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Using Data Sciences for Analyzing Residential Electricity Consumption in Marginalized Mexican Municipalities

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Abstract. In Mexico, the municipal marginalization index is used as a fundamental tool for planning and formulating public policies aimed at improving the socioeconomic conditions of the population. However, one of the limitations of this index is its exclusion of residential electricity consumption. In this regard, the present study explores the relationship between electricity consumption and the marginalization index. The research was conducted following the methodological framework of Data Science. As a result, geographic areas that cover municipalities with similar levels of residential electricity consumption were identified and characterized. An inverse correlation was found between such consumption and marginalization index. Finally, this research could improve decision-making processes in public policies aimed at reducing economic and social inequalities, thereby fostering more equitable development of the most disadvantaged municipalities.
Keywords: Data Science, Geospatial Analysis, Electricity Consumption, Marginalization Index.

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1 Introduction

In science, we work with data, whether qualitative or quantitative, primary or secondary. Data scientists analyze data to derive conclusions that advance knowledge. In this work, we integrate data management and scientific knowledge to provide innovative and cutting-edge solutions that can contribute to decision-making.

With approximately 130 million inhabitants, a favorable geography, privileged position, rich cultural heritage, and abundant natural resources, Mexico ranks among the fifteen largest economies in the world and is the second most competitive in Latin America (Schuwab, 2019; World Bank, 2025). However, the socioeconomic development of the population is unequal, resulting in social groups that do not enjoy the benefits of development and have also accumulated certain disadvantages and deficiencies, which negatively impact the quality of life of individuals.

To differentiate the impact experienced by a population as a result of lack of access to education, living in inadequate housing, having insufficient income, and residing in small localities, Mexico began measuring its marginalization index since the 1990s, using data from the National Institute of Statistics and Geography (INEGI). The marginalization index is a tool to differentiate states and municipalities according to the overall impact of population needs (Consejo Nacional de Población, 2020).

Within the context of marginalization, the characterization of the dwelling houses includes the following forms of exclusion: lack of sanitary drainage, absence of running water, dirt floors and overcrowding. In terms of electricity, only “no electricity” variable is included. However, some homes may have such low electricity consumption that it does not cover the basic human development needs. Despite this, these cases are not included in the calculation of the marginalization index.

Recognizing this limitation, this study provides a geospatial characterization of electricity consumption in Mexican households and its relationship with marginalization index, climatic factors and urban or rural population distribution. For this purpose, we use a Data Science methodological approach to identify additional patterns of exclusion, which will help to guide public policies aimed at improving living conditions of marginalized communities and groups.

2 Experimental procedures

The structured approach of the Data Science methodology (Rollins, 2015) allows complex problems to be addressed and solved through the use of data. Fig. 1 presents the guiding process used as the foundational strategy in this study.

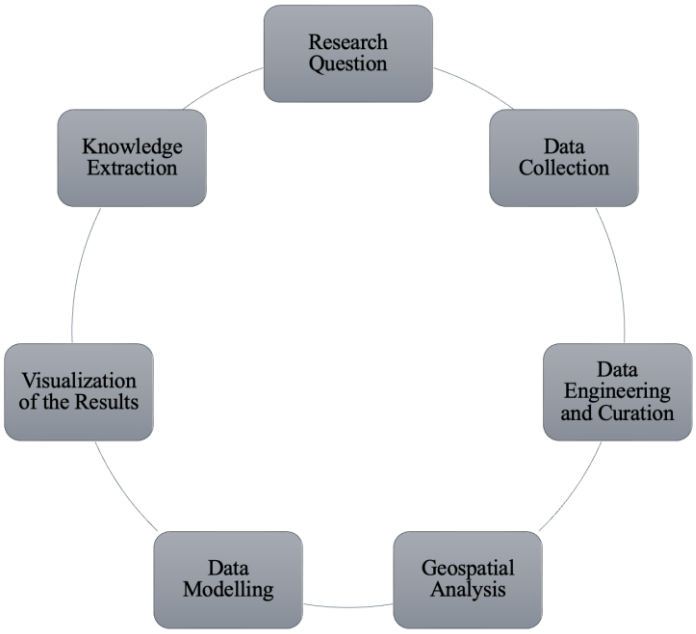

Fig. 1. Data Science Methodological Strategy.

