature for the case of the UK.

[20] http://www.lavanguardiadigital.com.ar/index.php/2017/02/22/sombras-tenebrosas-se-calcula-que-un-tercio-del-pbi-argentino-y-la-mitad-de-los-que-trabajan-estan-en-las-sombras/. This article explains that almost 30% of Argentinian income and 50% of work are hidden.

[21] It is worth clarifying why the OECD equivalence scale is introduced. In the present study, the unit of analysis is the household and not the individual. The needs of a household grow with each additional member but, due to economies of scale in consumption, not proportionally. With the use of equivalence scales, a value is assigned in proportion to the needs of each type of household since these are not three times greater for a three-member household than for a single person [53].Many equivalence scales exist, and the choice depends on the context in which they are applied. In 1982, the OECD established a scale for possible use in countries that have not established their own equivalence scale. A value of 1 is assigned to the first household member, 0.7 to each additional adult and 0.5 to each child. [55] proposed the modified OECD scale, which was adopted by the Statistical Office of the European Union. This scale assigns a value of 1 to the head of household, 0.5 to each additional adult and 0.3 to each child [53].

[22] Thus, the Boardman indicator found in the work by the Observatorio de Precios, Pobreza e Ingresos in 2016 was 34%. However, this work focused on Gran Buenos Aires for the period from January to October 2016. It did not use our survey but built a normative energy basket and quantified it based on the new tariff tables for the year 2016. In addition, Duran and Condori (2019) found an indicator of 18% for the case of Argentina in 2017–2018; in this case, they used data from the Permanent Household Survey (EPH), obtained quarterly by the INDEC. As this survey did not consider household expenditures, to estimate the cost of access to electricity, they used annual consumption data billed by the providers at the department level.

**Table 4**
Distribution of energy expenditure by income decile in dollars.

| Income decile | Total household spending by decile | Household energy spending (average) related to the decile | Percentage |
|---|---|---|---|
| 1 | $ 185 | $ 30 | 16.13% |
| 2 | $ 318 | $ 38 | 12,0% |
| 3 | $ 423 | $ 46 | 10.91% |
| 4 | $ 530 | $ 47 | 8.91% |
| 5 | $ 646 | $ 53 | 8.26% |
| 6 | $ 787 | $ 58 | 7.32% |
| 7 | $ 958 | $ 61 | 6.32% |
| 8 | $ 1196 | $ 70 | 5.84% |
| 9 | $ 1575 | $ 69 | 4.35% |
| 10 | $ 2768 | $ 88 | 3.17% |

Source: own elaboration from data form the National Households Expenditure November 2017–November 2018.

**Table 5**
Definition of variables.

| Variable | Definition |
|---|---|
| Dependent variables | |
| Facilities used for cooking | 1 if the household cooks with non-modern facilities; 0 if it cooks with modern facilities |
| Facilities used for heating | 1 if the household heats with non-modern facilities, 0 if it cooks with modern facilities |
| Independent variables | |
| Proxy energy poor household | 1 if the household is energy poor; 0 if the household is not energy poor |
| Gender of the breadwinner | 1 if she is a woman; 0 if he is a man |
| Age of the breadwinner | 1 if he/she has 50 or more years of age; 0 if he/she has 49 or less years of age |
| Education level of the breadwinner | 1 if he/she has non-high education; 0 if he/she has high education |
| Household size | 1 if it has 1 to 4 members; 0 if it has 5 or more members[a] |
| Type of dwelling | 1 if it is a sub-standard housing; 0 if it is an standard housing |

[a] To indicate the household size we have built a dichotomous variable grouping households from 1 to 4 members on the one hand, and with 5 or more members on the other, according to the results of contingency tables and the behavior of the standardized residuals.

those belonging to the three poorest income deciles, which is a similar result to Boardman's observation when she determined the 10% income threshold to define the energy-poor household indicator. Therefore, even though one limitation of Boardman's indicator is that it does not provide mechanisms to exclude wealthy households, in the specific case of Argentina, energy-poor households as determined by Boardman's indicator constitute a group of households among those with a low income. Therefore, this indicator is suitable for analysing energy poverty in Argentina.

## 4. Model

### *4.1. Logit models*

Once the energy poverty indicator has been calculated, the second step of our work is to determine how monetary energy poverty and other socioeconomic factors explain the use of non-modern facilities for cooking and heating. Then, we will investigate how the probability that a household uses non-modern facilities for cooking and heating, and therefore has an energy access problem, increases when this household is energy poor. Accordingly, we build two dichotomous variables, one indicating the facilities used for cooking and the other one indicating the facilities used for heating. As both dependent variables are dichotomous, for the estimations of each of the cases, we apply a univariant logit model. As shown in Section 2, discrete choice models are usually chosen for this type of analysis.

