

Localized Understanding of Multidimensional Energy Needs in states and municipalities in Mexico

Comprensión Localizada de Necesidades Energéticas Multidimensionales en estados y municipios de México

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ABSTRACT

We introduce LUMEN (Localized Understanding of Multidimensional Energy Needs), a novel index for measuring energy poverty with a municipality-level indicator in Mexico. Energy poverty restricts access to essential services, yet traditional metrics overlook local disparities. Building on the Multidimensional Energy Poverty Index (MEPI), LUMEN integrates Principal Component Analysis (PCA) to refine indicator selection and weighting, leveraging census and ENIGH data from INEGI for a robust analysis. By pinpointing areas of acute deprivation, LUMEN provides a data-driven tool for policymakers to prioritize interventions, allocate resources efficiently, and design equitable energy policies that improve livelihoods.

RESUMEN

Presentamos LUMEN: Comprensión Localizada de las Necesidades Energéticas Multidimensionales (*Localized Understanding of Multidimensional Energy Needs*, por sus siglas en inglés), un nuevo índice para medir la pobreza energética a nivel municipal en México. La pobreza energética limita el acceso a servicios esenciales, pero los indicadores tradicionales no capturan las disparidades locales. Basado en el Índice de Pobreza Energética Multidimensional (MEPI, por sus siglas en inglés), LUMEN incorpora Análisis de Componentes Principales (PCA) para refinar la selección y ponderación de indicadores, utilizando datos del censo y la ENIGH de INEGI para un análisis granular y robusto. Al identificar zonas de mayor vulnerabilidad, LUMEN ofrece una herramienta clave para que los responsables de políticas prioricen intervenciones, asignen recursos eficientemente y diseñen políticas energéticas equitativas que mejoren el bienestar.

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| México | ENIGH |
| Privación de energía |
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JEL Classification |

Clasificación JEL |
I32, Q41, O13, C38

INTRODUCTION

Energy poverty, defined as the lack of access to modern energy services (such as electricity and clean cooking facilities), remains a significant global challenge. In 2022, approximately 759 million people lacked reliable electricity, while 2.6 billion relied on inefficient and hazardous cooking systems (United Nations, 2023). These deficiencies constrain economic development, exacerbate public



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health crises, environmental degradation, and social inequality (Healy & Clinch, 2004). Although significant progress has been made, energy poverty remains unevenly distributed, disproportionately affecting rural and low-income communities, limiting educational and economic opportunities, and perpetuating intergenerational poverty traps.

Mexico faces these challenges despite significant progress in electrification. While national-level metrics suggest high energy access, such aggregated indicators obscure regional disparities, particularly in rural and indigenous areas where energy poverty persists (cf. Soriano-Hernández, *et al.*, 2022). The country's diverse geography, economic inequalities, and infrastructure constraints create substantial variations in energy availability, affordability, and quality. Yet current policy frameworks lack a municipality-level indicator to measure and address these disparities effectively. Without localized and multidimensional data, energy poverty interventions risk being misdirected, failing to account for region-specific needs and policy impacts.

To bridge this gap, we introduce the Localized Understanding of Multidimensional Energy Needs (LUMEN). Lumen is an index designed to measure energy poverty at a municipal level in Mexico which draws from INEGI's census and a national survey on household income and expenditures (ENIGH). Unlike other traditional measures, Lumen integrates multiple dimensions to offer a comprehensive framework. Such dimensions are availability, accessibility, affordability, and consumption. Additionally, we reduce subjectivity by selecting weights in the indicators using principal component analysis (PCA).

Our main objective in this paper is to provide a tool for the identification of specific areas of acute energy deprivation. We hypothesize that LUMEN, through its multidimensional and localized approach, provides a more effective measurement of regional disparities and a more accurate identification of areas with acute energy deprivation than current aggregated metrics. This allows policymakers to efficiently allocate scarce resources in interventions and design evidence-based energy policies tailored to the local reality. More importantly, the design of targeted region-specific solutions helps avoid “one-size-fits-all” approaches, which might sound good on paper, but have little to nonreal impact in the communities it's supposed to help.