2.1 Data Science Methodology

In the following subsections, the steps of the Data Science methodology are described in a general way, as shown in Fig. 1.

Research Question. The research question clearly identifies the objective of the study. ¿What is the relationship between residential electricity consumption and marginalization index at the municipal level in Mexico?

Data Collection. The analysis focuses on 2020, aligned with the latest Census and marginalization index report (Instituto Nacional de Estadística, Geografía e Informática, 2024; Consejo Nacional de Población, 2020). It is important to mention that electricity consumption in homes experienced significant fluctuations in this year due to COVID-19 pandemic restrictions, mainly reflecting an increase from lockdown measures (González-López & Ortiz-Guerrero, 2022). The source of data on electricity consumption was the Federal Electricity Commission (CFE) by request through the National Transparency Platform (Comisión Federal de Electricidad, 2023a). The electrical consumption of the dwelling house was classified according to the (Comisión Federal de Electricidad, 2023b).

Data Engineering and Curation. The 2020 National Census of Population and Housing yielded data of 2,469 municipalities in total, but only 2,463 have electricity consumption and marginalization index, corresponding to 125,822,502 inhabitants, representing 99.84% of the total population (Instituto Nacional de Estadística, Geografía e Informática, 2024). To estimate the marginalization index in Mexico, the National Population Council (CONAPO) considers the following dimensions of marginalization: education, housing, population distribution, and labor income. The present analysis includes more detailed data on exclusion in households, specifically related to electricity consumption (Consejo Nacional de Población, 2020). To classify each municipality by its temperate or warm climate, the study by García Ochoa and colleagues was consulted (García et al., 2022).

Geospatial Analysis. For the bivariate and geospatial analysis of residential electricity consumption and the marginalization index, a database management system PostgreSQL and a geographic information system QGIS were used

(https://www.postgresql.org/ ; https://www.qgis.org/). Mexico defines urban areas as urban localities with more than 2,500 residents and rural areas as those with less than 2,500 inhabitants, based on INEGI criteria (Instituto Nacional de Estadística, Geografía e Informática, 2024).

Data Modeling. At this stage, modeling techniques are chosen, parameters adjusted for model deployment in production, and validation is done.

Visualization of the Results. Once the model is deployed, the results obtained from data processing and modeling are analyzed and evaluated. At this stage, it is crucial to identify the patterns that can be translated into knowledge.

Knowledge Extraction. Based on the critical analysis of the visualization of the results, it is verified that the outcomes are consistent with the reality of the data, which facilitates the extraction of new knowledge and provides elements to support decision-making.

3 Results

After applying the Data Science Methodological Strategy (Fig. 1), this section presents the results, organized as follows: 1. Residential electricity consumption per person in 2020; 2. Municipal marginalization index and 3. Analysis of residential electricity consumption per person, marginalization index, and percentage of urban population. An area for discussion regarding the results is included at the end of the section.

3.1 Residential Electricity Consumption per Person in 2020

Considering only the residential sector, energy consumption in 2018 was estimated at 790 Petajoules of which 76% corresponds to thermal energy and the remaining 24% to electricity (Contreras et al., 2022).

According to CFE data (Comisión Federal de Electricidad, 2023a), in 2020 users of the basic electricity service (excluding self-supply) consumed a total of 206,435 GWh. The industrial sector was the largest consumer, with 119,496 GWh representing 57.9%, followed by the residential sector with 68,972 GWh (33.4%), the agricultural sector with 14,006 GWh (6.8%), and finally the services sector with 3,961 GWh (1.9%).

In 2020, 83.4% of the population residing in urban areas accounted for 89.4% of electricity consumption in the residential sector. This section presents the obtained results.

Low Residential Electricity Consumption per person. In 2020, the majority of the population had a low level of residential consumption per capita (approximately 78 million individuals or 62% of the total), with an average consumption of 278.6 KWh. 38.1% of the population with low consumption resides in municipalities with temperate climates, while 23.9% live in municipalities with warm climates; see Table 1 and Fig. 2 for more details.

Average Residential Electricity Consumption per Person. The average residential consumption per person was 660.7 KWh, and geographically it is located along the coasts and in the northern region of Mexico, specifically in the states of Chihuahua, Coahuila, and Nuevo León. This area encompasses a population of approximately 36.8 million people, representing 29.3% of the total population. Of this demographic, 5.9% reside in temperate municipalities while 23.4% inhabit warm municipalities. See Table 1 and Fig. 2 for further details.