Following the logit model methodology, we assume that there is a latent variable ($Y_i$*), so

$$Y_i^* = \alpha X_i + \varepsilon_i$$

where $X$ is the vector of the explanatory variables and $\varepsilon$ is the error term. This variable $Y^*_i$ is the estimated outcome, a binary variable equal to 1 if household $i$ uses non-modern facilities for cooking (first regression) and heating (second regression) and equal to 0 if the household uses modern facilities for cooking and heating. Thus, the probability that the household is vulnerable is:

$$P(Y_i = 1) = P(Y_i^* > 0) = P(\varepsilon_i > -\alpha X_i)$$

We assume that $\varepsilon_i$ follows a logistic distribution.

The variables used in the econometric analysis, all of them discrete, are described in Table 5.

As the energy poverty indicator depends on fuel expenditure, there can be an endogenous problem between our dependent variables, that is, non-modern facilities for cooking and heating, and the energy poverty indicator. Thus, to deal with endogenous exposure, we use instrumental variables. Following Arranz et al. [48], Greene and Hensher [49] and Jones [50], we employ a bivariate binary logit approach, which involves, in the first step, estimating a logit model for the determinants of the energy poverty indicator and, in the second step, including the former estimation as an explanatory variable in the logit models that explain the determinants of the use of non-modern cooking and heating facilities. We are modelling sequential decisions or events. These can be consistently and efficiently estimated via the method of full information maximum likelihood.

Our first equation, which determines the instrumental variable, is:

$$P_i = \beta_1 X_i + \beta_2 Z_i + \nu_i \quad (1)$$

where $X_i$ represents an overlapping vector of exogenous control variables that also affects $Y_i^1$ in Eq. (2) and $Y_i^2$ in Eq. (3), and $Z_i$ is a non-overlapping vector of variables that are correlated with $P_i$ but not with $Y_i^1$ and $Y_i^2$; therefore, $Z_i$ is the instrument. Besides, $\nu_i$ is the error term, a vector of unobservables associated with $P_i$ but also potentially correlated with $\mu_1$ in Eq. (2) and $\upsilon_i$ in Eq. (3). The definition of the variables used in this estimation and the outcomes obtained are presented in Table A1 in Appendix A.

The equations of which the outcomes are the use of non-modern facilities for cooking and heating are the following:

$$Y_i^1 = \delta_1 P_i + \delta_2 X_i + \mu_i \quad (2)$$

$$Y_i^2 = \sigma_1 P_i + \sigma_2 X_i + \upsilon_i \quad (3)$$

where $P_i$ is a proxy for the energy poverty indicator (as shown in Table A2 in Appendix A, all the coefficients of the estimation are strongly correlated with the outcome and are significant at the 1% level) and $X_i$ represents a vector of the exogenous control variables explaining the use of non-modern facilities for cooking and heating in our models.

To allow for the possibility that the outcomes of unobserved determinants of energy poverty and the outcomes of the use of both non-modern cooking and non-modern heating facilities are correlated, the disturbance terms $\nu_i$ and $\mu_1$; $\upsilon_i$ are assumed to have bivariate logistical distribution.

Because the events are dichotomous, there are four possible states of the world for the situation of cooking:

($P_i$=1, $Y_i^1 = 1$), ($P_i$=1, $Y_i^1 = 0$), ($P_i$=0, $Y_i^1 = 1$), and ($P_i$=0, $Y_i^1 = 0$) and four possible states of the world for the situation of heating:

($P_i$=1, $Y_i^2 = 1$), ($P_i$=1, $Y_i^2 = 0$), ($P_i$=0, $Y_i^2 = 1$), and ($P_i$=0, $Y_i^2 = 0$)

In this paper, we analyse the state of the world in which ($P_i$=1, $Y_i^1 =$ 1) and ($P_i$=1, $Y_i^2 = 1$).

### 4.2. ROC curves

To refine and improve the results of the two logit models presented below, we apply an ROC curve to each regression, using the probabilities obtained from the two estimations. These results are presented in a list of various test values and the corresponding sensitivity and specificity of the test at those values. Then, the graphical ROC curve is produced by plotting sensitivity (the true positive rate) on the y-axis against 1 – specificity (the false positive rate) on the x-axis for the various values tabulated.