Even though Mexico has made significant progress in the expansion of electricity access throughout the country, energy poverty remains a relevant challenge. Particularly in rural areas and remote towns. Mexico's geography and deep socioeconomic inequalities make it complex to provide access to safe and non-hazardous sources of energy evenly, since each region has its own level of energy access and affordability (García-Ochoa, *et al.*, 2022). Thus, energy poverty remains a complex issue that requires a balance between energy security, economic affordability, and environmental sustainability (cf. Khan, *et al.*, 2023). We wish to ensure accessible and affordable energy without exacerbating environmental degradation that may compromise energy security in the long run (Gunningham, 2013).

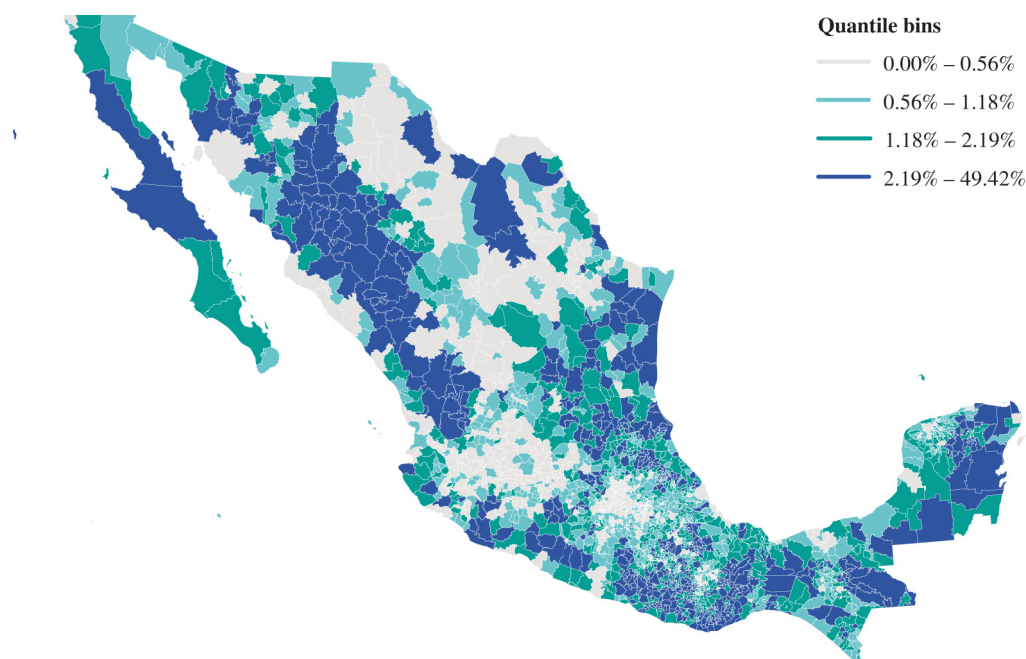
In a country as large and diverse as Mexico, more than a one-size-fits-all approach is required to address the nuanced realities of energy poverty across different municipalities. For instance, García, *et al.* (2023) report a case of the Guanacevi municipality, which reports a higher than average energy poverty, but in which local authorities decide to use the federal funds to provide citizens with solar boilers, which solves the problem of heating water in the households, but do not affect any of the indicators of multidimensional poverty provided by CONEVAL (2019).

While this action does not directly affect the multidimensional poverty metrics, it does alleviate the need to use gas in the municipality with the lowest temperature registered in the country. If a separate energy poverty indicator can show this alleviation, then local governments would have more margin to find suitable solutions to solve poverty locally, and incentives to create solutions that are fit for their communities.

One of our main insights is that municipalities in remote areas face challenges that might need to be accurately captured in poverty measurements. Figure 1 shows a map of the percentage of the population without access to electricity at a municipality level. Note that the municipalities where access to electricity is more restricted are those where access is more complex, like in mountain ranges, where infrastructure construction is difficult to access.

The nature of energy is complex and thus requires a multidimensional approach to measure. Traditional methods, which often focus solely on income or energy expenditure thresholds, fail to account for other critical dimensions, such as the quality of energy services, household energy efficiency, and the environmental impact of energy use.

Figure 1
Percentage of population without access to electricity by municipality in Mexico



Note: each degree of percentage is chosen by quantiles.