High Residential Electricity Consumption per Person. Residential high consumption per person averaged 1,539.3 KWh, which is nearly 5.5 times the average of the low consumption. In 2020, the number of inhabitants with this consumption was approximately 11 million (8.7% of the total population). These municipalities are characterized by a warm climate and are located in the following states: Baja California, Baja California Sur, Sonora, Sinaloa, Chihuahua, Coahuila, Nuevo León, Tabasco, Campeche, Yucatán, and Quintana Roo. This high electricity consumption can be associated with the use of appliances for refrigeration and thermal comfort, particularly during the summer months. See Table 1 and Fig. 2.

3.2 Municipal Marginalization Index

Low marginalization index. By 2020, the majority of the population exhibits a low marginalization index (approximately 105 million inhabitants, which corresponds to 83.6%). All 32 states have some percentage of the population with a low

marginalization index. The states with the highest number of inhabitants with this index are: State of Mexico (15.9 million inhabitants), Mexico City (9.2 million inhabitants), Jalisco (8.2 million inhabitants), Guanajuato (5.8 million inhabitants), Nuevo León (5.7 million inhabitants), Veracruz (4.9 million inhabitants), Puebla (4.5 million inhabitants), Michoacán (3.9 million inhabitants), Baja California (3.6 million inhabitants), Chihuahua (3.5 million inhabitants), Tamaulipas (3.4 million inhabitants), Coahuila (3.1 million inhabitants), Sonora and Sinaloa (2.9 million inhabitants each), Hidalgo (2.4 million inhabitants), Querétaro and San Luis Potosí (each with 2 million inhabitants). The following states have between 1.8 and 1.5 million inhabitants with low marginalization index: Morelos, Tabasco, Quintana Roo, Durango, Chiapas, Oaxaca, Yucatán, and Zacatecas. With less than 1.5 million inhabitants: For Aguascalientes, Guerrero, Tlaxcala, Nayarit, Baja California Sur, Campeche, and Colima, please refer to Table 2 and Fig. 3.

Table 1. Classification of residential electricity consumption per person and distribution of the population in temperate and warm climates (Comisión Federal de Electricidad, 2023a; García, 2022)

Classification	Minimum and maximum value [KWh]	Average [KWh]	Number of inhabitants and %	Population in climates
Low	From 6.95 to 467.6	278.6	78,028,950 (62%)	temperate 38.1% warm 23.9%
Medium	From 468.35 to 1,093.9	660.7	36,801,217 (29.3%)	temperate 5.9% warm 23.4%
High	From 1,100 to 2,874.9	1,539.3	10,920,900 (8.7%)	temperate 0.1% warm 8.6%

