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Measurement of energy poverty in the Colombian Caribbean region: a comparative analysis

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ABSTRACT

This research work is directed to analyze the level of energy poverty and its consequences on the quality of life of the population of the Colombian Caribbean region, by doing a comparison of the results obtained in that area with data regarding the population of Bogotá, capital of Colombia, and of the rest of the country. The method of meeting absolute energy needs was used to determine the energy poverty index at households (EPH). Results obtained indicate that EPH exceeds 60% in urban areas, and 96% in rural zones, where it was also evidenced a clear link between energy poverty and school dropout.

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1. INTRODUCTION

Lack of access and low quality of electrical energy supplied to a home to cover the basic needs of its occupants constitute a dimension of energy poverty, including indicators like coverage of electricity, cost of such energy, and possession of economic goods related to the final use of electricity [1]–[3]. The concept of energy poverty emerged in the United Kingdom during the 1980s, taking into account the inhabitants´ difficulties in keeping adequate heating in their homes during the winter, seasons in which the number of people affected by respiratory diseases increases [4], [5]. In 1991, Boardman stated that a household faces an energy poverty situation when the cost of paying energy bills exceeds 10% of the family income [6]. Therefore, energy-poor families are increasingly vulnerable, since people's quality of life is affected when they are forced to reduce their energy consumption [7].

In [8], it is stated that a household presents energy poverty when the sum of the total income of its inhabitants is below 60% of the national average income, and the necessary expenses to achieve thermal comfort are above the average level. In this way, energy poverty is defined as “Inability of a household to meet the cost of its basic energy needs” [4]. Furthermore, energy poverty varies according to a country’s level of development and geographical location. In developed countries, with high percentage of families having access to electrical energy, this indicator focuses on the inability to keep thermal comfort at household, while in developing countries that indicator is focused on the lack of connection to the electricity service.

Currently, 1,300 million people do not have access to electricity at their homes [4]. Consequently, measuring energy poverty is essential for formulating and implementing governmental policies for social and economic development. However, in Colombia, there is no statistical information on the subject, for that reason, this study focuses on analyzing the level of energy poverty and its consequences on the quality of life of the urban and rural population in the Caribbean region. Data from that region and from the rest of the country are compared with the aim of analyzing energy poverty behavior in Colombia. Results obtained can be used by decision-makers for them to have enough elements to develop plans and strategies directed to reduce and eliminate energy poverty [9], [10].

Electric power improves the inhabitants' quality of life by facilitating access to education, health, drinking water, and to many other benefits. Furthermore, the physical connection only to the electricity grid is not enough, since electricity must be affordable, efficient, reliable, and safe. On the other hand, an expensive and low-quality electricity service encourages families to take measures that may affect their health and well-being if using energy substitutes without fulfilling the minimum standards and necessary requirements [11], [12].

Economic and social growth leads to increase energy consumption, and, as there is a close relationship between poverty reduction and improvement in energy services [13], the link between electricity consumption and economic growth is expanded to the human development index (HDI) and the gross domestic product (GDP) per capita because these indicators are directly related to energy consumption. Over time, the role of access to electricity in a nation's development has started to be better understood. The interest of governments to expand coverage to the most remote areas of their territories has increased and given rise to international initiatives, such as "Sustainable energies for all," designed by the United Nations Organization, seeking to guarantee universal access to modern energies by 2030. In 2010, a European Commission recognized that "…energy poverty, which can deprive households, not only of heating or cooling, but also hot water, electricity, and other essential domestic needs, is another manifestation of severe deprivation."

The main obstacles for a country to have full coverage of the electricity system are not concentrated in financing or designing the system itself, but in the absence of efficient institutions, government transparency, and appropriate regulations [14], [15]. Governments often excessively focus on reducing energy poverty by means of energy subsidies, instead of implementing improvements in the electrical services efficiency, and energy consumption reductions, leading, consequently, to subsidy reduction [16]–[18].

According to social priorities, energy scenarios of each territory help in the process of decision-making regarding the transformation of the energy supply system based on sustainability and renewable energy sources [14]. Nowadays, energy is regarded as a strategic problem [15], manage and supplied by centralized management, where, neither the local endogenous potentialities are adequately appreciated, nor the alternatives for taking advantage of the local energy resources, a situation mainly accentuated in the poorest territories [16].

