



Capturing Multidimensional Energy Poverty in South America: A Comparative Study of Argentina, Brazil, Uruguay, and Paraguay

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Roughly 789 million people have no access to energy, and around 2.8 billion people lack access to clean cooking solutions according to the World Bank, and so we also find many people that cannot afford energy (reliable and clean) at the current prices. In the literature, accessibility, availability, and affordability are underlined as the key drivers of energy poverty. In South America, these aspects have not been studied in depth. This research is relevant because it provides a standardized, cross-country, and comparable analysis of multidimensional energy poverty in the region. The study of energy poverty is critical for the development and well-being of countries, especially in regions such as South America, where this issue can be affected by geographical, cultural, infrastructure, and/or socio-economic differences. In this study, we measured the magnitude of energy poverty in Argentina, Brazil, Uruguay, and Paraguay. This methodology is based on the analysis of energy poverty through a multidimensional approach, considering three parameters as drivers of energy poverty in the countries: accessibility, availability, and affordability. Through a two-step process, first, we calculate the Weighted Average Energy Poverty Index (WAEPI), based on three proposed scenarios (W_1 , W_2 , and W_3), and finally, through the Composite Energy Poverty Index (CEPI), we measure the existing gaps, based on the selected indicators, between the countries under study and the benchmark country. Additionally, we decided to focus our analysis on the country that has shown the highest level and gaps on multidimensional energy poverty in the region, as a case study to validate the results obtained through the chosen methodology. The results show that during the period of analysis (2000–2016), Paraguay has been the most energy-poor country among the countries under study, while Argentina has been the least energy-poor country. At the local level, we observed that, Paraguay, despite being one of the largest producers and exporters of clean hydroelectric energy in the region, still presents high levels of consumption of biomass or coal for cooking, while electricity only represents 17% of the total final energy consumption in the country (biomass and fossil fuels account for 83%). These results could lead the design of energy policies,

projects, and programs to reduce the multidimensional energy poverty, nationally, also at the common platform: MERCOSUR. Finally, this study includes an analysis of policy implications and alternative solutions to eradicate energy poverty in the region.

Keywords: energy poverty, energy poverty index, South America, multidimensional energy poverty, WAEPI, CEPI, Paraguay

INTRODUCTION

The evolution of technology and the lifestyle of human beings resulted in energy becoming an unavoidable element for the prosperity and well-being of people and enterprises.

As mentioned by “Red de Pobreza Energética” [Red de Pobreza Energética (RedPE), 2018], energy allows people to satisfy two main types of energy needs: *fundamentals* and *basics*.

The fundamental energy needs include those related to human health and well-being, while the basic energy needs are linked to the minimum needs that are required to satisfy a minimum standard of life, considering the social, climate, geographic, economic, and socio-cultural characteristics of each community or territory under evaluation.

In this context, if these needs cannot be satisfied or if there is a lack of sufficient, reliable, and clean energy supply to satisfy those needs, we can consider it as a situation of energy poverty (Reddy, 2000; Access to Energy in Developing Countries, 2002; Crentsil et al., 2019).

The study of energy poverty has taken two main methodological approaches: unidimensional and multidimensional analysis (Nussbaumer et al., 2012). Independently of the method, three kinds of indicators are commonly used to evaluate energy poverty: *energy accessibility* (indicators related to the number or % of people who have access to final energy sources—electricity or fuels for cooking—to satisfy their needs), *energy affordability* (indicators related to the levels of final energy consumption), and *energy availability* (indicators related to the availability of primary energy sources in a given place) (Boardman, 1991; Hills, 2011; Moore, 2012; Bouzarovski and Petrova, 2015; Legendre and Ricci, 2015).

We observe an evolution in the analysis of energy poverty from international and multilateral institutions. Historically, at the beginning, the Millennium Development Goals (MDG)¹ proposed by the United Nations (UN) for the period 2000–2015 did not include energy poverty as one of the main challenges to be overcome by the humanity (Gwénaëlle et al., 2009; González-Eguino, 2015).

Nevertheless, from 2015 with the adoption of the 2030 Agenda and the commitment of the 193 UN country members, the 17 Sustainable Development Goals (SDG)² have been established, including the SDG7 that highlights the challenges of the energy sector, especially those related to grant

the accessibility, affordability, and availability of clean and reliable energy.

In this context, the joint report from the World Bank and other agencies (IEA, IRENA, UNSD, World Bank, WHO, 2020) reports that, even though in the last decade relevant improvements have been accomplished worldwide, there still persist important challenges: 789 million people without access to electricity, 2.8 million people without access to clean energy for cooking, 82.3% share of total final energy consumption from non-renewable energy, and the need of improvements on energy efficiency from electronic apparels and buildings, in addition to the enormous gaps in the flux of investments to mobilize investments and innovation in clean energy sources in the least developed countries.

As underlined by the BID (2020), in Latin America and the Caribbean (LAC), important improvements have been accomplished in energy accessibility, but it represents only one of the drivers of energy poverty. Other issues, such as non-reliable and insufficient energy services, can also lead to the use of alternative energy sources that are usually less clean, more expensive, and unsafe.

Additionally, according to the BID (2016), the challenge of universal access to clean and modern energy remains, especially to satisfy cooking and warming needs. The authors estimate that in LAC, there are ~22 million people that have no access to energy, observing more difficulties in Central America and the Caribbean.

Added to access to the energy variable, the relevance of the affordability and availability in the multidimensional analysis of energy poverty must also be underlined. Then, considering these three variables, in the literature, we can identify three main groups of energy poor (Khanna et al., 2019): people that have no access to energy but can afford it; people with access to energy but not affordable; and people who have neither access to energy nor enough income to afford it.

Most of the literature focused on analyzing energy poverty have been oriented to study the last group (no energy access nor affordability), principally in Sub-Saharan Africa, while the situation in LAC mainly concerns people with no access to energy (first group) or with affordability issues (second group).

The methodology we utilize is derived from the multidimensional energy poverty measures proposed by Khanna et al. (2019) and have been implemented for the case of South American countries (Argentina, Brazil, Uruguay, and Paraguay). This study has been made through a top-down approach, and it has the objective of presenting a wider vision of multidimensional energy poverty in the selected countries. This study provides a starting point for the analysis of energy

¹ Millennium Development Goals (MDG): <https://www.un.org/millenniumgoals/>

² Sustainable Development Goals (SDG): <https://sustainabledevelopment.un.org/?menu=1300>

poverty from a general perspective, but not limiting the analysis to the particular context of each country. The multidimensional measures offer a general perspective of the problem of energy poverty in the region, allowing the identification of the challenges of each country and the comparability of the results.

The main contribution of our research is the systematization of the process of measurement of energy poverty based on a multidimensional approach. Moreover, we offer a new perspective to the analysis of energy poverty in South America, through a cross-country, comparable, standardized, replicable, and proved methodology. Then, we also provided a complementary analysis, at the domestic level for Paraguay, which is the country that has shown greater energy poverty gaps in the region. We consider that this research is a valuable contribution to the analysis of energy poverty in the region, considering the reduced number of studies in this topic, as well as approaches considering the regional level or cross-country comparisons.

In section Literature Review, we find the literature review related to the different methods used to measure energy poverty and the conceptualization of energy poverty adopted by their authors.

Then, in section Methodology, we explain the methodology to measure multidimensional energy poverty, considering the limitations of the previously reviewed methods available.

In section Result, we present the results, describing the improvements, challenges, and gaps on energy poverty indicators for the four countries under study during the period of analysis (2000–2016), with a special focus in the three main energy indicators: access, affordability, and availability. Section Limitations highlights the research limitations.

Finally, in section Conclusions and Policy Implications, we present the conclusions and policy implications that should be considered.

LITERATURE REVIEW

The study of energy poverty had its origin in Europe, during the 90's, with the analysis mainly focused on fuel poverty as a problem of households to satisfy their needs of energy for heating. In this context, Boardman (1991) defines energy poverty as “*the inability to afford adequate warmth because of the inefficiency of the home.*” The author analyzes energy affordability as a driver of energy poverty, arguing that poor households normally live in less thermally efficient and not well-insulated homes, spending a higher proportion of their incomes in heating (energy).

Next, from the 2000's, energy poverty literature started to grow as policymakers recognized its impact in the population's well-being, and consequently, the first methods and energy poverty indexes appeared.

Then, as mentioned by Nathan and Hari (2020), at the international level, it was not until 2002³ that the International Energy Agency (IEA) measured energy poverty for the first time. In 2010, during the review of the MDG, the IEA, UNDP (United Nations Development Program), and UNIDO (United Nations

Industrial Development Organization) published a joint product, redefining energy poverty and its elements (IEA, UNDP, and UNIDO, 2010).

Additionally, the UNGA (United Nations General Assembly), through the 65/151 Resolution, declared 2012 as the international year of “*Sustainable Energy for All*”⁴, reinforcing its commitment that same year, declaring the period 2014–2024 as the “*Decade of Sustainable Energy for All*”⁵.

Moreover, in 2015, energy has been officially included as one of the main challenges for humanity through the Sustainable Development Goals (SDG 7), considering energy indicators covering access, affordability, reliability, and efficiency.

The analysis of energy poverty has evolved in the last decades, passing from mainly unidimensional approaches (Boardman, 1991; Foster et al., 2000; Practical Action, 2012) focused on fuel poverty, to bidimensional or multidimensional approaches, recognizing energy poverty as something more than only the lack of income for energy or energy services (energy affordability).

For example, Nathan and Hari (2020) propose a method based on deprivation in modern cooking and lighting fuels to assess energy poverty in India. The methodology proposed in this study is limited to the access-based approach and it is only focused in urban areas in India; however, it allows the categorization of poor in three groups (extreme, moderate, and transitional energy poor) and the consideration of depth and severity of energy poverty. The results show that between the two selected variables, the access to modern cooking is a more fundamental need and a critical variable in the definition of energy poverty.

Then, Pachauri et al. (2004) propose a bidimensional measure of energy poverty and energy distribution, the so-called Energy Access Consumption Matrix (EACM), providing insightful information of the relation between energy poverty and changes in energy distribution for Indian households. The results show that higher levels of access to energy sources are often associated with higher levels of well-being and expenditure levels, and the evidence provided in the paper suggests that improvement and provision of energy services could be relevant drivers of the development of the countries.

In the last decade, energy poverty measures have also included methods based on the construction of indices, considering different variables such as energy use, lack of energy, household size, energy deprivation, energy service quality, and many others.

In this context, Mirza and Szirmai (2010), through the results of Energy Poverty Survey (EPS) conducted in Pakistan, have constructed the Energy Poverty Index (EPI), which considers variables such as energy use, energy shortfalls, and household size. According to Culver (2017), in comparison to other indexes, the EPI is very sensitive to energy poverty in cooking fuels, underlining the usability beyond access but limiting the analysis of the household's energy needs.

Furthermore, Nussbaumer et al. (2012) propose the Multidimensional Energy Poverty Index (MEPI), focusing

⁴UN (2012): <https://www.un.org/en/events/sustainableenergyforall/#:~:text=Sustainable%20Energy%20for%20All,-UN%20Home&text=Recognizing%20the%20importance%20of%20energy,of%20Sustainable%20Energy%20for%20All>

⁵UN (2012): <https://www.un.org/press/en/2012/ga11333.doc.htm>

³World Energy Outlook Report (IEA, 2002).

on the deprivation of access to modern energy services through the use of different variables including type of cooking fuel, cooking technology, electricity access, and the possession of other household appliances. The MEPI has been widely used in several studies, including developing and developed countries (Okushima, 2017; Sadath and Acharya, 2017; Santillán et al., 2020). However, the MEPI is often criticized because it does not include, because of the indicators used for the measurement of the index, the energy for productive uses and energy use beyond the household. Additionally, the energy variables are selected and classified in a top-down manner, which might not reflect local priorities and needs. In contrast, the MEPI has the advantage of focusing on energy services and energy deprivation, which allow capturing the incidence and the intensity of multidimensional energy poverty in countries.

Moreover, as mentioned by Khatib (2011), the IEA⁶ has also developed an index to measure energy poverty, the so-called Energy Development Index (EDI), which relates energy to human development. The EDI considers the following variables: per capita commercial electricity consumption, per capita electricity consumption in the residential sector, share of modern fuels in total residential sector energy use, and share of population with access to electricity. From a methodological perspective, we can observe that the EDI focuses on the energy system transition toward modern fuels, while the MEPI focuses explicitly on energy poverty (Nussbaumer et al., 2012). The EDI is often criticized because it does not consider how energy deprivation of households explains how the energy system is maturing (Culver, 2017).