An ROC curve is a graphical plot that illustrates the performance of a binary classifier system as its discrimination threshold is varied. By considering all possible values of the cut-off c, the ROC curve can be constructed as a plot of sensitivity (TPR) versus 1 − specificity (FPR). For any cut-off c, we can, following Calì and Longobardi [51], define:

$$TPR(c) = P(T \geq c|\mathrm{E}+)$$

$$FPR(c) = P(T \geq c|\mathrm{E}-)$$

Thus, the ROC curve is

$$ROC\ (\bullet) = \{\mathrm{FPR(c)}\ ,\mathrm{TPR(c)}\ ,\mathrm{c}\ \epsilon\ (-\infty, +\infty)\} \quad (4)$$

The ROC curve also can be understood as:

$$ROC\ (\bullet) = \{(\mathrm{t}, \mathrm{ROC(t)})\ ,\mathrm{t}\ \epsilon\ (0{,}1)\} \quad (5)$$

where the ROC function maps $t$ to $TPR(c)$, and $c$ is the cut-off corresponding to $FPR(c) = t$.

The area under the ROC curve (AUC) is a global measure of the ability of a model to discriminate whether a specific condition is present. An AUC of 0.5 represents a test with no discriminating ability (i.e., no better than chance), while an AUC of 1.0 represents a test with perfect discrimination.

When selecting an optimal threshold (or cut-off point), we need to consider the aims of the diagnostic test, considering the significance and costs of a false-positive or false-negative interpretation. Thanks to the ROC curves, we can determine the best cut-off points for each model.

## 5. Results

### 5.1. Results from the logit models

This section provides the results obtained through the estimation of the logit econometric model for cooking facilities, presented in Table 6, and for heating facilities, presented in Table 7. The marginal effects are also reported in the tables. While the coefficients in the binary models show the effect of a variable on the latent propensity for a positive result (the use of non-modern facilities for cooking and the use of non-modern facilities for heating), the values of the marginal effects – probability ratios – quantify the real impact of each of the explanatory variables on the probability of being in a situation of non-modern access to energy facilities.

**Table 6**
Results for the outcome non-modern facilities used for cooking.

| Variables | Coefficients | Probability ratios |
|---|---|---|
| Proxy energy poor household | 3,132*** | 0.762*** |
| | (0.170) | (0.041) |
| Gender of the breadwinner | −0.119*** | −0.029*** |
| | (0.041) | (0.010) |
| Age of main breadwinner | −0.844*** | −0.203*** |
| | (0.042) | (0.010) |
| Household size | 0.550*** | 0.136*** |
| | (0.052) | (0.013) |
| Education level of the breadwinner | 0.320*** | 0.076*** |
| | (0.062) | (0.015) |
| Type of dwelling | 1,837*** | 0.401*** |
| | (0.315) | (0.047) |
| Constant | −1,771*** | |
| | (0.070) | |

i) Standard errors are presented in parentheses.
ii) ***, **, * denote level of significance at 1%, 5% and 10% respectively. Number of obs. =21.053.

**Table 7**
Results for the outcome non-modern facilities used for heating.

| Variables | Coefficients | Probability ratios |
|---|---|---|
| Proxy energy poor household | 2,571*** | 0.271*** |
| | (0.181) | (0.054) |
| Gender of the breadwinner | −0.132*** | −0.026*** |
| | (0.043) | (0.008) |
| Age of main breadwinner | −0.456*** | −0.089*** |
| | (0.045) | (0.009) |
| Household size | 0.522*** | 0.109*** |
| | (0.053) | (0.012) |
| Education level of the breadwinner | 0.252*** | 0.048*** |
| | (0.070) | (0.013) |
| Type of dwelling | 1.165*** | 0.271*** |
| | (0.218) | (0.054) |
| Constant | −2,302*** | |
| | (0.078) | |

i) Standard errors are presented in parentheses.
ii) ***, **, * denote level of significance at 1%, 5% and 10% respectively. Number of obs. =21.053.

As can be seen in Tables 6 and 7, all the results are significant at the 1% level and have the expected sign. In fact, the results show that being an energy-poor household significantly increases the likelihood of having an accessibility problem for cooking and heating. In other words, an energy-poor home, that is, a household experiencing an energy affordability problem, is more likely also to have an energy accessibility problem than a home that is not characterized by non-monetary energy poverty.