The present document is grouped into five sections. The first one consists of a literary review of energy poverty, including its importance, and consequences for the population. The methodology used to characterize the energy landscape and the measurement of energy poverty according to [19] is given in the second section. The third one shows the results obtained with the methods used, while a discussion about the implications of energy poverty in the population of the Caribbean region is given in the fourth section. At the end, the conclusions are detailed taking into account the results obtained.

2. RESEARCH METHOD

The lack of reliable statistics necessary for developing indicators, actions, and plans to reduce energy poverty is one of the main obstacles to measuring this important index since those indicators constitute tools for communicating and understanding energy problems, as well as for allowing institutions to develop necessary policies to solve and reverse the situation [1], [20]. In Colombia, the quality of the electricity supply is quantified by the system of average interruption frequency index (SAIFI) and system of average interruption duration index (SAIDI), which allow calculating the average frequency and duration of interruptions that users have in each period [21]. Analysis of the percentage of income households dedicated to paying energy bills is in correspondence to the approach of [6]. In general, prospects for improving and supplying energy to the different departments of the Caribbean region are not good, mainly because of no public policies to help in solving this situation. Additionally, families must allocate a high percentage of their income to pay energy bills in those departments, no matter having few electrical appliances to meet their basic needs [22], [23].

In the region under study, the energy poverty index at household (EPH) was calculated using expression (1). Obtained from the method to meet energy needs described in [19].

$$EPH = \frac{1}{n}\sum_{i=1}^{n} BE_i < 1 \quad (1)$$

where *EPH* is energy poverty index at household, *Bei* is economic good *i*, and *n* is number of economic goods.

According to [19], the EPH index will be less than 100% when a household lacks some essential economic goods to satisfy its absolute energy needs. The number of goods (*n*) will change in relation to the geographical region where the household is located, so value *n* in the equation will vary in every locality where that index is applied. Figures for electricity coverage and possession of economic goods were extracted from the great integrated household survey (GIHS) of the National Administrative Department of Statistics (DANE) for 2018, reflecting the real situation of every department, whether in urban or rural areas.

The SAIDI and SAIFI indexes were provided by the single information system of home public services in September 2018. Data for analyzing income and expenses in energy bills were extracted from the survey of monetary and multidimensional poverty in Colombia of the DANE for 2018, where the average per capita income was determined not only in the capital but also in every department of the country. Figures obtained were multiplied by the number of people living in a household, taking into account an average of 3.8 in the departments of the Caribbean region, 3.1 in Bogotá, and 3.3 in the rest of the country, resulting, in this way, the average monthly income of the departments and the household members. The average monthly income of families in the Caribbean region, Bogotá, and the rest of the country was determined by using the income and expense approach [6]. Values of the average monthly bills for electricity service during 2018 are shown in Table 1.

According to Table 1, the average value of the monthly income Colombians need for paying electricity service bills is 5.2%, a proportion lower than the 10% threshold proposed in [6]. Households in Bogotá have the lowest expenditure on electricity service bills in the country, with 2.3% of their income. However, all departments of the Caribbean region, except the Atlantic, confront energy poverty since more than 10% of the monthly income is spent on paying electricity bills, exceeding both, the Boardman limit, and the national average.

Table 1. Comparing the average monthly income with the average monthly energy bill for electricity service

Department	Average monthly Income ($)	Average monthly energy bill ($)	Monthly energy expenditure (% of income)
Atlántico	2,216,308	185,205	8.4
Bolívar	1,690,856	167,255	10
Cesar	1,551,114	193,584	12.5
Córdoba	1,302,097	190,464	14.6
La Guajira	1,335,320	136,863	10.2
Magdalena	1,350,809	154,240	11.4
Sucre	1,396,819	149,189	10.7
Bogotá	3,263,035	74,531	2.3
National Average	2,061,827	108,292	5.2

3. RESULTS

According to figures from the GIHS, in 2018 the urban areas of Bogotá, the Caribbean region departments, and all the others of the country, had 99.8% of electricity coverage, while in rural areas, the behavior was completely different. In La Guajira, 44.6% of the rural population does not have an electrical connection, while in Bolívar and Cesar, the coverage deficit at households reaches 18.8% and 26.6%, respectively. Córdoba with 0.7%, Atlántico with 6.4%, and Sucre with 6.6% are the only departments in the Caribbean Region below the national average of 6.8% as shown in Figure 1.