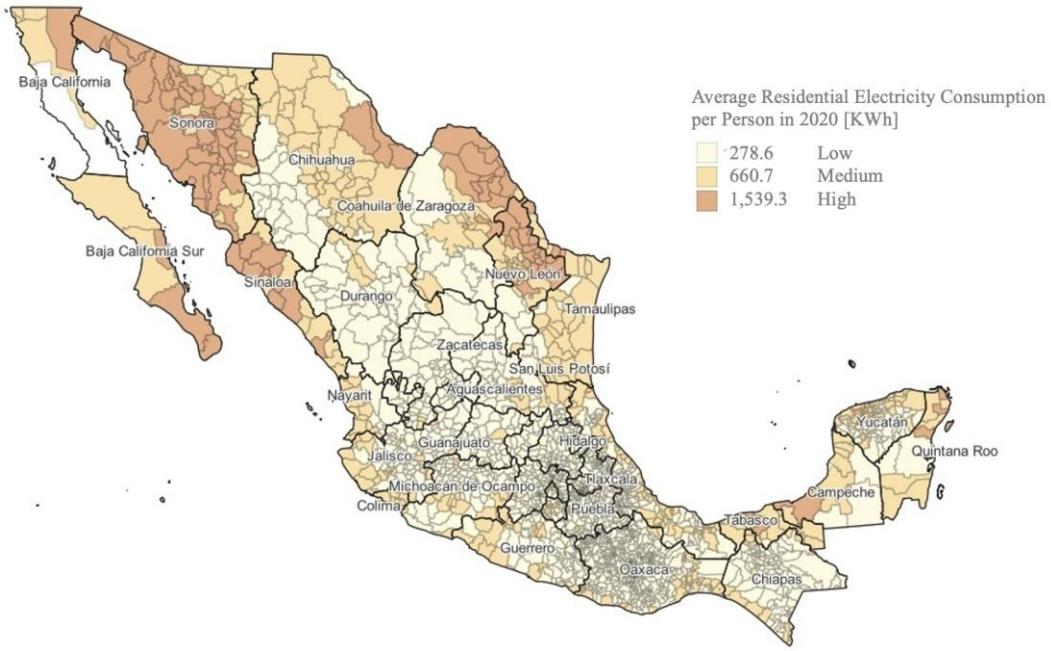

Fig. 2. Residential electricity consumption per person in 2020. Municipalities without data are shown in white (Comisión Federal de Electricidad, 2023a).

Medium marginalization index. Based on CONAPO data (Consejo Nacional de Población, 2020), it is found that 7.3% of the Mexican population is within the medium marginalization index (approximately 9.2 million inhabitants). The largest number of inhabitants with this marginalization index is found in the following states: Veracruz (1.3 million inhabitants), Chiapas (1.2 million inhabitants), Puebla (1.1 million inhabitants), Oaxaca (796,000 inhabitants), Tabasco (594,000 inhabitants), Michoacán (533,000 inhabitants), State of Mexico (516,000 inhabitants), Yucatán (509,000 inhabitants). The states of Hidalgo, Guerrero, San Luis Potosí, Guanajuato, and Querétaro have between 463,000 and 196,000 inhabitants with a medium marginalization index. Finally, the states of Quintana Roo, Sinaloa, and Zacatecas have between 154,000 and 102,000 inhabitants with this same marginalization index; see Table 2 and Fig. 3.

High marginalization index. Approximately 11 million inhabitants have a high marginalization index, corresponding to 9.1% of the total population. Chiapas is the state with the largest number of inhabitants experiencing high marginalization (2.75 million people), followed by Veracruz (1.78 million people), Oaxaca (1.76 million people), Guerrero (1.67 million people), Puebla (929,000 people), State of Mexico (600,000 people), and San Luis Potosí (353,000 people). With approximately between 270,000 and 209,000 inhabitants, the states are: Yucatán, Hidalgo, Michoacán, and Chihuahua, see Table 2 and Fig. 3.

Table 2. Classification of the municipal marginalization index 2020 (Consejo Nacional de Población, 2020)

Classification	Minimum and maximum value	Percentage of inhabitants [%]	Number of inhabitants
Low	From 0.85 to 0.98	83.6	105,207,549
Medium	From 0.82 to 0.85	7.3	9,214,023
High	From 0.33 to 0.82	9.1	11,400,930