Then, Bhatia and Angelou (2015) have proposed the Multi-tier Energy Access Method or Multi-Tier Framework (MTF), which considers a set of attributes to estimate the household's energy poverty, allowing the classification of households according to the levels of energy poverty intensities. The considered attributes include capacity (electricity consumption), duration (hours of electricity availability per day), reliability of electrical services, quality, affordability, legality, and health/safety. The core assumption of these methods is that energy service requires a certain level of energy quality, described through the different selected attributes. Additionally, the method received several critics, including the complexity of its implementation, the difficulty to access to reliable data in the different dimensions and attributes, the indefensible mathematic of the model, and the unintended implications of the methodology (Culver, 2017).

In recent years, some methods focused on energy affordability have emerged. For example, Teller-Elsberg et al. (2016) propose the Energy Burden (EB) indicator, which measures the extent and severity of fuel poverty, considering energy affordability variables (household's income and energy costs) as the drivers of fuel poverty. Some limitations of this study include not identifying, appropriately, households as fuel poor if the household fails to spend over the limit of 10% of its income on energy, and also counting households as fuel poor, even if the reason of spending above the limit of 10% is a result of trying to maintain their home at a higher temperature.

More recently, Betto et al. (2020) have also proposed a method related to the energy affordability dimension, called Hidden Energy Poverty (hEP), which considers variables as energy efficiency of buildings, poverty situation, energy consumption and climate sensitivity. This method has been first used in Belgium and then later adopted by the European Commission's EU Energy Poverty Observatory (Bouzarovski et al., 2020). The study shows that policymakers, aiming to decrease the impact of hEP, should consider the heterogeneity of the different regions of the country (climate zones) and the proposal of social bonuses only for energy-poor households. Most of the critics on this method are based on the limited access to reliable data needed to implement it, such as energy efficiency of buildings and the identification of climate zones (at regional and provincial level).

Then, Herrero (2017) analyzes the existing methods for energy poverty measurement, highlights the limitations of unidimensional metrics, and advocates for the implementation of multidimensional approaches, which reduces biases and the risk of omitting alternative understandings of the nature and factors behind energy poverty. In the same vein, Pachauri and Spreng (2011), underline the need of widening the scope of metrics, the design of energy poverty indicators, and the evaluation of policies.

Finally, as mentioned by Culver (2017): "*There is no one metric for energy poverty because there is no single, universally-accepted understanding of what it is to be below the energy poverty line.*" The author finds that energy poverty metrics can be classified into four main approaches: energy access [including the Energy Access Method (EAM)], energy inputs (including the EACM), outcomes of energy use, and quality of energy delivered (including the MTF).

Energy Poverty in Latin America

Poverty not only implies a low level of income but also encompasses many more dimensions. Addressing poverty from a multidimensional approach, where, for example, aspects of education, health, and quality of life standards can be addressed (including the access to electricity), allows a more comprehensive study of the deprivations and difficulties that the population experiences every day (Bronfman, 2014). Considering the aforementioned, Latin America is one of the richest regions in clean energy in the world.

In this sense, García Ochoa (2014) discusses the social aspects of the use of energy in Latin America and its impact on human development, sustaining that energy poverty is real issue and that it has implications in the field of economy, society, and environment. This directly affects the quality of life of the population. It is important to analyze the relationship between poverty and energy, which is the focus of analysis that must be considered for the creation of public policies in Latin American countries. This has been the starting point for the process of development of a conceptual and methodological framework for the study of energy poverty in the region.

In the last decade, studies related to energy poverty have increased in Latin America. The country case studies have taken various approaches over time. Groh (2014) carried out a study in Arequipa, Peru in which she obtained, as the main result,

⁶International Energy Agency (2011).

a close relationship between energy poverty, the isolation of communities, and the implications for people's development opportunities. This was achieved based on an analysis that included not only the classic income analysis but also the multidimensional approach and concepts of penalization for energy poverty that is based on the principle that people with less income suffer more the impact of expenses in energy. In this way, the discussion about the relationship between economic development and the quality of energy service in the low-income strata of the different countries began.

Additionally, Giannini Pereira et al. (2011) have studied the impact of economic and social policies, with a focus on the programs intended to expand the supply of energy to the most vulnerable people in Brazil. The authors have used a wide range of economic analytical indicators to analyze and define an energy poverty line for the case of Brazil. Then, they evaluated the efficiency of the policies implemented at the time in Brazil, finding that both energy poverty and energy inequality were reduced significantly.

In 2016, García Ochoa and Graizbord (2016a) proposed the method "Meeting of Absolute Energy Needs" (MAEN) as a metric of energy poverty in households, and Mexico was taken as a case study, where it was identified that ~43% of Mexican households were classified under the condition of energy poverty. This method is based on the fact that, when people do not satisfy their absolute energy needs, which are related to a series of satisfiers and economic goods that are considered essential in a certain place and time, they present the condition of energy poverty.

Then, an energy poverty indicator has been estimated for households in urban regions of Argentina, in the period 2002–2018, based on the indicator of 10% (Expenses/Income). The main result was that, between 2002 and 2015, there was a sharp decrease in energy poverty, reaching levels of <1%. After 2015, there was a relevant increase in energy poverty in the country, reaching levels even higher than 15% of households (Durán and Condori, 2016). Additionally, in the study made by Jacinto et al. (2018), the authors found that for the northeastern region, which has the lowest electrification rates and does not yet have access to natural gas through the network, an alternative to maximize energy inclusion could be, in addition to increasing the electrification rates and the access to natural gas networks, combining distributed renewable energy with grid electricity or liquefied petroleum gas (LPG).

Several studies addressed the analysis of energy poverty at the subregional level. García Ochoa and Graizbord (2016b) presented a subregional analysis based on the method of "Meeting of Absolute Energy Needs" (MAEN) in Mexico. The main result was that 36.7% of Mexican households are in a situation of energy poverty. It was possible to show, among other variables, as the geographical factor is very important in this analysis, always highlighting the focus from the satisfaction of needs.

Other cases of subregional level studies are those of Argentina and Colombia (Durán and Condori, 2016; Hernández et al., 2018), in which they were addressed from a multidimensional approach, based on the work of Nussbaumer et al. (2012), both with local databases (with their respective difficulties of quality and data reliability). In both cases, it was possible to

identify national subregions where energy poverty is experienced, especially in rural and isolated areas.

On the other hand, Villalobos Barría et al. (2019) analyzed the consequences of the use of different energy poverty metrics for the case of Chile. Consequently, the EPI was estimated based on the Boardman 10% rule, in addition to the use of MEPI. Based on local databases, both indices had similar results of energy poverty, although in subregional terms, there are discrepancies between the two methods, which are mainly explained by territorial factors. The main point of analysis was that the use of one or another indicator should not be used as a substitute but as a complement.

Quishpe et al. (2019), based on several indicators proposed by the European Union Energy Poverty Observatory (EPOV), used the MEPI to analyze the case of Ecuador. This was carried out taking into account local data, yielding a result that shows the presence of energy poverty in households in Ecuador.

Regarding a global and comparative analysis between Latin American countries, Santillán et al. (2020) recently carried out a study where the use of the MEPI is proposed. Seven Latin American countries were selected for this study (Mexico, Colombia, Dominican Republic, Guatemala, Haiti, Honduras, and Peru). The selection of the countries was not an easy task, mainly due to the lack of reliable information, considering that the ideal would be that all Latin American countries were analyzed for a clearer and more comprehensive vision. This selection of countries was mainly due to the availability of data that allowed the analysis, with some considerations and arrangements in the missing and discontinuous data of some of the selected countries.

The advances in energy poverty line have been quite important. For example, the MEPI of Nussbaumer et al. (2012) has been a tool successfully implemented in Africa and several Latin American countries; however, an element that has not been considered is thermal comfort. To achieve greater inclusion and design of more effective public development policies in the countries, it would be very important to consider thermal comfort and regional climatic aspects (Santillán et al., 2020). Another aspect that has been addressed by Amigo-Jorquera et al. (2019) is the relationship between energy poverty and gender inequality for the case of Chile.

Given that the study of energy poverty is growing in Latin America, the Organización Latinoamericana de Energía (OLADE) made a methodological proposal to develop a set of indicators that take into account approaches to social inequality and gender as conditioning elements for energy access and use. It represents a very interesting effort that would allow the evaluation of the degree of social inequality produced from the point of view of energy. It was possible to identify data sources and useful variables in several Latin American countries, which allowed a clear vision of the difficulties in terms of comparability between these variables, due to the high heterogeneity of the data (Rocha and Schuschny, 2018).

In the framework of the Latin American debate regarding Energy Poverty, Urquiza et al. (2019) address the different dimensions and approaches used for the analysis of energy poverty and present Chile as a sample case study that represents

the case of developing countries. Despite the large number of definitions and indicators proposed for the study of energy poverty, most of which were originally intended for developed countries, these can underestimate or overestimate the real situation of energy poverty in Latin American countries (which are mostly they are under development). We must underline that we have presented only some of the most relevant studies on energy poverty for the region; however, we are not presenting a full literature review for each of the countries under study.

The great territorial, economic, and cultural heterogeneity existing in Latin America is a huge challenge for standardization and analysis metrics. Urquiza et al. (2019) propose a three-dimensional framework sensitive to different contexts that can be useful to assess energy poverty for different case studies. The discussions about energy poverty issues in the different Latin American countries continue, but there is still a long way to go.

METHODOLOGY

This paper aims to present an overview of energy poverty in selected South American countries with a multidimensional approach. To achieve this objective, a six-step structured methodology has been implemented.

1. Selection of Indicators
2. Country Selection
3. Selection of Data Sources
4. Data Normalization
5. Analysis of results
6. Validation of the Results

Next, each step carried out in the proposed methodology is presented in detail.

Selection of Indicators

The indicators selected in this work are based on the multidimensional metrics of energy poverty proposed by Khanna et al. (2019), who have measured energy poverty considering three main parameters: energy availability, energy access, and energy affordability. The main advantage of this approach is that the selected parameters represent relevant and quantifiable energy indicators, with a well-established, standardized, and internationally approved methodology for data collection and reporting.

TABLE 1 | Variables of analysis.

Parameters	Indicators	Sub-indicators
Accessibility	Access to electricity	% Population with Access to electricity
	Access to clean fuels and technologies for cooking	% Population with Access to clean fuels and technologies for cooking.
Availability	Total primary energy supply	Total primary energy supply per capita
Affordability	Total final energy consumption	Total final energy consumption per capita

Then, in **Table 1**, we identify the parameters, indicators, and sub-indicators for the analysis:

For the implementation of the metrics proposed by Khanna et al. (2019), and that were selected for this work, it must be structured in two main phases:

- Measure of the Weighted Average Energy Poverty Index (WAEPI).
- Measure of the Composite Energy Poverty Index (CEPI).

Weighted Average Energy Poverty Index

To measure the WAEPI, we need to define some scenarios for energy poverty analysis, which can be determined through the different weight sets (W_1 , W_2 , and W_3) assigned to the sub-indicators identified as relevant to evaluate multidimensional energy poverty. It is important to highlight that the assignment of the weight sets used for this study was carried out based on Khanna et al. (2019), and these are the initial assumptions for calculating the CEPI. These weight sets allow us to analyze potential scenarios in Latin America and establish reference scenarios for methodological comparability of the results obtained in the different countries and regions.

In **Table 2**, we can observe the three scenarios (W_1 , W_2 , and W_3) that will be analyzed in this study. Next, we describe each scenario and the hypothesis assumed in each case.

In scenario 1 with the weight set W_1 , only the energy access variables have been considered. In this scenario, energy poverty is evaluated through a unidimensional approach, where energy poverty explained exclusively as an issue related to energy access. Historically, this approach has been widely used by international organizations [International Energy Agency (IEA), 2011, 2017; Culver, 2017] through the EAM.

This method has the advantages of a relatively easy implementation and access to standardized and fully available data, but fails to incorporate other indicators (availability and affordability) in the analysis of an eminently multidimensional issue.

In scenario 2 with the weight set W_2 , we change to a multidimensional approach for the analysis of energy poverty, assuming the hypothesis that the four indicators corresponding to the three mentioned dimensions analyzed in this paper (availability, access, and affordability) have an equal, proportional, and relevant role in explaining energy poverty.