In the departments of the Caribbean region, 72.5 power outages were recorded, with a total duration of 66.5 hours between January and September 2016 [21]. As shown in Figure 2, Córdoba is the department with the most extended duration of electricity service interruptions, with 11.1 hours during September. Negative behavior is also observed in Magdalena and Sucre when compared to the national average, with 9.7 and 8.7 hours, respectively, while lower values are reported in the other departments of the Caribbean region.

Figure 3 shows that, following Córdoba, with 13.8 times electrical interruptions, Magdalena, with an average of 11 times, is the second department with the highest frequency of interruptions. Sucre follows with an average of 10.6 times, and Cesar with a value of 9.5. Electricity service interruptions in these four departments are above the national average frequency of 9.19 times.

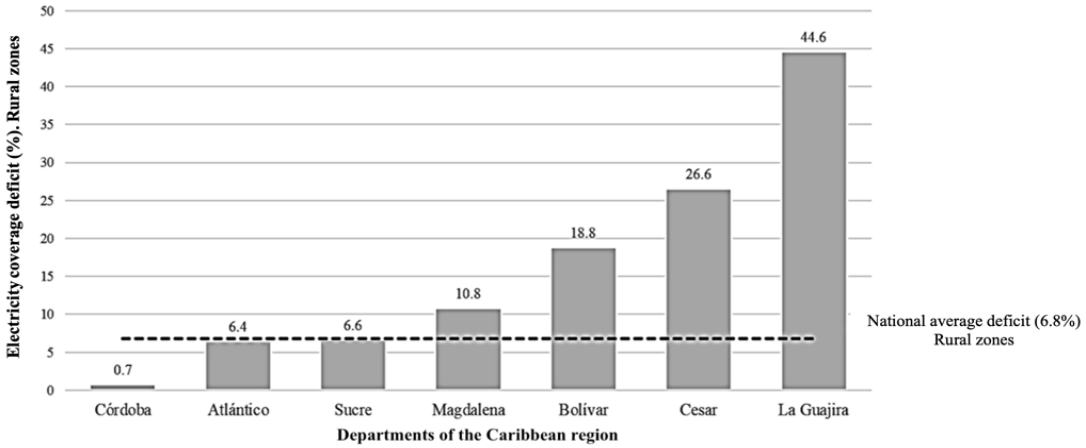

Figure 1. Electricity coverage deficit in rural areas of departments of the Caribbean region compared to the national average deficit

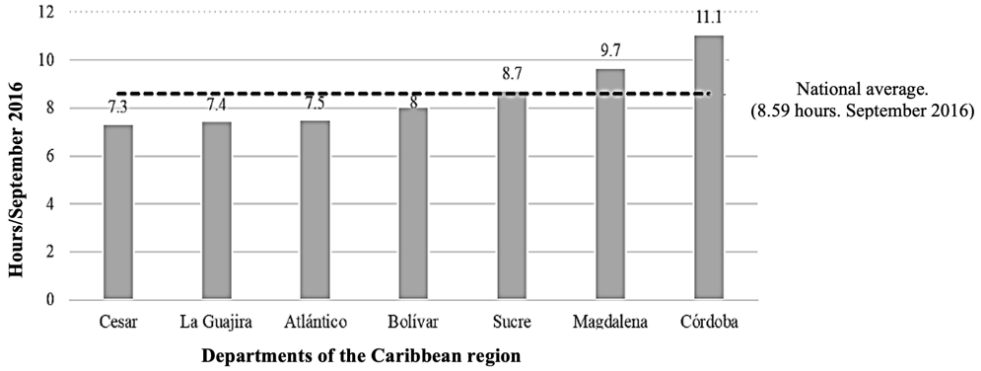

Figure 2. Duration of electricity service interruptions in the Caribbean region compared to the national average

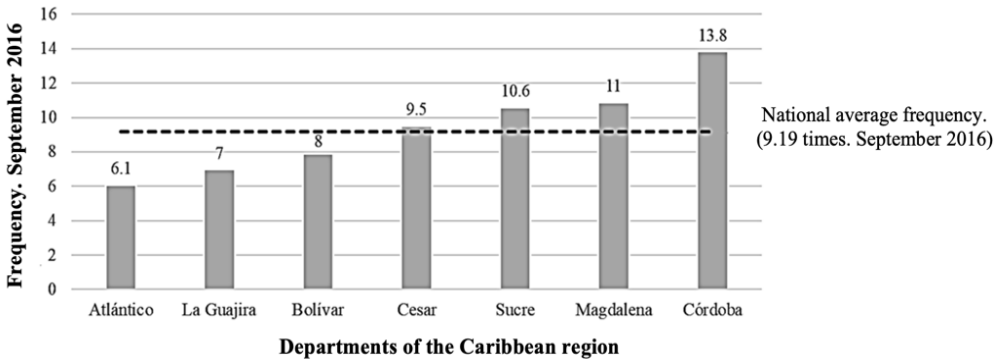

Figure 3. Frequency of electricity service interruptions in the Caribbean region compared to the national average