Source: self-made with 2020 census data from INEGI, using QGIS.

For instance, Figure 1 presents a municipality-level map of the percentage of population without access to electricity by municipality in Mexico. We can infer several things from this map. One is that the quartile with a higher percentage lives in the mountain range. The municipalities in the states of Chihuahua, Sinaloa and Durango with less access to electricity are the ones in Sierra Madre Occidental, where access to the grid is more difficult. But an important nuance this map does not show is how the solutions households come up with to access energy relates to its affordability.

In response to this gap, the index we propose aims to provide a more comprehensive understanding of energy poverty at the municipal level in Mexico. By incorporating availability, accessibility, affordability and consumption to the index, we offer a more accurate picture of energy deprivation in households which allow policymakers to create targeted solutions.

In the following section, we provide a literature review of the problem, then we show the data sources and methodology in section 2. In sections 3 and 4, we construct the LUMEN index and show the results of the analysis using PCA, which we discuss further in section 5. Last section concludes this paper.

I. LITERATURE REVIEW

Energy poverty is defined as the inability of a household to access adequate energy services that are essential for a decent standard of living. This includes heating, cooling, lighting and cooking (cf. Day, *et al.*, 2016; Nussbaumer, *et al.*, 2012). Note that this definition is not focused only on income or consumption, but encompasses factors that include energy accessibility, affordability and sustainability (Che, *et al.*, 2021; Isazade & Altan, 2023). For instance, consider a rural area without access to reliable electricity, that may have to use power generators which constitutes a less affordable and more pollutant option.

Climate change has revealed the urgency to assess and measure the state of accessibility to energy, given the United Nation's Sustainable Goal number 7, which calls for the access to affordable, reliable, sustainable and modern sources of energy "for all" (United Nations, 2023). Nevertheless, traditional poverty metrics, such as the multidimensional poverty index (MPI), do not always capture the nuances of energy deprivation. As a result, policymakers may have an incomplete understanding of the nature of the problem that leads to ineffective interventions (Culver, 2017; Streimikiene, *et al.*, 2021). We need a special measurement framework for energy poverty.

Defining and Measuring Energy Poverty

To properly measure energy poverty, we need to consider not only the lack of access to energy, but also affordability, reliability of access and the quality of the energy services (Isazade & Altan, 2023; Meyer *et al.*, 2018). Nussbaumer *et al.* (2012, 2013) have proposed the Multidimensional Energy Poverty Index (MEPI), which assesses energy deprivation across multiple dimensions: cooking, lighting, and appliance use. This approach provides a comprehensive view on how energy poverty affects households by considering the services that contribute to their well-being.

It should be evident by now that to properly measure energy poverty, it takes more than just the access to energy by the households, but they should be able to use it to perform functions they value (Sen, 1993). This entails the need to reflect local realities and subjective measurements, such as the ability to keep homes adequately warm or cool (Menyhert, 2023; Streimikiene, *et al.*, 2023). As Menyhert (2023) points out, different measures tend to identify different segments of the population.

To this day, there is no universally accepted definition of energy poverty (Culver, 2017; Isazade & Altan, 2023). The indicator of choice highly influences the households that we identify as energy-poor (Faiella & Lavecchia, 2021; Meyer, *et al.*, 2018). Moreover, a measure that is based on expenditure may not capture nuances, like a household that restrict its energy consumption due to affordability but that would otherwise use a different source, leading to an underestimation of energy poverty (Guzmán-Rosas, 2023).

But while nuances are important, data availability is one of the crucial aspects we must consider when creating a measurement, particularly in developing countries (Culver, 2017; Nico, 2020). We need detailed information on the dimensions we have early enumerated. This can make the creation of the measurement challenging, since the information may not be readily available or standardized (Che, *et al.*, 2021; Nussbaumer, *et al.*, 2012).

What we know so far about energy poverty in Mexico

Moving on to the Mexican context, energy poverty remains a pressing issue due to the country's socio-economic and geographic disparities. For instance, García-Ochoa and Graizbord (2016) found that 36.7% of Mexican households suffer from energy poverty, where “thermal comfort”, “efficient refrigeration” and “gas or electric stove” were the economic goods with higher deprivation levels.