Concretely, the results show that the probability of using non-modern facilities for cooking increases by 76.24% if the household is characterized by monetary energy poverty, and the probability that a household uses non-modern facilities for heating increases by 50.36% if the household is characterized by monetary energy poverty.

Regarding the control variables:

The probability that a household in which the breadwinner is a woman uses non-modern facilities for cooking decreases by 2.90%, and it decreases by 2.58% in the case of heating.

If the household breadwinner is older than 50 years of age, the probability that this household uses non-modern facilities for cooking decreases by 20.30%, and it decreases by 8.94% in the case of heating.

If the household lives in a substandard dwelling, the probability that it uses non-modern facilities for cooking increases by 40.13%, and it increases by 27.12% in the case of heating.

If the household has between one and four members, the probability that it uses non-modern facilities for cooking increases by 13.57%, and it increases by 10.93% in the case of heating.

If the breadwinner of the household does not have a high education level, the probability of this household using non-modern facilities for cooking increases by 7.67%, and it increases by 4.79% in the case of heating.

### 5.2. Results from the ROC curve analysis

This section shows the results of the ROC curves generated by the probabilities of the logit models. Concretely, Fig. 1 presents the ROC curve for the facilities used for cooking, Table 8 presents the AUC and Table 9 presents the related cut-off points.

Fig. 2 shows the representation of the ROC curve for the facilities used for heating, Table 10 presents the AUC and Table 11 indicates the related cut-off points.

As it can be seen in Tables 8 and 10, the two models have very similar

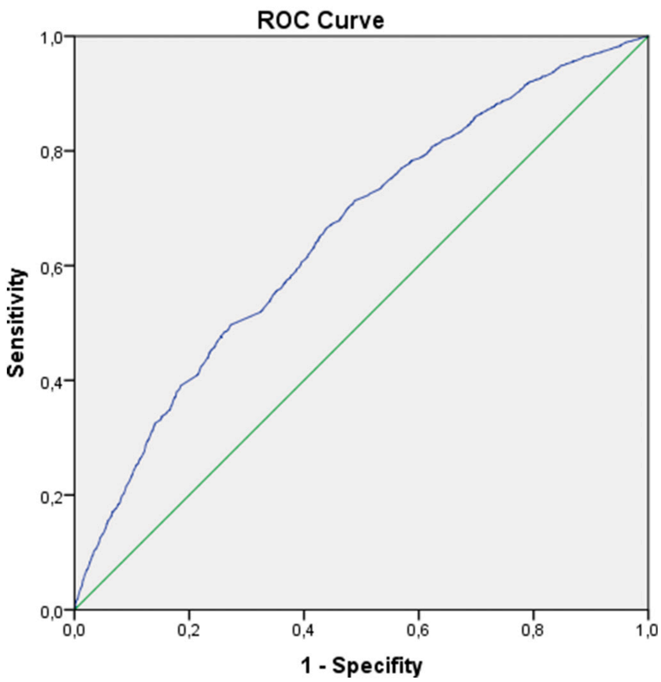


Fig. 1. Area under the curve (AUC) for cooking.

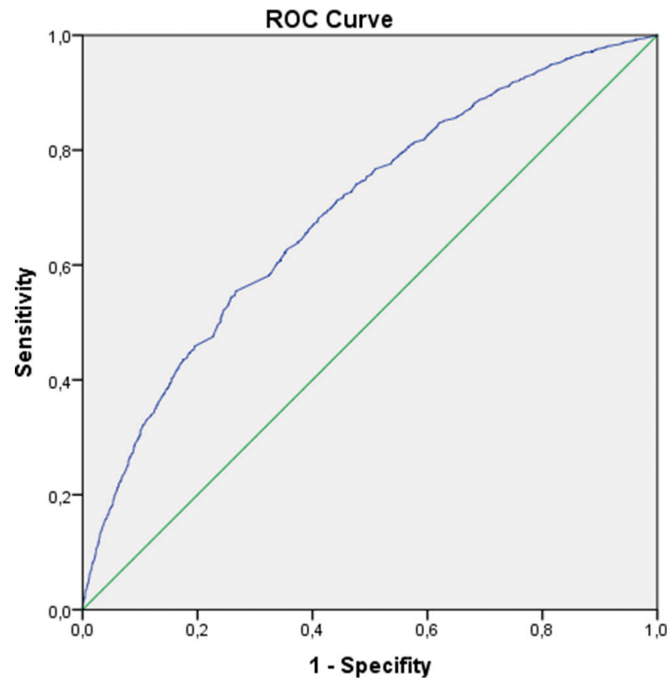


Fig. 2. ROC curve for heating.