3.1. Energy poverty index at household

Results of calculating the EPH index in 2018 in many urban areas of the departments of the Caribbean region when compared to the national average are shown in Figure 4. More than 60% of households in the Colombian Caribbean urban areas report energy poverty. Atlántico is the only department having EPH values below the national average.

Figure 5 shows the geographical distribution of the different departments of the Caribbean region and the percentage of energy poverty in each department. Sucre has the most critical situation, with an EPH index of 81%. The Atlántico Department reports 64%, being the only one below the national average of 67.8%.

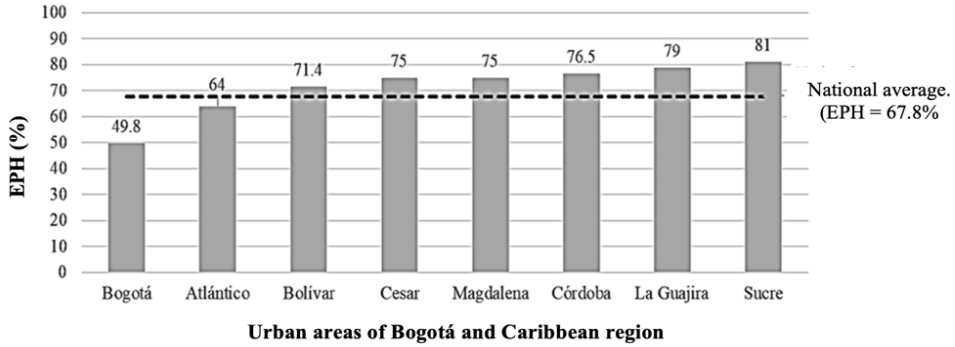

Figure 4. Energy poverty index at households (EPH) in urban areas of Bogotá and Caribbean region compared to the national average

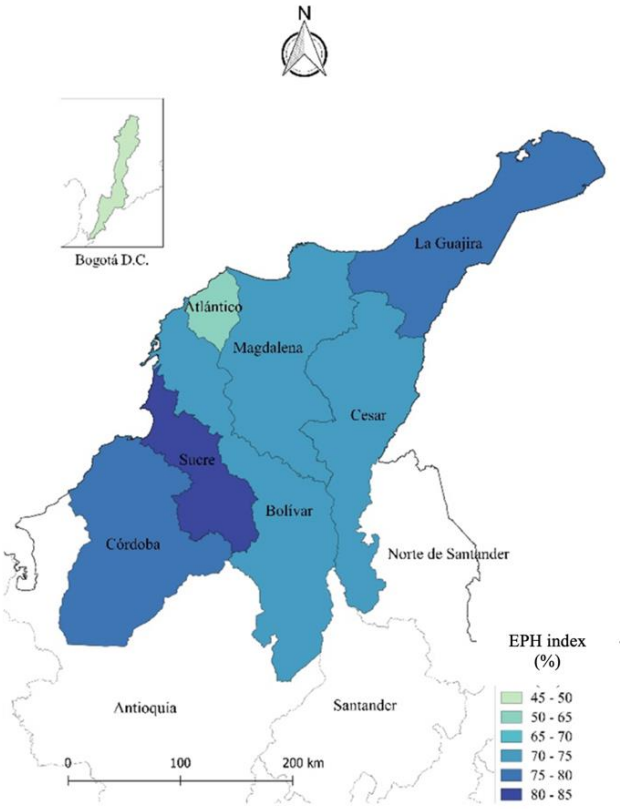

Figure 5. EPH index in urban areas of the Caribbean region

Regarding the EPH index in rural areas, the situation is really alarming in comparison with the national average of 90.52%. Analysis showed that all departments of the Caribbean region report levels above that number. The lowest EPH value (96%) is reported in the Atlántico Department, while Sucre presents the highest value (98.5%) as shown in Figure 6.