Finally, in scenario 3 with weight set W_3 , we continue with the multidimensional approach for the analysis of energy poverty, but in this case, a greater weight is given to energy access variables (40% each), assuming the hypothesis that this indicator plays a greater role determining multidimensional energy poverty. The availability and affordability indicators are included in the analysis with an equal and proportional weight of 10% each, playing a secondary role as explicative variable of energy poverty.

We must underline that, as stated by Nussbaumer et al. (2012), even though the issue of weights has been in the center of the debate in the analysis of the different energy poverty indices and considering that the different authors assign these weight sets, either explicitly or implicitly, the arbitrary nature of those and

the need to adjust the weighting sets depending on the analysis and/or the context must be recognized.

According to Khanna et al. (2019), the WAEPI can be expressed as follows:

$$WAEPI_{x,y} = \Sigma (W_1 * Access\ to\ electricity_n + W_2 * Access\ to\ modern\ fuels_n + W_3 * TFEC\ px_n + W_4 * TPES\ px_n)$$

Where:

- x = Country
- n = Normalized Indicator.

The WAEPI measures the level of fulfillment of the energy needs of the population of a country x , considering the three drivers of energy poverty previously identified: access, affordability, and availability.

As mentioned before, energy poverty is a challenge that requires an analysis from different approaches and scenarios, taking into account the characteristics of the population under study. Those different scenarios (including availability, access, and affordability) are shown in **Figure 1**.

From **Figure 1**, we observe that most of the literature on energy poverty have been oriented to the left branch of this energy poverty scenario analysis schema, where we assume no difficulties on energy availability, but limitations on energy access and/or energy affordability.

For this study, the selected South American countries follow that reasoning, considering that at the present, energy availability is not a main problem in those countries, but the challenge is clearly focused on energy access and energy affordability, especially in rural areas and isolated communities.

The diagram in **Figure 1** is a proposal made in order to systematize the multidimensional analysis of energy poverty at the regional, national, or subregional level. It can represent a basic guide to analyze the different case studies that can be addressed in the future.

Composite Energy Poverty Index

The CEPI, which uses the WAEPI results as an input, considers the four sub-indicators as well, which are mentioned in **Table 1**. The CEPI measures the existing gaps (in terms of energy poverty indicators), comparing the situation of a country x in the period

of time y , with the baseline from the reference country (EEUU), functioning as a benchmark.

According to Khanna et al. (2019), the CEPI can be expressed as follows:

$$CEPI_x = 100 - WAEPI_{x,y}$$

Where:

- x = Country
- y = Year of analysis.

Country Selection

The process of selecting countries, in studies as proposed here, is not an easy task, and it would have been ideal to carry out a study for all the countries in South America, but this process is limited both by the availability of data and by the specificities of each country in the region. Santillán et al. (2020) recommend that the selection of countries, for this type of studies, should be based on shared common characteristics (social, energy, economic, etc.).

Within the framework of this study, we have decided to evaluate multidimensional energy poverty in a group of four South American countries: Argentina, Brazil, Uruguay, and Paraguay. These selected countries are members of the *Mercado Común del Sur*⁷ (MERCOSUR) and represent an interesting starting point for a future general analysis of all South American countries. This is also due to the fact that the Rio de la Plata area (Argentina, Paraguay, and Uruguay) and the Paraná-Paraguay basin (Argentina, Brazil, and Paraguay) present very similar social, cultural, and energy conditions.

MERCOSUR (a multilateral economic agreement with more than 30 years of life, initiated between the four countries mentioned, and currently with associated countries such as Bolivia, Venezuela, and Chile) provides one of the most solid bases of economic integration in Latin America that can be used for the analysis, discussion, proposal, and implementation of regional development policies in various areas.

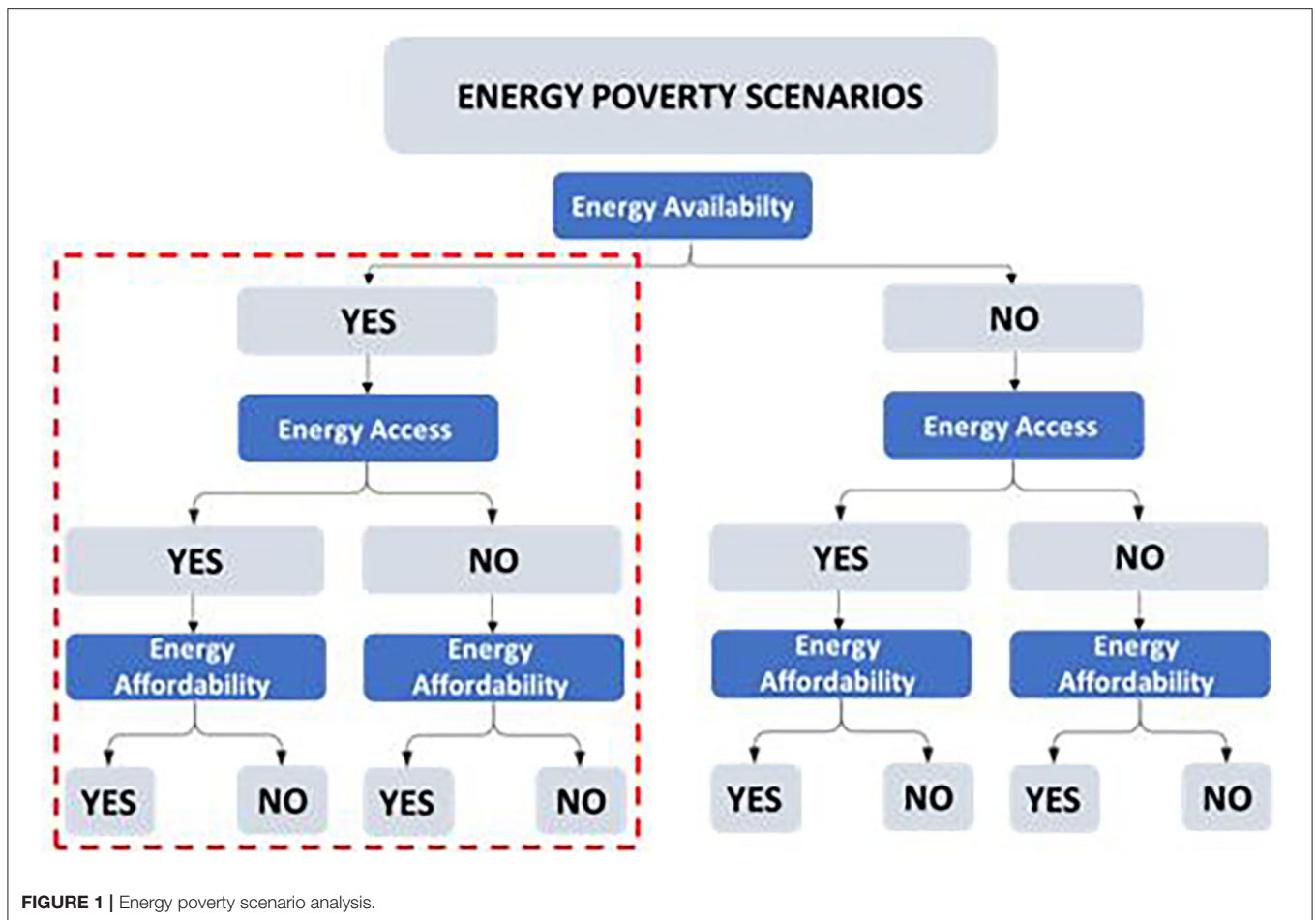
It is important to highlight that, among the four selected countries, there are very close and practically indivisible energy relations. Brazil and Argentina represent a large portion of the South American continent and with the highest population density and therefore require greater energy resources to meet the needs of their inhabitants. Paraguay and Uruguay, both smaller, in terms of territory and population, are linked to their neighbors not only by proximity but also economically and energetically

⁷Southern Common Market official website: <https://www.mercosur.int/>

TABLE 2 | Weight sets for WAEPI scenarios.

Indicators	Sub-indicators	W ₁	W ₂	W ₃ *
Access to electricity	% Population with Access to electricity %	0.5	0.25	0.4
Access to clean fuels and technologies for cooking	Population with Access to clean fuels and technologies for cooking.	0.5	0.25	0.4
Total primary energy supply	Total primary energy supply per capita	0	0.25	0.1
Total final energy consumption	Total final energy consumption per capita	0	0.25	0.1

*A sensitivity analysis could be applied to evaluate the different results that could be obtained according to different criteria.



and present a higher probability of satisfying the energy needs of their population.

The selected countries present, in terms of multidimensional energy poverty, similar difficulties and challenges, being an interesting case study to evaluate national and regional measures and policies that could be implemented to improve the well-being of the most vulnerable people (Durán and Condori, 2016; Contreras, 2019; Dehays and Schuschny, 2019; Santillán et al., 2020).

It is important to highlight the efforts to study, analyze, and start the debate on energy poverty in the selected countries. No reference on energy poverty could be found in the social and energy policy of the countries under study. For these reasons, it is urgent to address the problem in the simplest, most traceable, and flexible way possible.

The approach proposed by Khanna et al. (2019) presents an interesting methodological perspective to carry out a multidimensional and comparative analysis of energy poverty in the region. Then, to implement this methodology, it is necessary to use a regional benchmark (some Latin American country that presents a good performance in the area) or an international benchmark outside the region.

In this sense, we have considered the United States as the reference country for methodological purposes, serving as a

reference to measure the gaps between an ideal scenario (baseline = 100) on the selected energy indicators and the real situation of the South American countries. We are aware that we could have taken the option of using other countries in the region, such as Chile or Mexico, but we decided to take the United States as a reference due to its high performance in the indicators of the different dimensions.

Through this process, we can obtain a clear vision of the regional situation, given the standardized and relatively reliable available data used in the CEPI and WAEPI metrics at the national level.

Selection of Data Sources Database

The data used in this study come from different secondary data sources that are detailed in Table 3. These data have been compiled from publicly available databases from international organizations such as the World Bank (WB) and the IEA.

This research analyzes the data from the period 2000–2016, considering the previously identified parameters and indicators explaining multidimensional energy poverty.

Additionally, it must be underlined that we have also adopted the definitions of the parameters and indicators provided by the

TABLE 3 | Data sources for energy poverty indicators.

Indicators	Sub-indicators	Source
Access to electricity	% Population with Access to electricity	https://data.worldbank.org/
Access to clean fuels and technologies for cooking	% Population with Access to clean fuels and technologies for cooking.	https://data.worldbank.org/
Total primary energy supply	Total primary energy supply per capita	https://www.iea.org/data-and-statistics
Total final energy consumption	Total final energy consumption per capita	https://www.iea.org/data-and-statistics

international organizations (WB and IEA) in charge of updating the above-mentioned databases.

Data Normalization

In section Selection of Indicators, we identified the selected indicators and sub-indicators for the analysis of multidimensional energy poverty for this study, describing different types of information, expressed in different units (% , MJ, etc.). In order to study the data and drawing conclusions, these variables should be expressed in a common footing, so we proceed to the data normalization as expressed in the following formula:

$$x = \left(\frac{x_{c,n}}{x_{EEUU,n}} \right) * 100$$

x : normalized score of an Energy Poverty Indicator for a specific indicator.

$x_{c,n}$: score of an Energy Poverty Indicator for a specific indicator n in country c .

$x_{eeuu,n}$: score of an Energy Poverty Indicator for a specific indicator n in EEUU (reference country).

The data normalization consists, as mentioned by Khanna et al. (2019), in “restructuring of a relational database in accordance with a series of so-called normal forms to reduce data redundancy and improve data integrity.”

Assuming the reference country (EEUU) as the baseline for all variables (Table 4), the following interpretation rules should be considered:

- Indicator values greater than the baseline (100) upon normalization reflect a better performance than the reference country.
- Indicator values lower than the baseline (100) upon normalization reflect a performance worse than the reference country.
- This interpretation rule does not apply to the variable “Energy Use per \$1000 GDP,” where the reasoning is inverse (+ energy use, – energy efficiency).

In this study, we decided to make an analysis for four specific points during the period of analysis (2000–2016). This extensive analysis gives us a wider vision of the evolution of the performance of the countries in the different indicators and sub-indicators related to the multidimensional energy poverty.

The normalized data for the countries under analysis are presented in Appendix 2, specifying the results for each selected year (2000, 2006, 2012, and 2016). Additionally, in

Appendix 1, we offer the data, as originally compiled from the different databases.