**Table 8**
Area under the curve (AUC) for cooking.

| Area | Standard error[a] | Asymptotic significance[b] | 95% Asymptotic confidence interval | |
|---|---|---|---|---|
| | | | Lower limit | Upper limit |
| 0,693 | 0,004 | 0,000 | 0,690 | 0,756 |

[a] Under non parametric case.
[b] Null hypothesis: area = 0,5.

**Table 9**
Cut-off points for cooking.

| Positive if is greater than | Sensitivity | 1 - Specificity |
|---|---|---|
| 0.4631386 | 0.583 | 0.325 |
| 0.4634867 | 0.582 | 0.324 |
| 0.4641873 | 0.582 | 0.324 |
| 0.4650859 | 0.582 | 0.324 |
| 0.4659263 | 0.582 | 0.324 |
| 0.4667172 | 0.581 | 0.323 |
| 0.4673972 | 0.554 | 0.267 |
| 0.4679348 | 0.554 | 0.266 |
| 0.4686742 | 0.547 | 0.265 |
| 0.4691472 | 0.547 | 0.265 |
| 0.4995874 | 0.448 | 0.188 |
| 0.5002727 | 0.448 | 0.188 |

**Table 10**
Area under the curve (AUC) for heating.

| Area | Standard error[a] | Asymptotic significance[b] | 95% Asymptotic confidence interval | |
|---|---|---|---|---|
| | | | Lower limit | Upper limit |
| 0,653 | 0,004 | 0,000 | 0,646 | 0,665 |

[a] Under non parametric case.
[b] Null hypothesis: area = 0,5.

**Table 11**
Cut-off points for heating.

| Positive if is greater than | Sensitivity | 1 - Specificity |
|---|---|---|
| 0.2665771 | 0.671 | 0.447 |
| 0.2667876 | 0.671 | 0.446 |
| 0.2670213 | 0.671 | 0.446 |
| 0.2673454 | 0.671 | 0.446 |
| 0.2676134 | 0.665 | 0.439 |
| 0.2676373 | 0.664 | 0.439 |
| 0.2676856 | 0.664 | 0.438 |
| 0.2678767 | 0.663 | 0.438 |
| 0.2680499 | 0.663 | 0.438 |
| 0.2681134 | 0.661 | 0.436 |
| 0.2682117 | 0.658 | 0.435 |
| 0.2684604 | 0.658 | 0.434 |
| 0.2688163 | 0.657 | 0.434 |
| 0.2690479 | 0.657 | 0.434 |
| 0.4994514 | 0.081 | 0.027 |
| 0.5006410 | 0.081 | 0.027 |
| 0.5019152 | 0.072 | 0.023 |

values of the AUC: 0.693 for the cooking model and 0.653 for the heating model. The best cut-off points determined by the probabilities of the logit models are those that give more specificity.

In the first of our models, which determines the probability of using non-modern facilities for cooking, according to the ROC curve and the Yates index – which is used to determine the best cut-off point – the value that discriminates better is 0.467, which has sensitivity of 55.4% (identifying poor households) and specificity of 73.4% (identifying non-poor households). The value of 0.5 (the default value of the logit model) shows sensitivity of 44% and specificity of 82%, which are clearly worse.

In the second of our models, which determines the probability of using non-modern energy for heating, according to the ROC curve and the Yates index, the best cut-off point is the value of 0.267, which has sensitivity of 66.4% (identifying poor households) and specificity of 56.2% (identifying non-poor households). The value of 0.5 (the default value of the logit model) shows sensitivity of 8.1% and specificity of 97.3%, which are also clearly worse.

Thanks to the ROC curves, we can establish the best cut-off points (better than the ones generated by the logit models) not only to detect energy poverty but also to implement economic policies to correct this situation.

## 6. Conclusions

Energy poverty is a multidimensional problem that involves a lack of good access to energy services in homes. On the one hand, the literature on the subject has tackled energy poverty in developed countries as an affordability problem, that is, as a problem linked to having insufficient income to afford the level of consumption of energy services necessary to reach a minimum standard of comfort for the household. On the other hand, and for the case of developing countries, the literature has considered the problem as an accessibility one, that is, mainly as a problem of insufficient supply of energy services. However, this categorization of the problem of energy poverty is too simple as the situation of the so-called developing countries is diverse: while less developed countries may still have an energy supply problem, this is not the case in many developing or emerging countries, where there can be a problem of energy accessibility that is linked not to an insufficiency of energy supply but, in a broader sense of the concept, to the use of certain kinds of fuels or facilities to meet the energy needs of households that, due to their characteristics, face an energy accessibility problem. Moreover, due to its multidimensional character, energy poverty in most developing countries is a problem of both affordability and accessibility in its broader sense. Nevertheless, there is a lack of studies on energy poverty in developing and emerging countries that have analysed the problem from this double perspective. For example, Urquiza et al. [52], in the case of Chile, supported this line and concluded that the literature on energy poverty – which has mainly focused on developed or less developed countries – lacks a proper toolbox to tackle energy poverty in countries of medium development.