Figure 7 shows that in all departments of the Caribbean region, the percentage of the EPH index is high. Sucre has the most critical situation with an index of 98.54%. The Atlántico Department reports, no matter high, the lowest EPH index (96.03%).

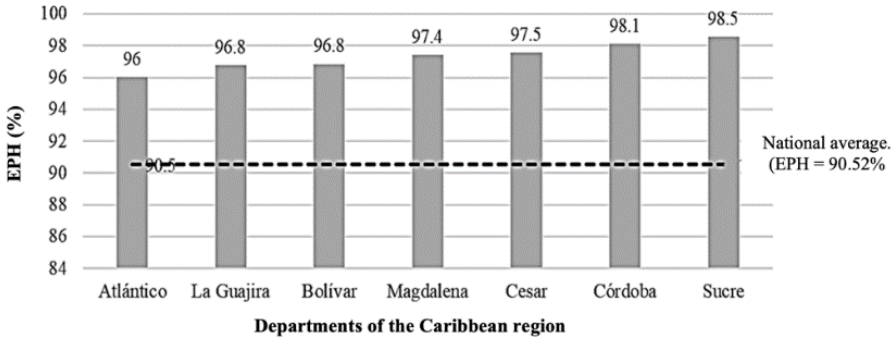

Figure 6. EPH index in rural areas of the Caribbean region compared to the national average

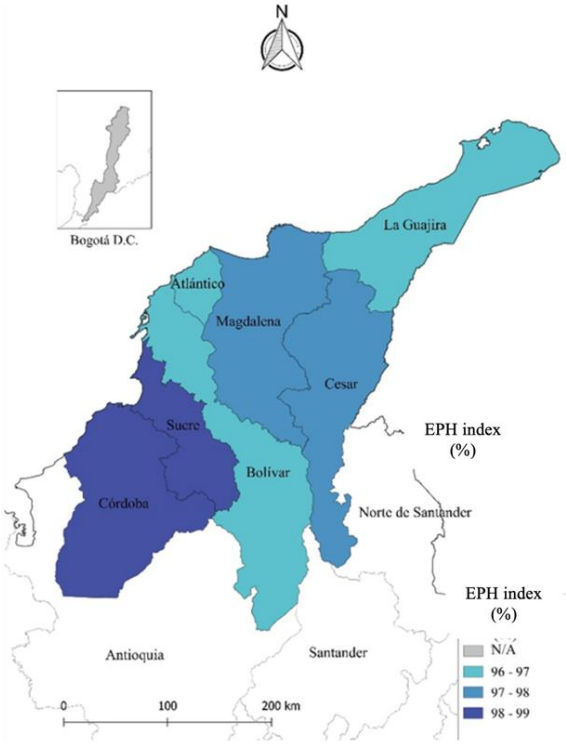

Figure 7. Households in rural areas of the Caribbean region with energy poverty

3.2. Links between EPH and school dropout

A low index of energy poverty in households may lead to poor conditions for guaranteeing adequate education, for example, low or poor lighting quality, thermal comfort, use of the computer, and different technological devices, among others. For those reasons, it may be difficult to study, increasing the possibility of school dropout [24], [25]. The DANE Formal Education Survey [26] recorded the number of students who left school in both, urban and rural institutions, and from preschool to high school, Table 2. In general, the dropout rate in rural areas exceeds that of urban areas, with departments of Sucre and Magdalena having the highest school dropout rates in the Caribbean Region.

Using the data obtained, a linear regression was adjusted by ordinary least squares (OLS) between the school dropout rate and the percentage of the population in energy poverty in rural areas of the Caribbean departments. Table 3 shows the regression results, indicating that energy poverty significantly increases the student dropout rate. Living in rural areas, although not statistically significant, has also influenced school dropout.

The previous results correspond to studies [27]–[33], stating that access to an electrical service of high quality, combined with possession of economic goods which satisfy basic needs, is essential to have access to education, favoring the creation of a comfortable environment to improve academic performance

and to reduce household expenses on inefficient fuels, in increasing, as a result, family possibilities to invest in education for all its members, mainly for children and youngsters.