Analysis of Results

The metrics were implemented by calculating the CEPI for each of the selected countries and subsequently analyzing the results in detail for each of the cases studied.

Validation of the Results

As a way to validate the results obtained with the implementation of the CEPI, an analysis of energy poverty at the domestic level was carried out for the case of the country with the lowest performance according to CEPI.

RESULTS

CEPI Results

In Figure 2, we observe the results of the CEPI (W_1 , W_2 , and W_3) for the four countries under analysis. The results provide many insightful details that can be described as follows:

- Analyzing energy poverty from a unidimensional perspective, and only considering the energy access indicator (CEPI- W_1), we observe that Argentina and Uruguay have had positive and consistent results during all the periods of analysis (2000–2016). Brazil, at the beginning of the period of analysis (2000), showed greater gaps in terms of energy access, but important improvement in the following periods of analysis can be observed, reducing energy poverty by almost 75% in the same period of analysis. Then, Paraguay has shown the worst performance, with energy poverty levels almost 11 times greater than Uruguay in the year 2000. During the period 2000–2016, Paraguay reduced energy poverty by ~46%, but the gaps in comparison with its neighbors remains, showing an energy poverty level 21 times greater than Argentina in the last period of analysis (2016). This approach could underestimate energy poverty levels, as it only considers one aspect of the problem.
- From the multidimensional perspective of energy poverty, assuming equal weights for the four indicators of the analyzed dimensions of energy poverty, accessibility, availability, and affordability (CEPI- W_2), we again find Paraguay as the most energy-poor country in the analysis, showing the worst performance during the period 2000–2016, and has only reduced energy poverty by 11% in the same period of time. Argentina presents again one of the best performances in the region, but the improvements are more modest in comparison with the previous scenario. Then, Brazil and Uruguay show remarkably similar results during the period of analysis, with

TABLE 4 | Energy indicators data – EEUU (2000, 2006, 2012, 2016).

N°	Indicator	Unit	EEUU			
			2000	2006	2012	2016
1	Access to electricity, urban population	%	100	100	100	100
2	Access to electricity, rural population	%	100	100	100	100
3	Total population with access to electricity	%	100	100	100	100
4	Access to clean fuels and technologies for cooking	%	100	100	100	100
5	Total primary energy supply per capita (TPESpc)	toe/capita	8.1	7.7	6.8	6.7
6	Total final energy consumption per capita (TFECpc)	(kg of oil equivalent)	5,480	5,224	4,608	4,697
7	Energy intensity	MJ/\$2011 PPP GDP	7.34	6.37	5.69	5.41
8	Electric power consumption per capita (Kwh)	KWh	13,671.05	13,583.27	12,964.33	12,993.96
9	Fossil fuel energy consumption	%	85.88	85.63	83.44	82.43
10	Energy use	(kg of oil equivalent) per \$1000 GDP (constant 2011 PPP)	176.45	152.62	135.73	127.92

Source: Compiled from <https://datos.bancomundial.org/>; <https://www.iea.org/data-and-statistics>.

very small reductions of energy poverty in the same period of time, with Uruguay being more consistent and Brazil showing a stagnation in the improvement since 2012. In this scenario, closer gaps between countries and greater levels of energy poverty in the region can be observed.

- In the last scenario (CEPI- W_3), the same trend as in the previous scenarios remains, with Paraguay having the worst performance and a greater level of energy poverty in the region, while Argentina consolidates its position as the least energy-poor country.
- Despite the limited analysis of the three proposed scenarios, we observed from the results that energy accessibility is not the main problem in the region, as shown in the results for scenario W_1 (excepting Paraguay). Nevertheless, when including energy affordability and energy availability, energy poverty gaps tend to increase, worsening the results of the CEPI for scenarios W_2 and W_3 . Additionally, we note scenario W_2 as a baseline for the analysis of multidimensional energy poverty, from which we could start a sensitivity analysis including different weight sets according to the context of each country.
- Considering these results, we decided to analyze the case of Paraguay at the city level, in order to improve our understanding of the causes of its performances in the different indicators used to measure energy poverty gaps in this study (see section Energy Poverty at the city level: Paraguay).

CEPI Results – Country Analysis Argentina

Access to Electricity and Other Modern Energy Sources

Argentina shows an optimal result in electricity access, having access to electricity rates nearly 100% at the national level. Nevertheless, there are still gaps to be filled in terms of access to modern and clean energy for cooking (see **Figure 3**).

Consumption of Modern Energy Sources

A high level of consumption of fossil fuels, aligned with the position of the country as a producer of oil and gas, and its recent role as one of the biggest players on the production of shale gas through the exploitation of the Neuquén basin, known as Vaca Muerta, can be observed. Additionally, the energy consumption per 1000 US\$ GDP represents ~84% in comparison to the reference country (EEUU) for the last period of analysis (2016) (see **Figure 3**).

Energy Supply

The total primary energy supply per capita is much lower than the reference country. Nonetheless, it must be underlined that the country has a very diversified supply of energy, including nuclear energy (1.107 MW)⁸, an interesting mix of renewable energy sources (stimulated through the RenovAR program⁹), hydraulic energy [representing 33% (11.170 MW) of the installed capacity of the country for electricity generation]¹⁰, other thermal energy sources, and fossil fuels (see **Figure 3**).

Overall Situation

Argentina is the country with the best performance in almost every scenario (W_1 , W_2 , and W_3) of multidimensional energy poverty evaluated in this study, considering the three indicators (energy access, energy availability, and energy affordability) guiding this holistic approach.

Moreover, Argentina has shown sustained and positive results throughout the period of analysis (2000–2016), especially in the electricity access rates that had a notorious growth in rural areas in the last decades (see **Figure 4**).

⁸ Argentina's Ministry of Energy: <https://www.argentina.gob.ar/produccion/energia/electrica/nuclear/centrales>

⁹ RenovAR Program: <https://www.argentina.gob.ar/energia/energia-electrica/renovables/renovar>

¹⁰ Argentina's Ministry of Energy: <https://www.argentina.gob.ar/energia/energia-electrica/hidroelectrica/hidroelectricidad-en-argentina-y-en-el-mundo>

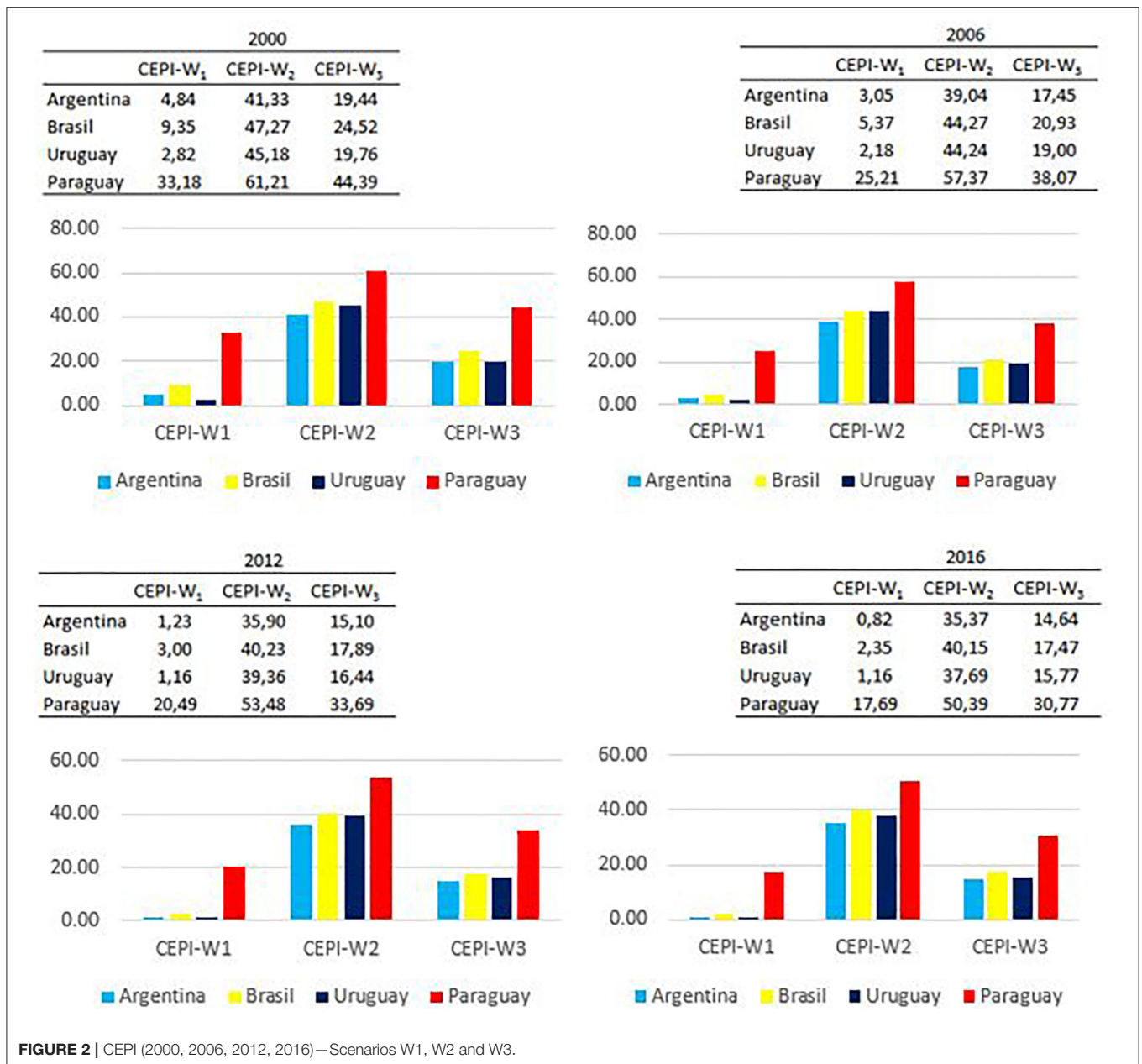


FIGURE 2 | CEPI (2000, 2006, 2012, 2016)—Scenarios W1, W2 and W3.

Brazil

Access to Electricity and Other Modern Energy Sources

Brazil shows high levels of electricity access rates, both in rural and in urban areas, achieving almost 100% electricity access rates at the national level. Nevertheless, there still exists a small gap to be closed in terms of energy access in rural areas (including isolated and indigenous communities), where access to modern and clean energy sources for cooking and heating should also be improved (see Figure 5).