Further, García-Ochoa *et al.* (2022) employed an access deprivation approach, focusing on the access of energy services, defined by Cravioto (2022) as “benefits for human well-being” produced using energy at home. This is a very wide definition that narrows down by focusing on lighting, information-entertainment, food, hygiene, and thermal comfort. As the authors point out, external factors such as climate, urbanization levels and inequality have a significant influence in how energy poverty is experienced in different regions throughout the country (García-Ochoa, *et al.*, 2022).

Therefore, we build upon the Multidimensional Energy Poverty Index (MEPI) to create LUMEN as a localized index, adapting to use available data from the Mexican census and the National Survey on Household Income and Expenditures (ENIGH), both from the National Institute of Statistics and Geography (INEGI). Our adaptation ensures availability and reliability of the data, addressing the need for granular, municipality-level insights.

II. DATA SOURCES AND METHODOLOGY

LUMEN index is integrated by two primary datasets: the 2020 Population and Housing Census and ENIGH, from INEGI. The first one is the foundational dataset that captures indicators of availability and accessibility of energy services. It provides key variables, such as access to electricity, piped water, and essential household appliances. This allows us to identify disparities in access to energy at a municipal level. For instance, we take the proportion of households without electricity as part of the analysis, along with the ownership of refrigerators and microwaves.

To complement the information from the census, we use ENIGH datasets to include information on energy-related spending and to construct the affordability dimension of the index. This is created by computing the expenditure-to-income ratio as a proxy to weigh the economic burden due to energy costs. We recognize that this is an imperfect way to measure the burden energy cost entails in households, since energy consumption might be endogenous to its level of income. For instance, a family might decide to increase its level of consumption of energy by using air conditioning as soon as their income level rises. So, by observation of the energy expenditure to income ratio, these two households might seem identical, but they are very different in terms of energy poverty.

To ensure consistency and accuracy, we standardized data between datasets, extrapolating the ENIGH data for the municipality level. This is a necessary step, since ENIGH has statistical significance only at national and state level (INEGI, 2023).

To derive the weights for the index components we used Principal Component Analysis (PCA). This allows us to ensure that each dimension contributes proportionally, based on its statistical importance. This way, we minimize subjectivity in the weight assignment, for any given weight we assign might still be subjective, however backed from theory.

As a result, the LUMEN index provides a standardized score for each municipality, with a relative poverty status across the four dimensions we selected. A municipality with a higher score indicates more incidence of

energy poverty, while lower scores highlight more energy deprivation. In the next section we describe in depth the construction of the index.

III. CONSTRUCTING THE LUMEN INDEX

To construct the index, we account for four dimensions: availability, accessibility, affordability, and consumption. In this section, we explain the rationale for selecting them, what we expect to learn from the index by including them, and how they were integrated from the data.

Each indicator was carefully chosen based on its ability to capture a specific facet of energy poverty while being compatible with the available data from the 2020 Population and Housing Census and the National Survey on Household Income and Expenditure (ENIGH) of the same year. These indicators are representative of their respective dimensions and were normalized to ensure comparability.

To construct the LUMEN Index and ensure meaningful aggregation of diverse indicators, all data were normalized to a scale of zero to one. This standardization process harmonizes metrics that are inherently different in nature, such as the percentages of households affected by specific deficiencies and expenditure ratios, enabling their integration into a unified analytical framework.

Table 1 shows the dimensions of the LUMEN index: the availability dimension focuses on the foundational access to essential infrastructure. The inclusion of electricity access serves as a baseline measure of energy poverty, as it determines whether households can perform basic modern activities such as lighting, refrigeration, and communication. Similarly, access to piped water, while primarily a metric of water infrastructure, underscores the interdependence of energy and water services in regions where infrastructure deficits are pronounced.