Table 2. The school dropout rate in urban and rural zones of departments of the Caribbean region and Bogotá compared to the national average

Department	Urban Zone	Rural Zone
	School dropout rate (%)	School dropout rate (%)
Atlántico	3.3	3.5
Bolívar	3.4	4.4
Cesar	3.0	4.0
Córdoba	3.7	3.9
La Guajira	3.6	3.3
Magdalena	3.2	4.5
Sucre	4.9	5.5
Bogotá	2.2	1.3
National Average	3.2	4.2

Table 3. Result of the simple linear regression between the school dropout rate and energy poverty in rural zones

	Coefficient	Standard error	p-value
EPH	0.034	0.007	0.001
Rural zone	0.014	0.362	0.778

4. DISCUSSION

The absence of electrical connection in 117,213 homes in the Caribbean region leads to energy poverty and low quality of life since those families cannot meet their basic energy needs. When applying the SAIDI and SAIFI indicators, results showed adverse effects on productivity and on the inhabitants' quality of life due to frequent and prolonged electricity interruptions, which affected, at the same time, many economic, social, commercial, and industrial activities.

According to the approach of [4], the higher the percentage of income a family spends on electricity bills, the more difficulties it will have to guarantee minimum comfort. At a national level, households in the capital, having higher income levels, spend only 2.3% on electricity bills. In the Caribbean region, the Atlántico Department presents the lowest bill spending, only 8.4%, and the highest income in the area, being both above the national average. On the contrary, Córdoba and Magdalena's departments present the last positions in terms of bill payment, having one of the highest levels of energy expenditure, with 14.6% and 11.4%, respectively.

The figures for possession of home appliances show gaps in the quality of life between urban and rural families. While many families living in urban areas have adequate equipment for cooking and refrigerating food, entertainment, thermal comfort, and access to ICTs, families living in rural areas have a low percentage of devices and home appliances.

Rural households which cook with fuels derived from biomass and do not refrigerate their food are more likely to suffer from diseases of the digestive and respiratory systems, caused by food decomposition and the harmful gases emitted by burning those kinds of fuels. In 2016, respiratory tract infections were among the ten main causes of death in urban and rural areas in Colombia, with 15.73 and 9.76 people per 100,000 inhabitants, respectively [27]. This type of risk to people in rural areas is in correspondence to a higher EPH index, exceeding 96% in the Caribbean region, because of the lack of essential home appliances.

The Atlántico Department has the best situation in the Caribbean region, with a coverage deficit of 6.4%, rare electricity interruptions, and the highest percentage of households in urban and rural areas with good means for cooking, entertainment, and thermal comfort, among others. Consequently, that department reports the lowest urban and rural EPH indexes in the entire region, being below the national average in urban areas, and the least number of students who dropped out of their studies in rural areas. In contrast, the La Guajira department has the second-highest urban EPH in the region, with 79%, and 96.8% in rural zones. Additionally, La Guajira presents the most significant school dropout in rural areas, with 5,489 cases in 2016.

5. CONCLUSION

The high levels of energy poverty in urban and rural areas of the Caribbean region represent an obstacle to improving the inhabitants' quality of life because their basic needs, such as food, health, education, free time, and social activities are directly affected. Daily life is very difficult for people who do not have an

electrical connection or have a low-quality service, apart from the negative effects on their income, personal and family development, and the sustainable progress of the territory. A direct relationship between energy poverty and school dropout is mainly due to the lack of minimum necessary conditions to encourage children and young people to feel comfortable with their studies, favoring school dropout.

Results of this study show the existence of energy poverty in all departments of the Caribbean region, having the most significant impact in the rural areas, where more than 96% of the households present deprivation in their basic energy needs, exceeding the 90.7% of the national average, which is a high value. Therefore, formulation and implementation of governmental policies and strategies in the Caribbean region are essential to expand, access, coverage, and quality improvement of the electricity service. In that way, the gap existing in the quality of life of inhabitants of the Colombian Caribbean region in relation to the population of the rest of the country can be reduced.

REFERENCES

[1] P. Nussbaumer, M. Bazilian, and V. Modi, "Measuring energy poverty: Focusing on what matters," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 231–243, Jan. 2012, doi: 10.1016/j.rser.2011.07.150.

[2] G. Pereira, A. Gonzalez, and R. Rios, "Energy poverty in Paraguay: A multidimensional approach," in *2020 IEEE Congreso Bienal de Argentina (ARGENCON)*, Dec. 2020, pp. 1–8, doi: 10.1109/ARGENCON49523.2020.9505489.