Consumption of Modern Energy Sources

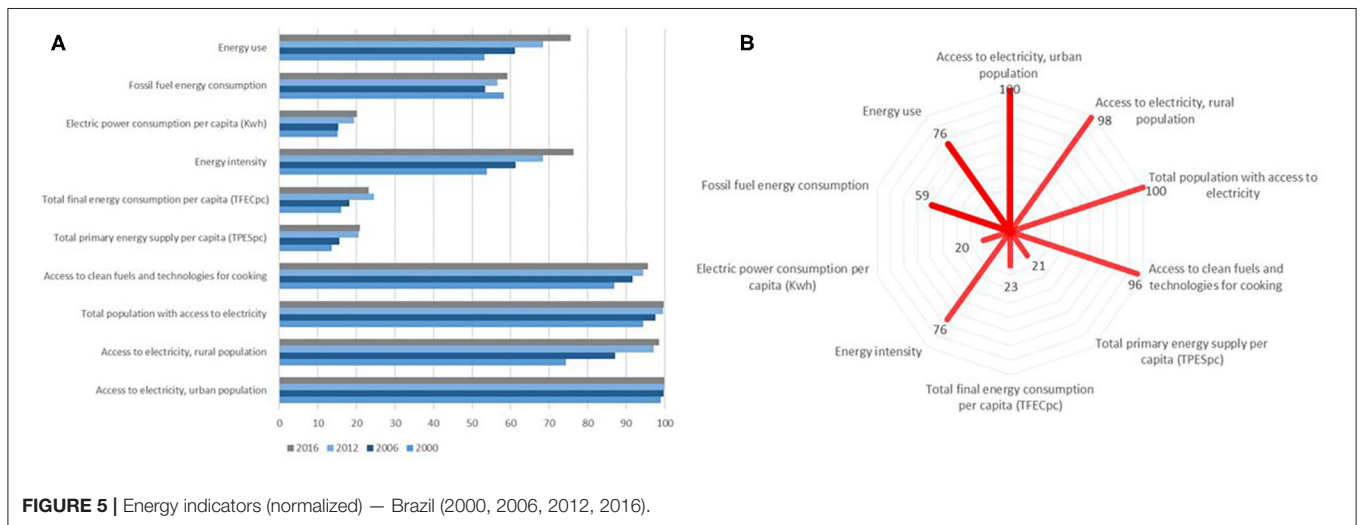
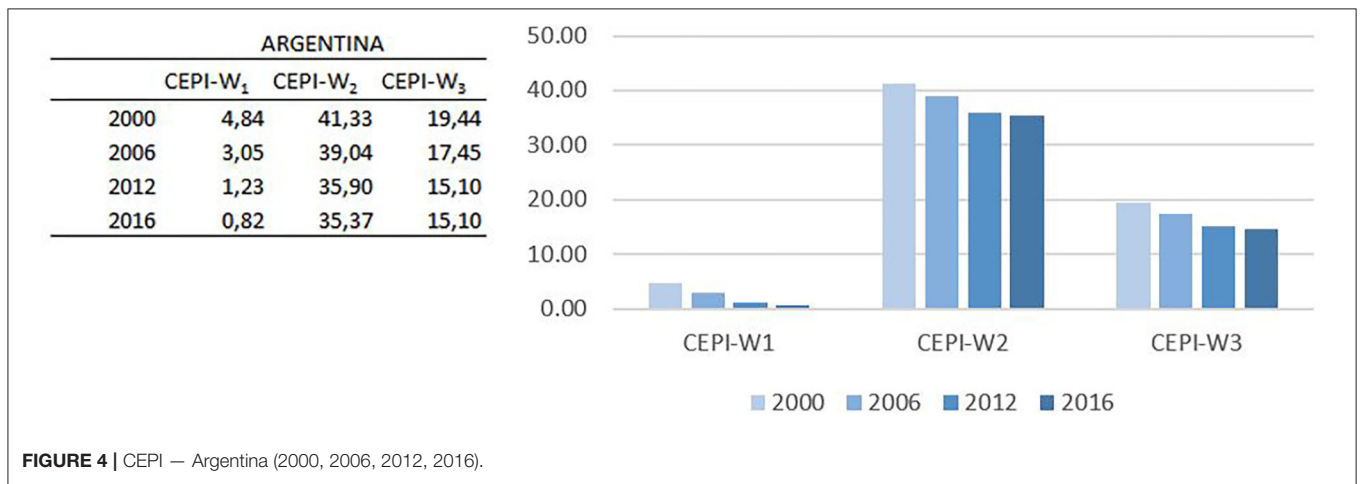
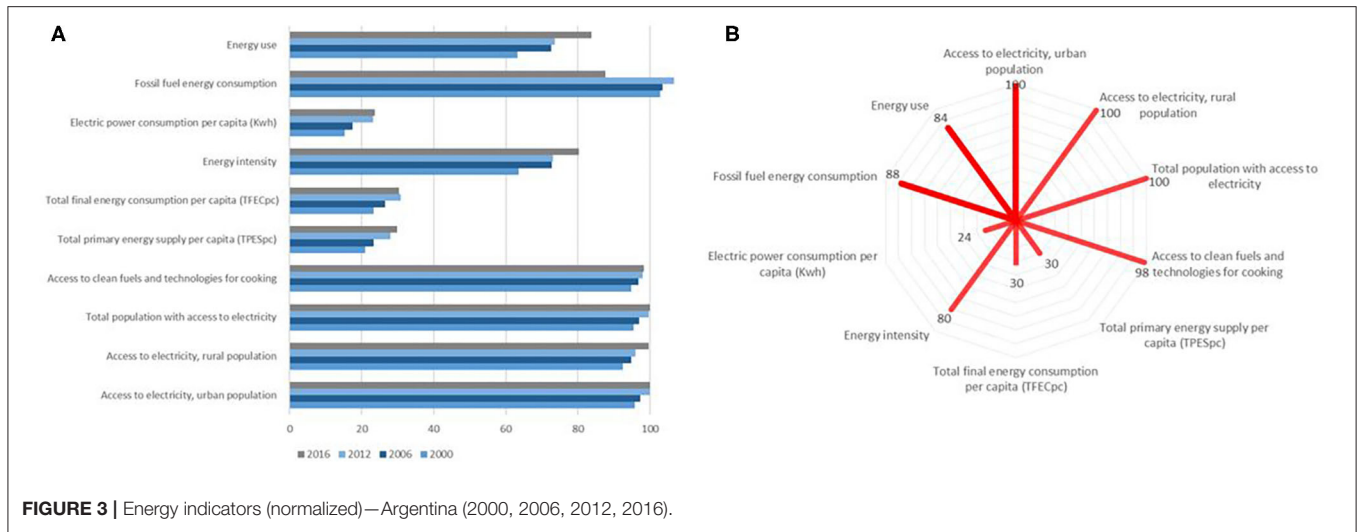
There is a relatively high consumption of fossil fuels in comparison with the reference country. The country has

important oil and gas deposits (onshore and offshore), some of which are being exploited and others are auctioned.

The energy consumption per 1000 US\$ GDP is ~76% of the consumption of the reference country. Despite being one of the greatest producers of hydroelectric energy in the world, Brazil shows a notoriously low electricity consumption per capita, as well as final energy consumption per capita, in comparison to the reference country (see Figure 5).

Energy Supply

The total final energy supply per capita is 21% in comparison to the baseline of the reference country. It must be underlined that with a growing population, having the seventh largest megacity



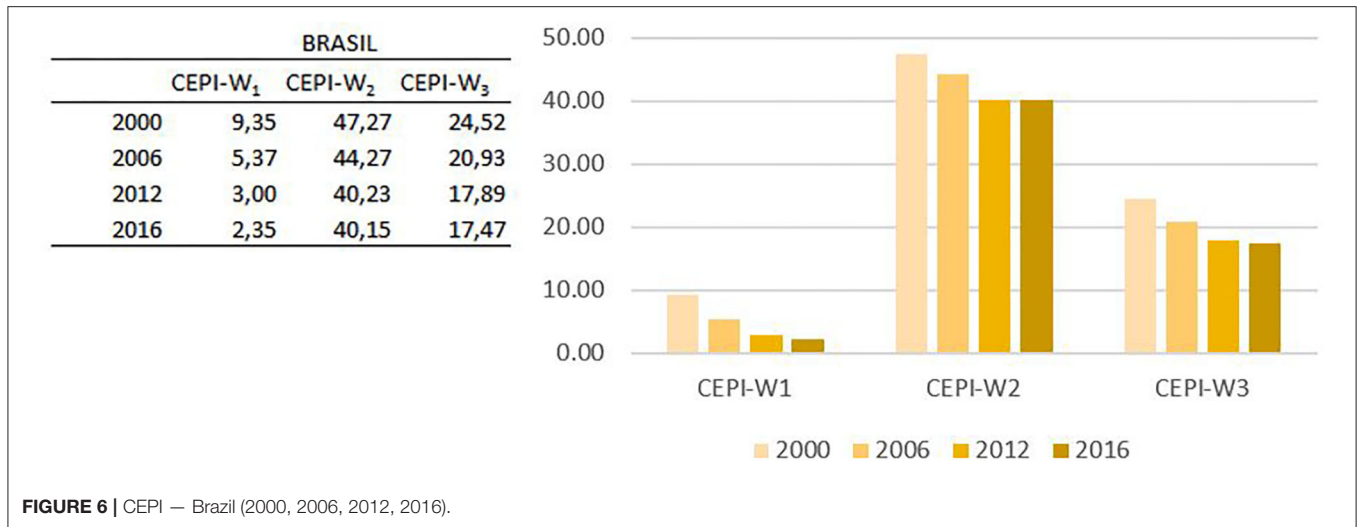


FIGURE 6 | CEPI — Brazil (2000, 2006, 2012, 2016).

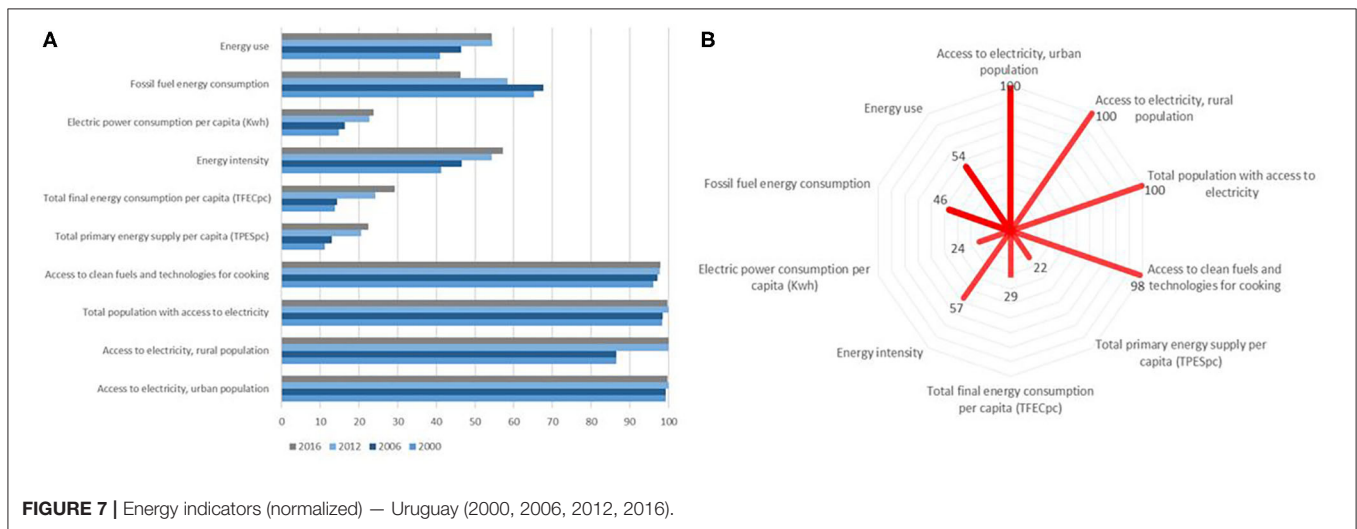


FIGURE 7 | Energy indicators (normalized) — Uruguay (2000, 2006, 2012, 2016).