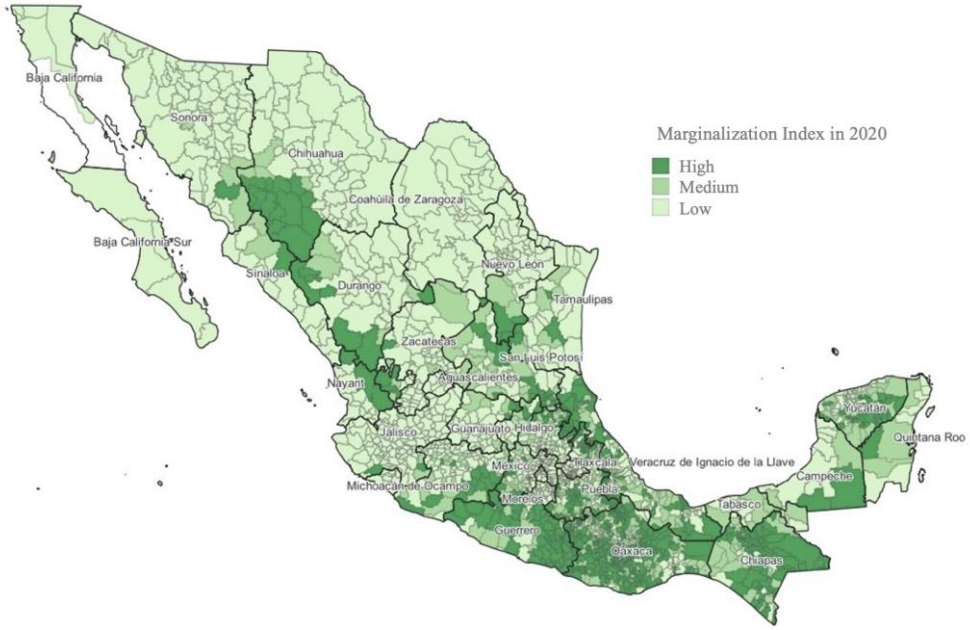

Fig. 3. Municipal Marginalization Index in 2020 Municipalities without data are shown in white (Consejo Nacional de Población, 2020).

3.3 Analysis of residential electricity consumption per person, marginalization index, and percentage of urban population

Low residential electricity consumption per person and marginalization index. For ease of reading, this section has been subdivided into the sub-sections below.

Low residential electricity consumption per person and high marginalization index. In relation to the low residential electricity consumption per person and the high marginalization index, approximately 10.7 million individuals are affected, representing 8.5% of the total population included in the available data. In this category, the average percentage of the urban population was the lowest (20.1%). The inhabitants with these characteristics are mainly found in the following states: Chiapas (2.637 million inhabitants), Oaxaca (1.698 million inhabitants), Veracruz (1.643 million inhabitants), Guerrero (1.452 million inhabitants), and Puebla (929 million inhabitants). To a lesser extent, the states of Mexico, San Luis Potosí, Yucatán, Hidalgo, Chihuahua, Michoacán, and Durango also had inhabitants with both low residential electricity consumption and high marginalization, ranging from 600,000 to 145,000 people (see Table 3 and Fig. 4).

Low residential electricity consumption per person and medium marginalization index. Approximately 6.9 million inhabitants have low residential electricity consumption per person and live in areas with a medium marginalization index. (5.6%). The

average percentage of the urban population was 28.1%. The states with inhabitants who share these characteristics are: Puebla and Chiapas each have approximately 1 million inhabitants with these characteristics, followed by Veracruz with 970,000, Oaxaca with 604,000, Mexico with 516,000, Hidalgo with 463,000, and San Luis Potosí with 423,000 inhabitants. In the states of Michoacán, Guanajuato, Guerrero, Yucatán, Querétaro, and Zacatecas, between 389,000 and 102,000 inhabitants have these characteristics (see Table 3 and Fig. 4).

Low residential electricity consumption per person and low marginalization index. 47.9% of the population (approximately 60.3 million inhabitants) had low residential electricity consumption per person and a low marginalization index. The average percentage of the urban population was 62.1%, the highest in the category of low residential electricity consumption per person. The State of Mexico, with approximately 15.8 million inhabitants, ranks first, followed by Mexico City with 8.1 million inhabitants; Jalisco with 6.1 million; Guanajuato with 5.6 million; Puebla with 4.4 million; Michoacán with 3.5 million; Hidalgo with 2.4 million; Querétaro with 2.1 million; San Luis Potosí and Zacatecas with 1.5 million each; Aguascalientes and Coahuila with 1.4 million each; and Tlaxcala, Veracruz, and Durango with 1.3 million inhabitants each. Oaxaca with 876,000 inhabitants, Morelos with 555,000, Chiapas with 508,000, Guerrero with 296,000, and Chihuahua with 124,000 inhabitants (see Table 3 and Fig. 4).

Table 3. Low residential electricity consumption per person, marginalization index, and average percentage of urban population (Comisión Federal de Electricidad, 2023a; Consejo Nacional de Población, 2020; Instituto Nacional de Estadística, Geografía e Informática, 2024)

Residential electricity consumption per person	Marginalization Index	Average residential electricity consumption per person [KWh]	Average percentage of urban population [%]	Number of inhabitants	Percentage of the total population [%]
Low	High	225.4	20.1	10,733,842	8.5
	Medium	295.4	28.1	6,986,212	5.6
	Low	324.3	62.1	60,308,896	47.9