[3] S. M. Chaudhry and M. Shafiullah, "Does culture affect energy poverty? Evidence from a cross-country analysis," *Energy Economics*, vol. 102, Oct. 2021, doi: 10.1016/j.eneco.2021.105536.

[4] CEPA and IndEP, "Effect of increases tariffs in the homes of the Metropolitan region (in Spanish Efecto de los incrementos tarifarios en los hogares de la Región Metropolitana)," *CEPA and IndEP*, 2017. Accessed: Jan. 20, 2022. [Online], Available: http://www.iade.org.ar/system/files/pobreza-energetica-efectos-de-los-incrementos-tarifarios-en-la-region-metropolitana_0.pdf ()

[5] R. García Ochoa and B. Graizbord Ed, "Privation of energy services in Mexican households: An alternative measure of energy poverty," *Energy Research and Social Science*, vol. 18, pp. 36–49, Aug. 2016, doi: 10.1016/j.erss.2016.04.014.

[6] B. Boardman, *Fuel poverty: from cold homes to affordable warmth*. Pinter Pub Limited, 1991.

[7] K. Chabhadiya, R. Ranjan Srivastava, and P. Pathak, "Growth projections against set-target of renewable energy and resultant impact on emissions reduction in India," *Environmental Engineering Research*, vol. 26, no. 2, Apr. 2020, doi: 10.4491/eer.2020.083.

[8] M. Rodríguez-Gámez, A. Vázquez-Pérez, G. A. Loor-Castillo, J. M. Guerrero, C. G. Villacreses-Viterí, and J. R. Núñez Alvarez, "Energy repowering using photovoltaic microgrids-a case study in the Province of Manabí in ecuador," *International Journal on Engineering Applications (IREA)*, vol. 10, no. 3, May 2022, doi: 10.15866/irea.v10i3.20485.

[9] J. D. Healy, *Housing, fuel poverty and health: A Pan-European analysis*. Taylor and Francis Group, 2004.

[10] A. V. Prieto, J. García-Estévez, and J. F. Ariza, "On the relationship between mining and rural poverty: Evidence for Colombia," *Resources Policy*, vol. 75, Mar. 2022, doi: 10.1016/j.resourpol.2021.102443.

[11] D. Malerba, "Poverty alleviation and local environmental degradation: An empirical analysis in Colombia," *World Development*, vol. 127, Mar. 2020, doi: 10.1016/j.worlddev.2019.104776.

[12] H. Thomson and C. Snell, "Quantifying the prevalence of fuel poverty across the European Union," *Energy Policy*, vol. 52, pp. 563–572, Jan. 2013, doi: 10.1016/j.enpol.2012.10.009.

[13] J. Yao, E. Xiao, X. Jian, and L. Shu, "Service quality and the share of renewable energy in electricity generation," *Utilities Policy*, vol. 69, Apr. 2021, doi: 10.1016/j.jup.2020.101164.

[14] A. Cotte Poveda and C. I. Pardo Martínez, "Trends in economic growth, poverty and energy in Colombia: long-run and short-run effects," *Energy Systems*, vol. 2, no. 3–4, pp. 281–298, Nov. 2011, doi: 10.1007/s12667-011-0036-7.

[15] M. Bazilian *et al.*, "Improving access to modern energy services: insights from case studies," *The Electricity Journal*, vol. 25, no. 1, pp. 93–114, Jan. 2012, doi: 10.1016/j.tej.2012.01.007.

[16] E. V. M. Merchán, M. D. V. Gutiérrez, D. A. M. Montenegro, J. R. N. Alvare, and J. W. G. Guerrero, "An analysis of electricity generation with renewable resources in Germany," *International Journal of Energy Economics and Policy*, vol. 10, no. 5, pp. 361–367, Aug. 2020, doi: 10.32479/ijeep.9369.

[17] K. Kaygusuz, "Energy services and energy poverty for sustainable rural development," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 2, pp. 936–947, Feb. 2011, doi: 10.1016/j.rser.2010.11.003.

[18] J. Nathwani and D. M. Kammen, "Affordable energy for humanity: a global movement to support universal clean energy access," *Proceedings of the IEEE*, vol. 107, no. 9, pp. 1780–1789, Sep. 2019, doi: 10.1109/JPROC.2019.2918758.