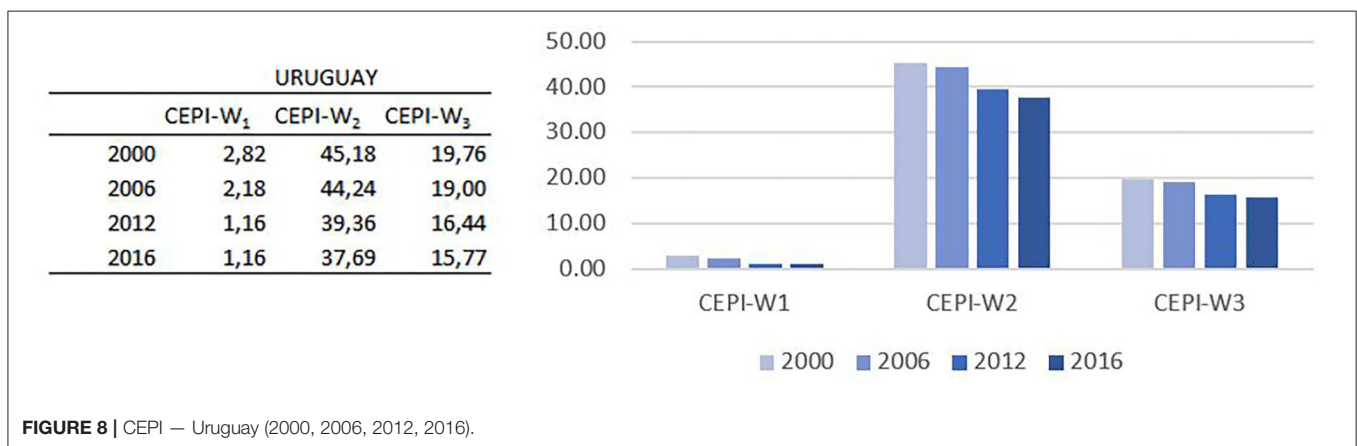
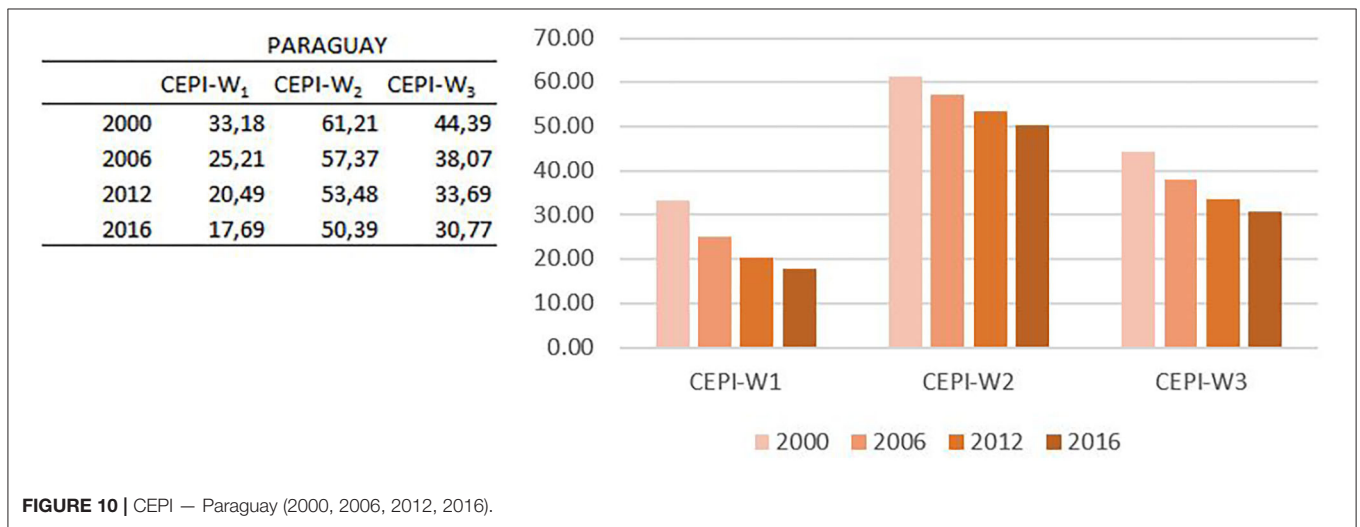
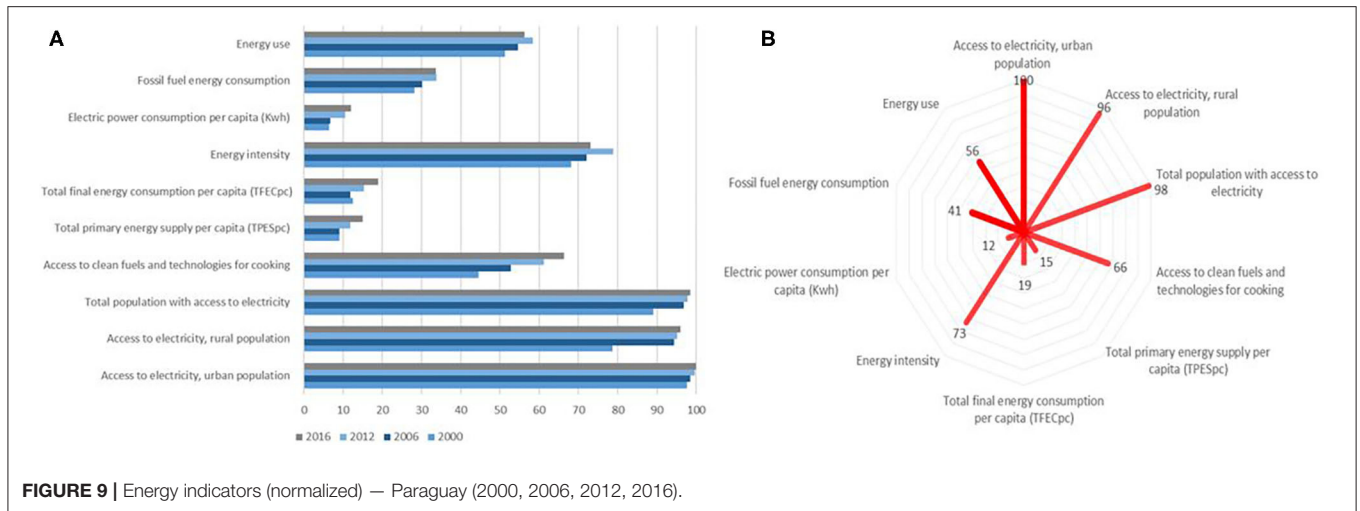


FIGURE 8 | CEPI — Uruguay (2000, 2006, 2012, 2016).



of the world (i.e., São Paulo¹¹), and a high population density in slums (i.e., favelas), Brazil needs to increase its energy supply, capable of providing sufficient and reliable energy services to the people (see **Figure 5**).

Overall Situation

Brazil is a country that has achieved a remarkable improvement in electricity access rates in rural areas, with a steady and fast improvement during the period of analysis (2000–2016). These results are also reflected in the CEPI results, especially in the scenario CEPI-W₁.

Nevertheless, when the energy availability and energy affordability variables are included, we observe that during 2012 and 2016, there was almost no improvement in the reduction of energy poverty in the country (see **Figure 6**).

¹¹Demographia World Urban Areas (2020): <https://www.newgeography.com/content/006693-demographia-world-urban-areas-2020-tokyo-lead-diminishing>

Uruguay

Access to Electricity and Other Modern Energy Sources

Access to electricity rates in Uruguay has grown rapidly in the last decade, especially in the rural areas, which closed the gap between urban and rural areas and helped the country in accomplishing an almost 100% electricity access rate at the national level. On the other hand, we observe some difficulties with access to modern and clean energy for cooking, as many of the South American countries under analysis (see **Figure 7**).

Consumption of Modern Energy Sources

Uruguay has shown a remarkable reduction in the consumption of fossil fuels, a situation that can be explained by the strategy of the country, focused on renewable energy. In the period 2000–2016, Uruguay has invested ~US\$ 7.800 million in electric infrastructure, and in 2018, the breakdown of its electric energy generation is as follows: 38% wind energy, 3% solar energy, 7% biomass, <3% thermal energy sources, and almost 50%

hydroelectric energy¹². Despite the favorable context described before, there are still gaps to be filled in the access to clean energy for cooking (see **Figure 7**).

Energy Supply

Uruguay has remarkably improved its energy supply in the last decade, diversifying its sources of energy generation since 2013, increasing investments on renewable energies and specially in wind energy, which at the present is the second largest contributor in the generation of electric energy at the national level¹³. Furthermore, the country continues to invest in several projects and programs to improve energy efficiency (Project Movés—Sustainable and Efficient Urban Mobility), circular economy for energy generation (Circular Opportunities Program and BioValor Program), and many others (see **Figure 7**).

Overall Situation

Uruguay shows one of the best and more consistent performances throughout the period of analysis, having accomplished important improvements in energy affordability and energy availability indicators. The country had successfully leveraged investments in the energy sector to accelerate the penetration of renewable energies, reducing their dependence in fossil fuels and mitigating the impact of multidimensional energy poverty (see **Figure 8**).

Paraguay

Access to Electricity and Other Modern Energy Sources

Paraguay has high electrification rates at the national level, but they are lower than those of its regional neighbors, showing important gaps in electricity access in rural areas and isolated communities. Moreover, only 2/3 of the population has access to modern and clean energy for cooking, with moderate improvements in the last 20 years (see **Figure 9**).

Consumption of Modern Energy Sources

Paraguay imports all the oil and gas consumed nationally for energy uses, which should be regarded as an energy security issue.

Despite being one of the largest producers of hydroelectric energy through binational projects with Brazil (Itaipú Binacional) and Argentina (Entidad Binacional Yacyreta), high rates of non-certified biomass consumption can be observed.

Furthermore, the electric power consumption per capita is lower than that observed in the region and the country has low industrialization rates, enabling it to export its hydroelectric surplus to its neighbors at lower prices than the market price (see **Figure 9**)¹⁴.

¹²Promoción de Inversión, Exportación e Imagen País (Uruguay): [https://www.uruguayxxi.gub.uy/es/noticias/articulo/uruguay-lider-en-energias-renovables/#:~:sim\\$=text=URUGUAY%2C%20L%C3%8DDER%20EN%20ENERG%C3%8DAS%20RENOVABLES&text=En%202018%20el%2038%25%20de,%2Dcasi%20la%20mitad%2D%20hidroel%C3%A9ctrica](https://www.uruguayxxi.gub.uy/es/noticias/articulo/uruguay-lider-en-energias-renovables/#:~:sim$=text=URUGUAY%2C%20L%C3%8DDER%20EN%20ENERG%C3%8DAS%20RENOVABLES&text=En%202018%20el%2038%25%20de,%2Dcasi%20la%20mitad%2D%20hidroel%C3%A9ctrica)

¹³Uruguay's Ministry of Industry, Energy and Mining: <https://ben.miem.gub.uy/oferta3.html>

¹⁴The Itaipú's and Yacyreta's treaties oblige Paraguay to sell (cede) its energy surplus to each country from the binational companies at a preferential price

Energy Supply

The total primary energy supply per capita is the lowest among the countries under study in comparison with the baseline of the reference country. Even so, Paraguay is one of the largest producers of hydroelectric energy per capita in the world and one of the largest exporters of electricity in the region (43.564.247 MWh in 2017)¹⁵.

Nevertheless, the country still has problems to achieve the full use of its available energy, having low levels of industrialization rates, lack of sufficient investments in transmission and distribution infrastructure for electric energy, and low quality and reliability of the energy services (BID, 2020).

Moreover, the country shows a relatively important dependence on fossil fuels (representing 40% of total final energy consumption), which are fully imported in the international market. Additionally, an important role of biomass on the energy mix of the country can be observed, representing 36% of the country's energy supply and 43% of the total final energy consumption [Vice-Ministerio de Minas y Energía (VMME), 2020].

Nevertheless, the extremely high rates of deforestation in the Gran Chaco and particularly in Paraguay must be underlined, where the forest lost nearly 44,000 km² in the 1987–2012 period (see **Figure 9**)¹⁶.

Overall Situation

Paraguay has accomplished an important improvement in electricity access rate at the national level, but the gap in rural areas and isolated communities remains, a situation that should be addressed to effectively reduce energy poverty.

Additionally, the country has two main challenges: increasing access to clean and modern energy for cooking rates (especially in rural areas) and reducing its dependence on imported fossil fuels, improving the use of its own and available hydroelectricity in the final energy consumption.

Finally, Paraguay shows the highest levels of energy poverty, in all the scenarios (CEPI-W₁, CEPI-W₂ y CEPI-W₃), among the evaluated countries (see **Figure 10**).

Energy Poverty at the City Level: Paraguay

From previous results, we found that Paraguay has the highest level of energy poverty, facing important challenges in the near future. Taking a closer look at the case of Paraguay, in the analysis of cities and departments, we observe that energy poverty is not a problem of energy availability (electricity and biomass) or electricity access, but an issue of energy affordability and access to technologies and cleaner sources of energy for cooking, which should be considered a priority, in order to reduce multidimensional energy poverty at the national level.

In **Table 5**, we observe high rates of electricity access in Asunción (capital of the country) and the main departments of Paraguay, but analyzing the energy used for cooking, only Asunción has <10% of its population using biomass or coal for

¹⁵Vice-Ministerio de Minas y Energía: https://www.ssme.gov.py/vmme/index.php?option=com_content&view=article&id=1218&Itemid=605

¹⁶Earth Observatory (NASA): <https://earthobservatory.nasa.gov/images/92078/deforestation-in-paraguay>

TABLE 5 | Electricity access (%) & fuel for cooking (%) - Asunción and Paraguay's main departments (2019).

Department	Electricity access	Fuel used for cooking					
		Liquefied petroleum gas (LPG)	Biomass/coal	Electricity	Kerosene, alcohol	Other ^a	None/Doesn't cook
Asunción	99.93	66.76	6.34	23.37	0.00	0.05	3.47
Concepción	99.07	41.59	43.56	12.78	0.00	2.07	0.00
San Pedro	99.27	25.05	57.82	14.75	0.00	0.00	2.37
Cordillera	99.53	42.04	43.70	11.74	0.00	0.00	2.51
Guairá	99.45	30.70	52.66	14.38	0.00	0.12	2.14
Caaguazú	99.59	35.03	46.33	16.09	0.00	0.00	2.54
Caazapá	99.31	31.08	54.23	13.47	0.00	0.00	1.22
Itapúa	99.81	50.31	31.45	16.58	0.00	0.00	1.67
Misiones	99.58	51.75	32.04	14.44	0.00	0.00	1.77
Paraguarí	98.20	27.87	60.63	9.50	0.00	0.00	2.00
Alto Paraná	99.88	77.12	11.45	9.59	0.00	0.00	1.83
Central	99.91	66.30	12.58	19.71	0.00	0.00	1.41
Ñeembucú	98.34	56.81	33.24	7.34	0.00	0.00	2.61
Amambay	97.98	80.37	15.04	2.32	0.00	0.00	2.27
Canindeyú	99.58	54.12	35.19	7.81	0.00	0.00	2.88
Presidente Hayes	97.98	48.82	25.83	22.82	0.00	0.00	2.53

Source: DGEEC Encuesta Permanente de Hogares Continua 2019. Promedio anual.