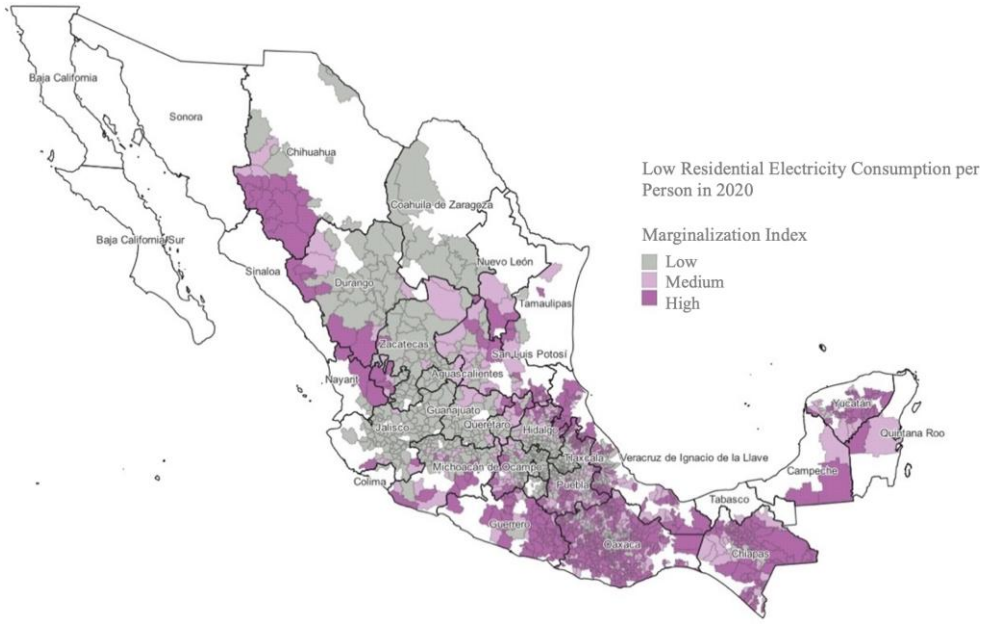

Fig. 4. Low residential electricity consumption per person in 2020 and marginalization indexes: low, medium, and high (Comisión Federal de Electricidad, 2023a; Consejo Nacional de Población, 2020; Instituto Nacional de Estadística, Geografía e Informática, 2024).

Medium residential electricity consumption per person and marginalization index. For ease of reading, this section has been subdivided into the sub-sections below.

Medium residential electricity consumption per person and high marginalization index. According to the data, an estimated 662,000 inhabitants, equivalent to 0.5% of the population, have medium residential electricity consumption per person and live in areas with a high marginalization index. Within medium residential consumption, the average percentage of the urban population was the lowest at 32.6% (see Table 4 and Fig. 5).

Medium residential electricity consumption per person and medium marginalization index. With an average residential electricity consumption per person and a medium level of marginalization, there were approximately 2.1 million inhabitants, equivalent to 1.7% of the total population. The average percentage of urban population was 45.6%; see Table 4 and Fig. 5.

Medium residential electricity consumption per person and low marginalization index. The data indicate that around 34 million inhabitants, equivalent to 21.7% of the total population, have medium residential electricity consumption per person and a low marginalization index. Within medium residential consumption, the average percentage of the urban population reached its highest value at 64.4% (see Table 4 and Fig. 5).

Table 4. Medium residential electricity consumption per person, marginalization index, and average percentage of urban population (Comisión Federal de Electricidad, 2023a; Consejo Nacional de Población, 2020; Instituto Nacional de Estadística, Geografía e Informática, 2024)

Residential electricity consumption per person	Marginalization Index	Average residential electricity consumption per person [KWh]	Average percentage of urban population [%]	Number of inhabitants	Percentage of the total population [%]
	High	561.9	32.6	662,773	0.5
Medium	Medium	582.8	45.6	2,144,311	1.7
	Low	688.9	64.4	34,061,253	21.7