In this article, focusing on the case of Argentina, we have analysed energy poverty as both an affordability and an accessibility problem, using microdata from the Argentinian National Households Budgets Survey (November 2017–November 2018), thus filling the gap in the literature on countries of medium development. From an affordability perspective, we found that 27.7% of Argentinian households were energy poor in the year analysed. In this same year, from an accessibility perspective, 35.90% of Argentinian households had an energy accessibility problem for cooking and 23.40% had one for heating. To complete the analysis of this double dimension of energy poverty, we estimated two logit models to show whether and how the problem of affordability of energy services can explain the choice of energy facilities or fuels, indicating a problem of accessibility in its broader sense. We found a positive and significant relationship between monetary energy poverty and the choice of what we have called non-modern facilities for cooking and non-modern facilities for heating. Concretely, the probability that a household uses non-modern facilities for cooking increases by 76.24% if the household is characterized by monetary energy poverty, and the probability that a household uses non-modern facilities for heating increases by 50.36% if the household is characterized by monetary energy poverty. The calculation of the ROC curves permitted us to assess the sensitivity of this kind of analysis, determining a better cut-off than the default value (0.5) usually established through discrete choice models. This cut-off value can be used to make a better selection of beneficiaries in public policies against energy poverty and therefore should be used regularly in this kind of literature.

Thus, we can conclude that, in Argentina, it is much more probable that households with an energy affordability problem have an energy accessibility problem. Therefore, monetary energy poverty explains the use of facilities for cooking and heating that indicate an energy accessibility difficulty, thus highlighting the interrelation between the two aspects of energy poverty that characterizes this economic situation in countries of medium development. This work has thus shown that, even though most works on energy poverty in developing and emerging countries have focused mainly on the accessibility dimension of the problem, it is important to tackle the affordability dimension as the Argentinian case in fact demonstrates that it could be an affordability energy problem that explains the energy accessibility difficulties faced by households in such economies and therefore in countries with a medium development level.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A

**Table A1**
Definition of variables of the estimation of energy poverty households determinants.

| Variable | Definition |
|---|---|
| Dependent variables | |
| Index of energy poor household | 1 if the household is energy poor according to Boardman and 0 if the household is not energy poor according to Boardman |
| Independent variables | |
| Education level of the breadwinner | 1 if he/she has not high education and 0 if he/she has high education |
| Household size | 1 if it has 1 to 2 members and 0 if it has 3 or more members[a] |
| Household's car | 1 if it has not a car and 0 if it has one or more cars |
| Labour situation of the breadwinner | 1 if he/she is unoccupied or inactive and 0 if he/she is occupied. |
| Medical insurance of the breadwinner | 1 if he/she does not have medical insurance and 0 if he/she has medical insurance |
| Household's loan | 1 if it has got a loan to build or repair the dwelling and 0 if it did not get a loan to build or repair the dwelling |

[a] To indicate the household size we have built a dichotomous variable grouping households from 1 to 2 members on the one hand, and with 3 or more members on the other, according to the results of contingency tables and the behavior of the standardized residuals.

**Table A2**
Results of the outcome for energy poor households.

| Variables | Coefficients |
|---|---|
| Education level of the breadwinner | 0.569*** |
| | (0.048) |
| Household size | 0.303*** |
| | (0.039) |

(*continued on next page*)

**Table A2** (*continued*)

| Variables | Coefficients |
|---|---|
| Household's car | 0.479*** |
| | (0.038) |
| Labour situation of the breadwinner | 0.265*** |
| | (0.038) |
| Medical insurance of the breadwinner | 0.205*** |
| | (0.042) |
| Household's loan | −0.289*** |
| | (0.046) |
| Constant | −1622*** |
| | (0.049) |

i) Standard errors are presented in parentheses.
ii) ***, **, * denote level of significance at 1%, 5% and 10% respectively. Number of obs. =21.053.

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