^aIncludes: Sawdust.

Red > 30%; 10% < Orange < 30%; Green < 10%.

cooking. On the other hand, we find that in other departments, the percentage of the population using biomass or coal is higher than 10%, and in some cases, even higher than 60%.

Paradoxically, despite being one of the largest producers and exporters of clean hydroelectric energy in the region, Paraguay still has low levels of electricity as source of final energy consumption (17%), while biomass and fossil fuels account for 83% of the total final energy consumption [Vice-Ministerio de Minas y Energía (VMME), 2020]. As observed in **Table 5**, the main challenge concerning the transition from biomass/coal to cleaner energy sources for cooking is located outside the capital (Asunción), and especially in non-urban zones or departments where the main economic activities are agriculture and/or cattle raising.

Additionally, we observe that the population of Asunción also has higher levels of access to home appliances and electrical devices in general (refrigerators, air conditioners, TVs, electric water heater, etc.), as well as cleaner technologies for cooking (electric kitchens, microwaves, LPG kitchens, electric oven, etc.), providing better conditions for well-being and development of the cities and people (Dirección General de Estadísticas, Encuestas y Censos, 2020).

Then, if we analyze the technologies used for transport, we find that in the city of Asunción, most of the population have a car (51.2%) or a motorcycle (22.5%), while at the department level, we have the opposite results (in average), with more people having access to motorcycles (67.6%) rather than cars (30.2%) (Dirección General de Estadísticas, Encuestas y Censos, 2020). In both cases, fossil fuels are needed, and as we mentioned before, the country imports 100% of its demand of oil and LPG.

In Organización Latinoamericana de Energía (OLADE) (2020), we observe that energy prices in Paraguay have been stable in recent years. During the period 2015–2019, the price of electricity for the residential sector has been around 58.30–61.00 US\$/MWh, that for the commercial sector is in the range 62.70–70.00 US\$/MWh, and that for the industrial sector is between 38.50 and 45.50 US\$/MWh. On the other hand, during the period 2014–2018, LPG prices have been around 1.25–0.73 US\$/kg, while gasoline prices for the transport sector have been between 1.16 and 0.88 US\$/L. Although energy prices in Paraguay are very competitive at the regional level, energy affordability should not be underestimated as an important variable in multidimensional energy poverty, especially at the city level and when considering the affordability of clean fuels and technologies for cooking, where more data are needed to follow-up the improvements or setbacks in this indicator.

Then, when analyzing multidimensional energy poverty in Paraguay, we find a mixed set of conditions in the different cities and departments, where access to electricity is not a major issue. Nevertheless, energy affordability and the access to clean fuels and technologies for cooking still represent big challenges for the country, especially in isolated regions (i.e., Chaco Paraguayo) and with the most vulnerable population (people in extreme poverty).

LIMITATIONS

The methodology implemented in this study had some implications in the obtained results, which are explicated by its limitations. The main limitations include the following aspects:

- The choice of EEUU as the reference country (benchmark). It is a decision that could overestimate energy poverty situation in the analyzed region, considering the current gaps, in terms of energy indicators, between EEUU and South American countries.
- The results are very sensitive to the selection of different weights (W_1 - W_2 - W_3) for the different approaches proposed for the analysis of energy poverty. The results must be interpreted cautiously.

Despite the limitations, the study offers a wide range of results that provide a good diagnosis of energy poverty in the region, considering the challenges each country will have to face to mitigate the consequences and to reduce the gaps (nationally and regionally), considering energy access, affordability, and availability.

CONCLUSIONS AND POLICY IMPLICATIONS

Through the measure of the CEPI and its multidimensional approach, we have been able to evaluate the multidimensional energy poverty in a group of South American countries. Then, independently of the weights assigned to each variable (W_1 - W_2 - W_3), we observe a predominant trend, where Paraguay presents greater difficulties concerning energy poverty in the region, as well as existing important gaps with Brazil, even greater compared to Argentina and Uruguay, which, from a general perspective, present the best performances.

Despite limiting our analysis to three scenarios, we identified that energy accessibility is not the main problem in the region; however, when including energy affordability and energy availability, energy poverty gaps tend to increase, worsening the CEPI for scenarios W_2 and W_3 in the countries under study.

Overall, as expected, each country presented different characteristics in the supply and demand of energy. Regionally, the energy accessibility rates observed, at the country level, are high; however, further studies are needed to evaluate the lack of access in rural (or isolated) areas within the countries, and the impact of the deprivation of energy services on the well-being of the population. Nevertheless, there are different initiatives regionally, from multilateral institutions (BID, FONPLATA, CAF, PNUD, etc.) and public-private partnerships, financing projects to close the energy infrastructure gaps and to reduce energy vulnerability.

Additionally, results show that countries with national projects to accelerate the integration of renewables in the energy mix reduced the multidimensional energy poverty in the period of analysis, as shown in the cases of RenovAr in Argentina, and the numerous wind energy projects in Uruguay. On the other hand, countries like Paraguay, which has not diversified its energy mix in the last decades, introduced new renewable energy sources, or improved its final energy consumption of electricity, have higher levels of multidimensional energy poverty, depending heavily on fossil fuels and non-certified biomass.

The results obtained for the countries studied reflect the current situation from a macro perspective, and having a critical review of the implemented methodology, when we analyze the case of Paraguay, with local data, the results clearly show, at the level of the capital and main departments, high electricity availability and also high rates of electricity access; however, energy affordability is a problem that is reflected in aspects such as cooking with biomass or coal, which has negative well-known effects in well-being and health. We decided to study Paraguay at the local level because it became the most representative case of multidimensional energy poverty in the region and has been a country that is not usually studied or mentioned in the global literature of this topic. We are convinced that the results of our study can serve as a starting point for discussions on multidimensional energy poverty in the country. Moreover, this case study allowed the validation of the general results obtained through the implementation of the multidimensional energy poverty metrics proposed for the countries under analysis, showing an evidence of the current situation of the country and the need to deepen the study of energy poverty.

Furthermore, the results show that during the period of analysis (2000–2016), Argentina and Uruguay have had a consistent performance in many energy indicators, considerably reducing energy poverty. These cases require an in-depth analysis to better understand the causes behind those good performances. A common strategy in both countries has been their investments in renewable energy through different programs.

We observed that an analysis of energy poverty, exclusively done through the lens of the energy access (CEPI- W_1), can underestimate the problem in the countries under study. In this context, we consider the use of multidimensional approaches to study energy poverty in the region necessary, in order to have a holistic vision, closer to the real situation of the region. Then, from a multidimensional approach, evaluated through the scenarios CEPI- W_2 and CEPI- W_3 , we conclude that further studies are needed to evaluate the quality of the selected indicators used to measure the multidimensional energy poverty in the region, and if it is necessary to add new variables to improve the quality of the proposed index and to reflect a closer reality of energy poverty in the countries under analysis. In this regard, we can already observe the efforts of the OLADE¹⁷, to guide the regional discussion to standardize the measuring and reporting of energy indicators, in order to facilitate the measure and comparability of energy poverty in the future.

Policy Implications

From a public policy perspective, efforts should focus on improving access to modern and clean energy for cooking, especially in rural and isolated areas. Additionally, we observe high levels of fossil fuel consumption, which is a situation that needs further study to understand if that is aligned

¹⁷In 2020, OLADE conducted a series of workshops with the Energy Statistics Departments of the country members, in order to discuss the methodological harmonization of energy statistics in the region.

with the national strategies and energy policies of the countries we have analyzed, and how, under this context, energy poverty of the most vulnerable population can be reduced. We have not identified any official document from the analyzed countries evaluating transnational actions or policies to reduce energy poverty in the region. Instead, we observe geopolitical situations and barriers to regional energy integration¹⁸. We are convinced that a regional commitment and policies to the reduction of multidimensional energy poverty are needed. Considering the wide range of potential variables affecting the multidimensional energy poverty, the scope of actions from the countries should include regional energy integration policies, regional incentives on energy efficiency, tougher sanctions and regulations on the use of non-certified biomass, incentives on technology transfers oriented to the improvement of technologies for cooking, and many others. In this regard, some of the regional commercial incentive policies and technology transfers could be discussed through the MERCOSUR platform, while other policies concerning more wider aspects could be analyzed through sectorial round tables established with representatives of each country.

Moreover, decision-makers and policymakers must understand that energy poverty is a multidimensional issue that requires actions on many fronts. Nowadays, we observe that most of the strategies against energy poverty in the region are focused on tariff subsidies (energy affordability) for the household's electricity consumption.

Solutions to the multidimensional energy poverty at the regional level must necessarily involve a wider discussion, which should consider the challenges and energy gaps identified in each country, focusing efforts on the design and implementation of a regional agenda of development, oriented to the creation of synergies and achievement of shared objectives. On the other hand, at the domestic level, we consider that energy poverty should be part of the academic debate and decision-making in different countries, for the construction of the different public policies on energy and development. We suggest strengthening the role of local administrations (municipalities, states, or other respective administration established at the domestic level in each country) in the development of different projects to reduce multidimensional energy poverty, especially in vulnerable cities and isolated communities within the countries.

Furthermore, it is important to underline that these countries, as members of the UN, have adopted the 2030 Agenda and the commitment with the SDGs, including the SDG 7, focused on granting universal access to energy, at affordable prices, from modern and clean sources and technologies.

We must underline that within the dimension of "energy access," the indicators of "*proportion of population with access to electricity*" and "*proportion of population with primary reliance on clean fuels and technology*" are the same indicators used by the SDG 7 included in the 2030 Agenda. These indicators refer to the SDG indicators 7.1.1 and 7.1.2, respectively, and considering

the evolution of the results and improvements achieved by the selected countries in these indicators, they seem to be in the path to partially achieve SDG 7 (at least in 7.1.1, but in 7.1.2, the gaps are greater and more complex to improve). Finally, regional energy policies should be analyzed to create synergies and to improve energy services (quality and reliability), funding projects for energy system integration, cross-border cooperation, and programs targeting the improvement of the access to clean and affordable energy for the most vulnerable communities in these countries.

Future Research Work

Future research work should be oriented to the implementation of regional and standardized multidimensional energy poverty indicators, as those proposed by Dehays and Schuschny (2019) from the OLADE. However, energy poverty measures at the domestic level (cities, departments, etc.) should not be neglected, considering that it is at this level where this issue takes place, and its effects could be distributed with high levels of heterogeneity within the countries.

Additionally, a wider study of multidimensional energy poverty, including all the countries in South America, could provide a more realistic vision of this issue in the region. The metrics used in the proposed methodology addresses multidimensional energy poverty in a simple and reliable way, taking into account the difficulties and restrictions that arise with regard to data availability. Then, these complementary analyses could also lead to the consideration of a closer country as benchmark for the analysis and the use of additional parameters for the study of multidimensional energy poverty. Moreover, a sensitivity analysis that assigns different weights to the indicators in order to have a wider vision of possible results (according to the different weights sets) is also recommended.

We also recommend the use of a regional benchmark that is not a single country in the region, but the general average of all the indicators of the countries under study, in a certain period of time (i.e., the average performance of a decade), in order to avoid underestimating or overestimating energy poverty and provide a comparable result to that obtained through a traditional benchmark such as that of the United States used in this case.

Finally, we must underline the importance of a regional academic network for the study of multidimensional energy poverty from different perspectives, in a collaborative approach. Some successful experiences in the region, such as Red de Pobreza Energética (RedPE in Chile)¹⁹, influenced many academic works in addition to public policies that could be emulated in different countries. Other emerging regional collaboration networks, such as the Red de Inclusión Energética Latinoamericana (RedIEL in Latin America)²⁰, the Observatorio de Pobreza Energética en México²¹, and the Red Energías Solidarias, should strengthen regional academic

¹⁸This is especially the case of Paraguay with Brazil and Argentina, through the binational projects (Itaipú and Yacyreta).