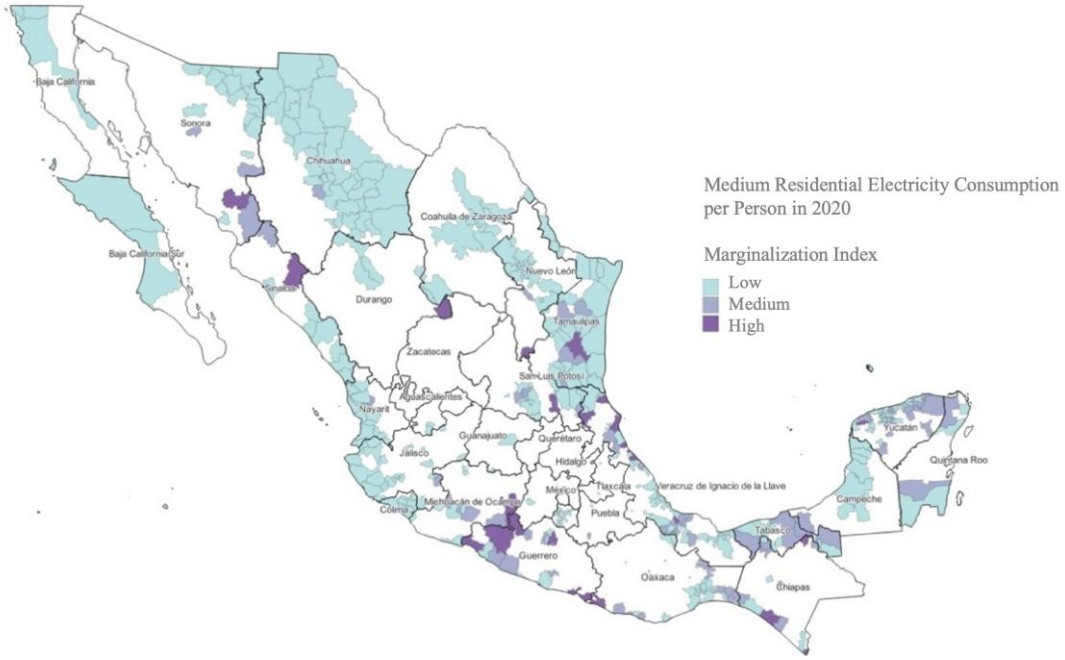

Fig. 5. Medium residential electricity consumption per person in 2020 and marginalization indexes: low, medium, and high (Comisión Federal de Electricidad, 2023a; Consejo Nacional de Población, 2020; Instituto Nacional de Estadística, Geografía e Informática, 2024).

High residential electricity consumption per person and marginalization index. For ease of reading, this section has been subdivided into the sub-sections below.

High residential electricity consumption per person and high marginalization index. There are no inhabitants within the classification of high residential electricity consumption with high marginalization index (see Table 5 and Fig. 6).

High residential electricity consumption per person and medium marginalization index. Approximately 85,000 inhabitants (0.1% of the total population) exhibited high residential electricity consumption and a medium marginalization index. The urban population averaged 39.6% (see Table 5 and Fig. 6).

High residential electricity consumption per person and low marginalization index. Ultimately, it was found that approximately 10.8 million inhabitants, comprising 8.6% of the total population, exhibited high residential electricity consumption per person and low marginalization index. The average urban population for this group was 50.4% (see Table 5 and Fig. 6).

Table 5. High residential electricity consumption per person, marginalization index, and average percentage of urban population (Comisión Federal de Electricidad, 2023a; Consejo Nacional de Población, 2020; Instituto Nacional de Estadística, Geografía e Informática, 2024)

Residential electricity consumption per person	Marginalization Index	Average residential electricity consumption per person [KWh]	Average percentage of urban population [%]	Number of inhabitants	Percentage of the total population [%]
High	High	No data available	No data available	No data available	0
	Medium	1,470.3	39.6	83,500	0.1
	Low	1,540.5	50.4	10,837,400	8.6