Table 1
Dimensions of the LUMEN Index

<i>Dimension</i>	<i>Description</i>	<i>Indicators</i>
Availability	Measures the fundamental presence of energy services, focusing on access to essential infrastructure.	Percentage of households without access to electricity (census): Captures basic connectivity to the energy grid, essential for modern living. Percentage of households without access to piped water (census): Reflects related infrastructure gaps.
Accessibility	Assesses the ease with which households access energy-related goods and appliances necessary for daily life.	Percentage of households with a refrigerator (census): Proxies access to energy-powered appliances for food preservation. Percentage of households with a washing machine (census): Reflects access to energy-powered appliances for convenience and hygiene.
Affordability	Examines the economic strain households face in accessing energy services relative to their income.	Average energy expenditure-to-income ratio (ENIGH): Represents the proportion of household income allocated to energy costs, highlighting economic vulnerability. (Available only at state level due to data limitations.)
Consumption	Captures energy-dependent lifestyle aspects, emphasizing connectivity and technology access.	Percentage of households without a television (census): Proxies limited access to energy-driven entertainment and information. Percentage of households without a cellphone (census): Indicates technological deprivation and its impact on mobility and communication.

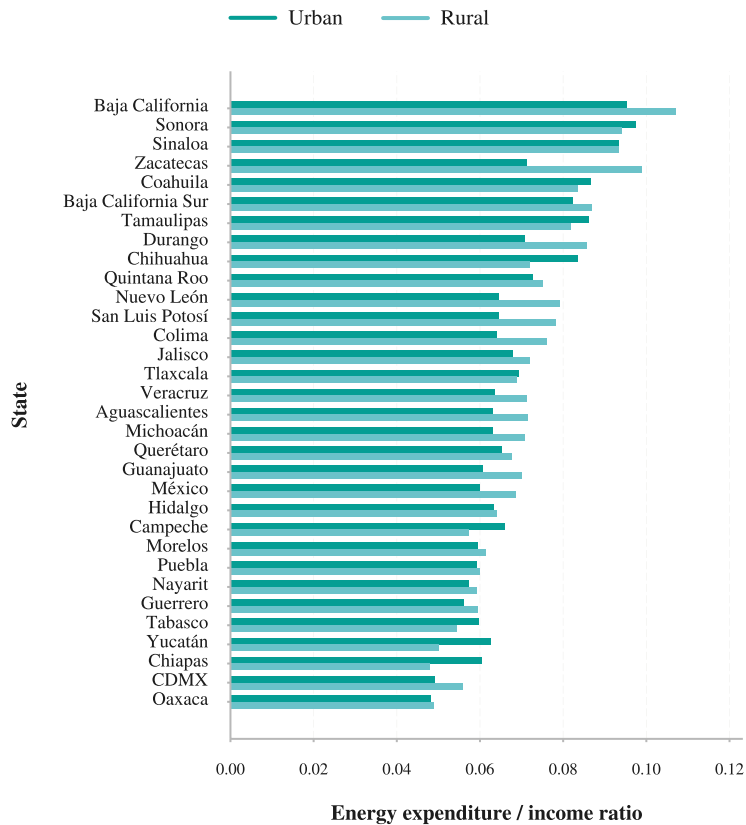
Source: self-made.

The accessibility dimension emphasizes the availability of energy-dependent household appliances that contribute to quality of life. The presence of refrigerators is critical not only for food preservation but also for ensuring food safety, linking energy access directly to health outcomes. Washing machines, on the other hand, highlight disparities in household convenience and access to labor-saving technologies, shedding light on broader social and economic inequalities.

The affordability dimension addresses the economic burden of energy services on households. The energy expenditure-to-income ratio is a pivotal indicator that reveals the financial strain of accessing energy. It provides insight into the trade-offs households must make when allocating limited resources, such as sacrificing other essential needs to pay for energy. Figure 2 shows the average energy expenditure to income ratio by state. We can notice that the states with a higher ratio seem to be those with higher variations in temperature.

Lastly, the consumption dimension extends the analysis beyond basic needs to consider the role of energy in enabling broader social and economic participation. Access to televisions and cellphones serve as proxies for connectivity, education, and communication, which are services provided by the energy, as recommended by Rizal *et al.* (2024) and the authors cited by them. These indicators illustrate the importance of energy in facilitating inclusion in modern economic and social systems, highlighting its role in fostering opportunities for education, employment, and social engagement.