[19] M. Hassan *et al.*, "Removal of antibiotics from wastewater and its problematic effects on microbial communities by bioelectrochemical Technology: Current knowledge and future perspectives," *Environmental Engineering Research*, vol. 26, no. 1, Feb. 2020, doi: 10.4491/eer.2019.405.

[20] UN, "Energy poverty in Latin America (in Spanish Pobreza energética en América Latina)," United Nations, 2014. https://www.cepal.org/es/publicaciones/36661-pobreza-energetica-america-latina (accessed Jan. 02, 2022).

[21] A. Arsenopoulos, V. Marinakis, K. Koasidis, A. Stavrakaki, and J. Psarras, "Decision support tools for energy efficiency obligated parties towards energy poverty alleviation," in *2020 11th International Conference on Information, Intelligence, Systems and Applications (IISA*, Jul. 2020, pp. 1–6, doi: 10.1109/IISA50023.2020.9284363.

[22] M. A. Bashar, R. Nayak, K. Astin-Walmsley, and K. Heath, "Machine learning for predicting propensity-to-pay energy bills," *Intelligent Systems with Applications*, vol. 17, Feb. 2023, doi: 10.1016/j.iswa.2023.200176.

[23] D. Rodríguez-Urrego and L. Rodríguez-Urrego, "Photovoltaic energy in Colombia: Current status, inventory, policies and future prospects," *Renewable and Sustainable Energy Reviews*, vol. 92, pp. 160–170, Sep. 2018, doi: 10.1016/j.rser.2018.04.065.

[24] K. Palomino, F. Reyes, J. Núñez, G. Valencia, and R. H. Acosta, "Wind speed prediction based on univariate ARIMA and OLS on the Colombian Caribbean coast," *Journal of Engineering Science and Technology Review*, vol. 13, no. 3, pp. 200–205, 2020, doi: 10.25103/jestr.133.22.

[25] R. Anguzu *et al.*, "Household poverty, schooling, stigma and quality of life in adolescents with epilepsy in rural Uganda," *Epilepsy & Behavior*, vol. 114, Jan. 2021, doi: 10.1016/j.yebeh.2020.107584.

[26] R. Debnath *et al.*, "Words against injustices: A deep narrative analysis of energy cultures in poverty of Abuja, Mumbai and Rio de Janeiro," *Energy Research and Social Science*, vol. 72, Feb. 2021, doi: 10.1016/j.erss.2020.101892.

[27] D. J. Roncancio, S. L. Cutter, and A. C. Nardocci, "Social vulnerability in Colombia," *International Journal of Disaster Risk Reduction*, vol. 50, Nov. 2020, doi: 10.1016/j.ijdrr.2020.101872
[28] M. Gomathinayagam and S. Balasubramanian, "Various demand side management techniques and its role in smart grid-the state of art," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 1, pp. 150–156, Feb. 2022, doi: 10.11591/ijece.v12i1.pp150-156.
[29] R. Day, G. Walker, and N. Simcock, "Conceptualising energy use and energy poverty using a capabilities framework," *Energy Policy*, vol. 93, pp. 255–264, Jun. 2016, doi: 10.1016/j.enpol.2016.03.019.
[30] C. Quispe, "Quality of the electrical service of the Peruvian electrical system in comparison with international countries through data envelope analysis," in *2022 5th Asia Conference on Energy and Electrical Engineering (ACEEE)*, Jul. 2022, pp. 18–22, doi: 10.1109/ACEEE56193.2022.9851870.
[31] M. D. Faraby, O. Penangsang, R. S. Wibowo, and A. Fitriati, "Coordinated planning in improving power quality considering the use of nonlinear load in radial distribution system," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 6, pp. 4610–4621, Dec. 2021, doi: 10.11591/ijece.v11i6.pp4610-4621.
[32] F. G. Merconchini, L. V. Seisdedos, J. C. Oliva, J. R. N. Alvarez, and D. Checa-Cervantes, "Study of electric power quality indicators by simulating a hybrid generation system," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 2, pp. 1044–1054, Jun. 2023, doi: 10.11591/ijpeds.v14.i2.pp1044-1054.
[33] M. Rodríguez Gámez, A. Vázquez Pérez, M. Torres Pérez, and J. R. Núñez Alvarez, "Local development applied to the energy scheme using the geographic information system for decision making," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 12, no. 4, pp. 3343–3351, Aug. 2022, doi: 10.11591/ijece.v12i4.pp3343-3351.

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