¹⁹RedPE: <http://redesvid.uchile.cl/pobreza-energetica/>

²⁰RedIEL: <https://www.rediel.org/>

²¹Observatorio de Pobreza Energética en México: <https://pobrezaenergetica.mx/>

collaboration in order to influence public policies (nationally and regionally).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

GP: conceptualization, methodology, validation, formal analysis, investigation, literature review, data curation, writing original draft, visualization, and supervision. AG: conceptualization, validation, methodology, literature review, and project administration. RR: conceptualization, methodology, and

validation. All authors contributed to the article and approved the submitted version.

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REFERENCES

- Access to Energy in Developing Countries (2002). *Parliamentary Office of Science and Technology*. Available online at: <https://www.parliament.uk/documents/post/pn191.pdf> (accessed July 5, 2020).
- Amigo-Jorquera, C., Guerrero-González, M. J., Sannazzaro, J., and Urquiza-Gómez, A. (2019). Does energy poverty have a female face in Chile? *Tapuya* 2, 378–390. doi: 10.1080/25729861.2019.1608038
- Betto, F., Garengo, P., and Lorenzoni, A. (2020). A new measure of Italian hidden energy poverty. *Energy Policy* 138:111237. doi: 10.1016/j.enpol.2019.111237
- Bhatia, M., and Angelou, N. (2015). *Beyond Connections Energy Access Rede_ned*. Technical Report. Washington, DC: Energy Sector Management Assistance Program; World Bank Group. doi: 10.1596/24368. Available online at: <https://openknowledge.worldbank.org/handle/10986/24368>
- BID (2016). *Luces Encendidas? Necesidades de Energía para América Latina y el Caribe al*. Washington, DC.
- BID (2020). *Calidad y Confiabilidad de los Servicios Eléctricos en América Latina*. Washington, DC.
- Boardman, B. (1991). *Fuel Poverty – from Cold Homes to Affordable Warmth*. London: Belhaven Press.
- Bouzarovski, S., and Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. *Energy Res. Soc. Sci.* 10, 31–40. doi: 10.1016/j.erss.2015.06.007
- Bouzarovski, S., Thomson, H., Cornelis, M., Varo, A., and Guyet, R. (2020). *Towards an Inclusive Energy Transition in the European Union: Confronting Energy Poverty Amidst a Global Crisis*, Publications Office of the European Union. Luxembourg.
- Bronfman, J. (2014). *Beyond Income: A Study of Multidimensional Poverty in Chile*. Munich: MPRA. Available online at: <https://mpra.ub.uni-muenchen.de/63256/>
- Contreras, S. (2019). *Vulnerabilidad energética en Montevideo y área metropolitana: conceptualización, medición y distribución*. TesisMaestría en Demografía y Estudios de Población - Montevideo: UR.FCS. Unidad Multidisciplinaria. Montevideo: Programa de Población.
- Crentsil, A. O., Asuman, D., and Fenny, A. P. (2019). Assessing the determinants and drivers of multidimensional energy poverty in Ghana. *Energy Policy* 133:110884. doi: 10.1016/j.enpol.2019.110884
- Culver, L. C. (2017). “The stanford natural gas initiative energy poverty: what you measure matters,” in: *Pre-symposium White Paper for Reducing Energy Poverty With Natural Gas: Changing Political, Business, and Technology Paradigms* (California, CA: Stanford University). Available online at: https://ngi.stanford.edu/sites/g/files/sbiybj14406/f/Reducing_Energy_Poverty_Symposium_Action_Paper_Final1.pdf
- Dehays, J., and Schuschny, A. (2019). *Pobreza Energética en América Latina y el Caribe: Una propuesta de indicadores que midan el acceso a la energía con enfoque de desigualdad social y de género*. Documento de Trabajo de OLADE -DTO 2019/008. Available online at: <http://biblioteca.olade.org/opac-tmpl/Documentos/old0430.pdf> (accessed January 8, 2020).
- Dirección General de Estadísticas, Encuestas y Censos (2020). *(DGEEC) Principales Resultados Departamental EPHC 2017-2019*. Asunción: Paraguay.
- Durán, R. J., and Condori, M. A. (2016). *Índice multidimensional de pobreza energética para Argentina: su definición, evaluación y resultados al nivel de departamentos para el año*. Buenos Aires: Asociación Argentina de Energías Renovables y Medio Ambiente (ASADES).
- Foster, V., Tre, J.-P., and Wodon, Q. (2000). *Energy Prices, Energy Efficiency, and Fuel Poverty*. World Bank Group, Technical Report.
- García Ochoa, R. (2014). *Pobreza energética en América Latina*. Santiago de Chile: United Nations.
- García Ochoa, R., and Graizbord, B. (2016a). Privation of energy services in Mexican households: An alternative measure of energy poverty. *Energy Res. Soc. Sci.* 18, 36–49. doi: 10.1016/j.erss.2016.04.014
- García Ochoa, R., and Graizbord, B. (2016b). Caracterización espacial de la pobreza energética en México. Un análisis a escala subnacional. *Econ. Soc. Territ.* 16, 289–337. doi: 10.22136/est002016465
- Giannini Pereira, M., Vasconcelos Freitas, M. A., and da Silva, N. F. (2011). The challenge of energy poverty: Brazilian case study. *Energy Policy* 39, 167–175. doi: 10.1016/j.enpol.2010.09.025
- González-Eguino, M. (2015). Energy poverty: an overview. *Renew. Sustain. Energy Rev.* 47, 377–385. doi: 10.1016/j.rser.2015.03.013
- Groh, S. (2014). The role of energy in development processes—The energy poverty penalty: Case study of Arequipa (Peru). *Energy Sustain. Dev.* 18, 83–99. doi: 10.1016/j.esd.2013.12.002
- Gwénaëlle, L., Ines, H., Nigel, B., and Sophie, B. (2009). *The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-saharan Africa*. New York, NY: Published by UNDP and WHO.
- Hernández, M. F., Aguado, L. F., and Duque, H. (2018). Índice de pobreza energética multidimensional por regiones para Colombia, ipem_rc 2013. *Econ. Coyuntural* 3, 35–72.
- Herrero, S. T. (2017). Energy poverty indicators: a critical review of methods. *Indoor Built Environ.* 26, 1018–1031. doi: 10.1177/1420326X17718054
- Hills, J. (2011). *Fuel Poverty: The Problem and Its Measurement*. London: London School of Economics and Political Science.
- IEA, IRENA, UNSD, World Bank, WHO (2020). *Tracking SDG 7: The Energy Progress Report*. Washington DC: World Bank.
- IEA, UNDP, and UNIDO (2010). *Energy Poverty — How to Make Modern Energy Access Universal? Special Early Excerpt of the World Energy Outlook 2010 for the UN General Assembly on the Millennium Development Goals*. Paris: International Energy Agency.
- International Energy Agency (2002). *World Energy Outlook 2002*. Paris: OECD; IEA.
- International Energy Agency (2011). *World Energy Outlook 2011*. Paris: OECD Publishing. doi: 10.1787/weo-2011-en

- International Energy Agency (IEA) (2011). *World Energy Outlook*. IEA, Paris.
- International Energy Agency (IEA) (2017). *World Energy Outlook 2017*. Paris: OECD Publishing, Paris/International Energy Agency.
- International Energy Agency (IEA) (2020). *Database*. Available online at: <https://www.iea.org/data-and-statistics> (accessed March 19, 2021).
- Jacinto, G. P., Carrizo, S. C., and Gil, S. (2018, October 3). Energía y pobreza en la Argentina. Instituto Argentino del Petróleo y el Gas, 26–30. Available online at: <https://ri.conicet.gov.ar/handle/11336/84629>
- Khanna, R. A., Li, Y., Mhaisalkar, S., Kumar, M., and Liang, L. J. (2019). Comprehensive energy poverty index: Measuring energy poverty and identifying micro-level solutions in South and Southeast Asia. *Energy Policy* 132, 379–391. doi: 10.1016/j.enpol.2019.05.034
- Khatib, H. (2011). IEA world energy outlook 2010—a comment. *Energy Policy* 39, 2507–2511. doi: 10.1016/j.enpol.2011.02.017
- Legendre, B., and Ricci, O. (2015). Measuring fuel poverty in France: Which households are the most fuel vulnerable? *Energy Econ.* 49, 620–628. doi: 10.1016/j.eneco.2015.01.022
- Mirza, B., and Szirmai, A. (2010). *Towards a New Measurement of Energy Poverty: A Cross-Community Analysis of Rural Pakistan*. United Nations University, Maastricht Economic and social Research and training centre on Innovation and Technology, UNU-MERIT Working Paper Series. Maastricht.
- Moore, R. (2012). Definitions of fuel poverty: implications for policy. *Energy Policy* 49, 19–26. doi: 10.1016/j.enpol.2012.01.057
- Nathan, H. S. K., and Hari, L. (2020). Towards a new approach in measuring energy poverty: household level analysis of urban India. *Energy Policy* 140:111397. doi: 10.1016/j.enpol.2020.111397
- Nussbaumer, P., Bazilian, M., and Modi, V. (2012). Measuring energy poverty: focusing on what matters. *Renew. Sustain. Energy Rev.* 16, 231–243. doi: 10.1016/j.rser.2011.07.150
- Okushima, S. (2017). Gauging energy poverty: a multidimensional approach. *Energy* 137, 1159–1166. doi: 10.1016/j.energy.2017.05.137
- Organización Latinoamericana de Energía (OLADE) (2020). *Precios de la Energía en América Latina y el Caribe: Informe Anual*. Quito.
- Pachauri, S., Mueller, A., Kemmler, A., and Spreng, D. (2004). On measuring energy poverty in Indian households. *World Dev.* 32, 2083–2104. doi: 10.1016/j.worlddev.2004.08.005
- Pachauri, S., and Spreng, D. (2011). Measuring and monitoring energy poverty. *Energy Policy* 39, 7497–7504. doi: 10.1016/j.enpol.2011.07.008
- Practical Action (2012). *Poor People's Energy Outlook 2012. Energy for Earning a Living*. Warwickshire: Practical Action Publishing Ltd. doi: 10.3362/9781780440651.000
- Quishpe, P., Paloma, T. L. P., and Francisco, J. T. (2019). Energy poverty in Ecuador. *Sustainability* 11:6320. doi: 10.3390/su11226320
- Red de Pobreza Energética (RedPE) (2018). *Medir Pobreza Energética: Alcances y Limitaciones de Indicadores Internacionales para Chile*. Santiago de Chile: Documento de Trabajo.
- Reddy, A. (2000). *Energy and Social Issues. World energy council and UNEP Energy and the Challenge of Sustainability*. New York, NY: United Nations Development Programme Bureau for Development Policy One United Nations Plaza. Available online at: <https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=2423&menu=35>
- Rocha, J. D., and Schuschny, A. (2018). *Una propuesta de indicadores para medir la pobreza energética en América Latina y el Caribe*. Quito: Organización Latinoamericana de Energía (OLADE).
- Sadath, A. C., and Acharya, R. H. (2017). Assessing the extent and intensity of energy poverty using multidimensional energy poverty index: empirical evidence from households in India. *Energy Policy* 102, 540–550. doi: 10.1016/j.enpol.2016.12.056
- Santillán, O. S., Cedano, K. G., and Martínez, M. (2020). Analysis of energy poverty in 7 Latin American countries using multidimensional energy poverty index. *Energies* 13:1608. doi: 10.3390/en13071608
- Teller-Elsberg, J., Sovacool, B., Smith, T., and Laine, E. (2016). Fuel poverty, excess winter deaths, and energy costs in Vermont: burdensome for whom? *Energy Policy* 90, 81–91. doi: 10.1016/j.enpol.2015.12.009
- Urquiza, A., Amigo, C., Billi, M., Calvo, R., Labraña, J., Oyarzún, T., et al. (2019). Quality as a hidden dimension of energy poverty in middle-development countries. Literature review and case study from Chile. *Energy Build.* 204:109463. doi: 10.1016/j.enbuild.2019.109463
- Vice-Ministerio de Minas y Energía (VMME) (2020). *Balance Energético Nacional 2019, Asunción, Paraguay*. World Bank database.
- Villalobos Barria, C., Chávez Rebolledo, C., and Uribe, A. (2019). *Energy Poverty Measures and the Identification of the Energy Poor: A Comparison Between the Utilitarian and Multidimensional Approaches in Chile (No. 243)*. IAI Discussion Papers. Göttingen. doi: 10.2139/ssrn.3564827

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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