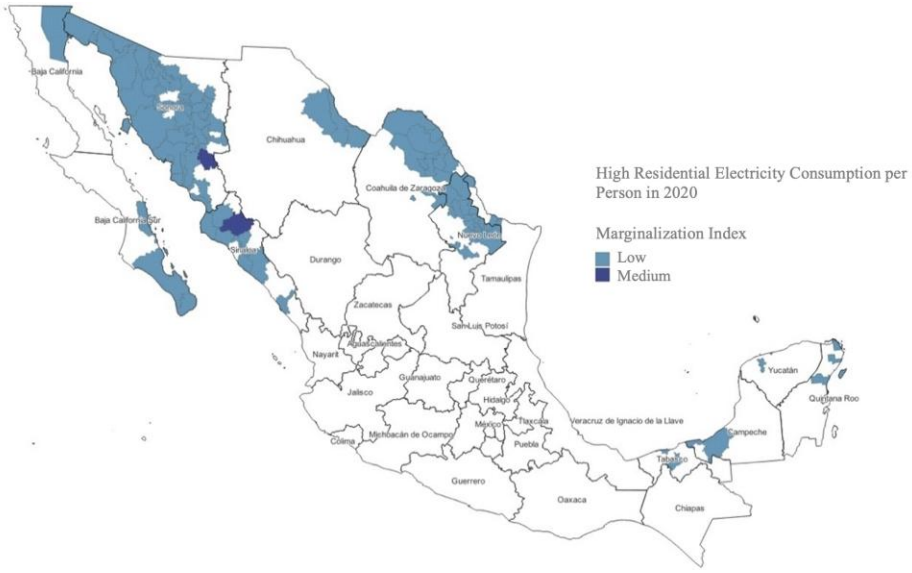

Fig. 6. High residential electricity consumption per person in 2020 and marginalization indexes: low and medium (Comisión Federal de Electricidad, 2023a; Consejo Nacional de Población, 2020; Instituto Nacional de Estadística, Geografía e Informática, 2024).

4 Discussion on the Results

High and medium residential electricity consumption is largely linked to the geographical location of municipalities, appearing mainly in the Northeast, Northwest regions and California, Yucatan peninsulas. This reflects the need to maintain comfortable temperature conditions in homes and preserve food, which increases the demand for electricity, especially during the summer. Additionally, this high electricity consumption is largely associated with low marginalization index and can be considered as an indicator of living standards. This is due to the increased use of electronic devices for education, communication, and entertainment in households. On the other hand, low electricity consumption was found in municipalities with predominantly temperate climates.

In 2020, approximately 78 million individuals (62% of the total population) exhibited low electricity consumption, followed by 36.8 million inhabitants (29.3%) with medium consumption, while 10.9 million people (8.7%) who had high electricity consumption.

In terms of the marginalization index, for the same year, approximately 11.4 million (9.1% of the total population) have a high index, followed by 9.2 million inhabitants (7.3%) with a medium marginalization index. The majority of the population has a low marginalization index, with around 105.2 million inhabitants, representing 83.6% of the total population.

When examining household electricity consumption per person and municipal marginalization index, an inverse correlation is observed. In contrast, a positive correlation exists between electricity consumption in households and the percentage of urban population. This means that as residential electricity consumption per person decreases, the marginalization index increases, and the percentage of the population living in urban areas decreases.

This analysis facilitates the identification of municipalities characterized by low residential electricity consumption and high marginalization index. This helps to guide policy makers toward areas requiring greater attention to achieve well-being and promote fairer, more equitable development.

A viable option for meeting electricity needs in vulnerable areas is the application of clean technologies. Access to energy services through the use of solar photovoltaic energy (PV) plays a key role in reducing poverty and promoting sustainable human development (Rumbayan et al., 2025; Wang et al., 2024). In Yucatan, a water pumping system using PV technology was implemented (El-Mekaoui et al., 2024). Meanwhile, in Tabasco, autonomous photovoltaic systems were installed that allowed communities, such as artisanal communities, to have electricity for their daily activities (Alvarado et al., 2025).

5 Conclusions

Undoubtedly, a contributing factor to the research results was the adherence to the methodological approach of Data Science, as it facilitated the management and processing of large volumes of data from diverse sources and domains.

Answering the research question: ¿What is the link between residential electricity consumption and marginalization index at the municipal level in Mexico? was the main contribution of the research.

It should be noted that the geographic areas were defined based on the intensity of structural deficiencies experienced by their inhabitants, considering the marginalization index and household electricity consumption. This approach provides a solid criterion for prioritizing policy actions aimed at reducing economic and social inequalities at regional and local levels.

To meet the electricity needs of municipalities located far from the national transmission grid, it is recommended to use distributed generation systems based on renewable energy sources, which enhance the autonomy of communities and result in lower greenhouse gas emissions.

Finally, considering the increase in the frequency and intensity of heatwaves caused by climate change, special attention should be paid to municipalities located in warm regions where residential electricity consumption is low and the degree of marginalization is high, as these two factors make them more vulnerable. As well as addressing the issue of thermal comfort, especially in areas where the regulation of high temperatures depends on the use of electrical devices (air conditioners and fans).

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