Figure 2
Average energy expenditure to income ratio by state (split by rural and urban)



Source: National Survey on Household Income and Expenditure (ENIGH, 2020) using R.

The affordability dimension, which examines the economic strain households face in accessing energy services, presents unique challenges at the municipal level due to data limitations. The direct energy expenditure-to-income ratio, a pivotal indicator at the state level, is not available with sufficient granularity for municipal analysis (INEGI, 2023). Therefore, we adapted the state-level affordability data, incorporating average energy costs to compute the relative financial burden faced by the households. This measurement highlights the financial vulnerabilities specific to different local contexts and economic challenges of energy access across municipalities.

As a result, with this index we attempt to capture the multifaceted nature of energy poverty that identifies across dimensions.

Methodological Foundation: Principal Component Analysis (PCA)

We leverage on a Principal Component Analysis (PCA) approach to derive weights for each dimension. Since the weight of each component of the index does not have an objective value, this method ensures that subjective appreciation does not get in the way of creating a proper index. Though the advantage is a more objective measurement, the data from different years should yield slightly different results.

We start by calculating the covariance matrix of all normalized indicators. This reveals the interrelationship and variance among dimensions of energy poverty. Thus, we derive its eigenvalues and eigenvectors that represent the variance explained by each principal component and their relevant importance, respectively. The first principal component, which accounts for the largest proportion of variance, is used to assign weights to each dimension. The weights are proportional to the statistical significance of the dimension as captured by its eigenvalue.

The weight for a given dimension j is calculated using the formula:

$$w_j = \frac{\lambda_j}{\sum_{j=1}^k \lambda_j}$$

where λ_j is the eigenvalue for dimension j , and k is the total number of dimensions.

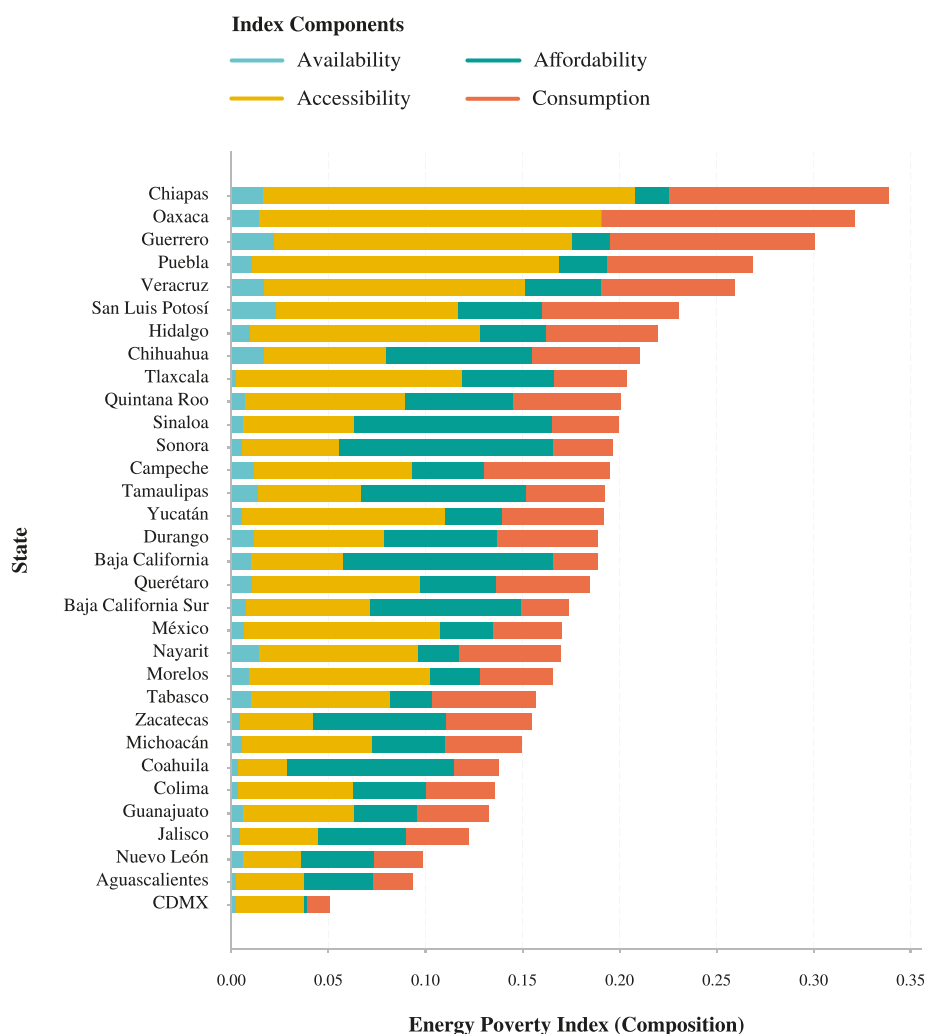
To compute the LUMEN Index score for each municipality i , the weighted sum of the normalized indicators is used, represented by the formula:

$$LUMEN_i = \sum_{j=1}^n (w_j \times Z_{ij})$$

Here, w_j represents the PCA-derived weight for indicator j , and Z_{ij} is the normalized value of indicator j for municipality i .

Figure 3 depicts that most of the weight assigned by the PCA algorithm was assigned to the accessibility of the energy, while availability took second place. The rest was distributed between affordability and consumption. We can observe that there is a significant variation in how the weights are distributed among states. For instance, note that the affordability dimension is more relevant in southern states such as Chiapas, Oaxaca or Guerrero, where energy costs amount to 20% or more of the household income.

Figure 3
Composition of the elements of the LUMEN index derived from PCA



Source: self-made with data from INEGI (Census & ENIGH), using R and Python.

This approach ensures that the LUMEN Index reflects the multidimensional nature of energy poverty while maintaining statistical rigor. By deriving weights directly from the data, PCA provides an unbiased framework that highlights the most significant contributors to energy deprivation in Mexico.

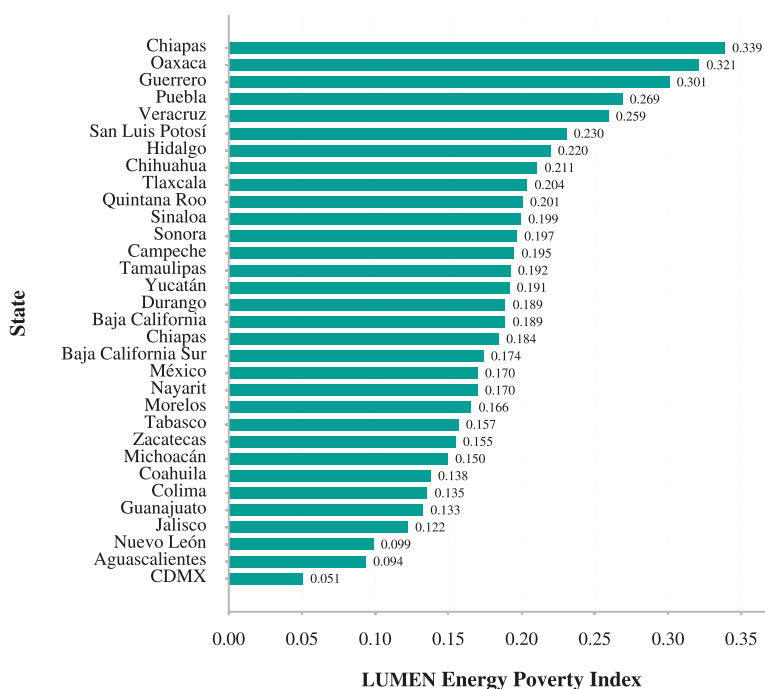
IV. RESULTS AND REGIONAL DISPARITIES

The results of the LUMEN Index reveal critical insights into the distribution of energy poverty in Mexico, emphasizing stark regional and municipal disparities.

Figure 4 shows the computed Lumen index by state. In Mexico, southern states such as Chiapas, Oaxaca, and Guerrero demonstrate pronounced affordability challenges, with households spending a disproportionately high percentage of their income on energy services. This aligns with studies indicating that regions with lower

income levels tend to experience higher energy burdens, exacerbating the economic vulnerability of affected households (Abdoulaye & Mokaddem, 2022).

Figure 4
Energy poverty index LUMEN by state



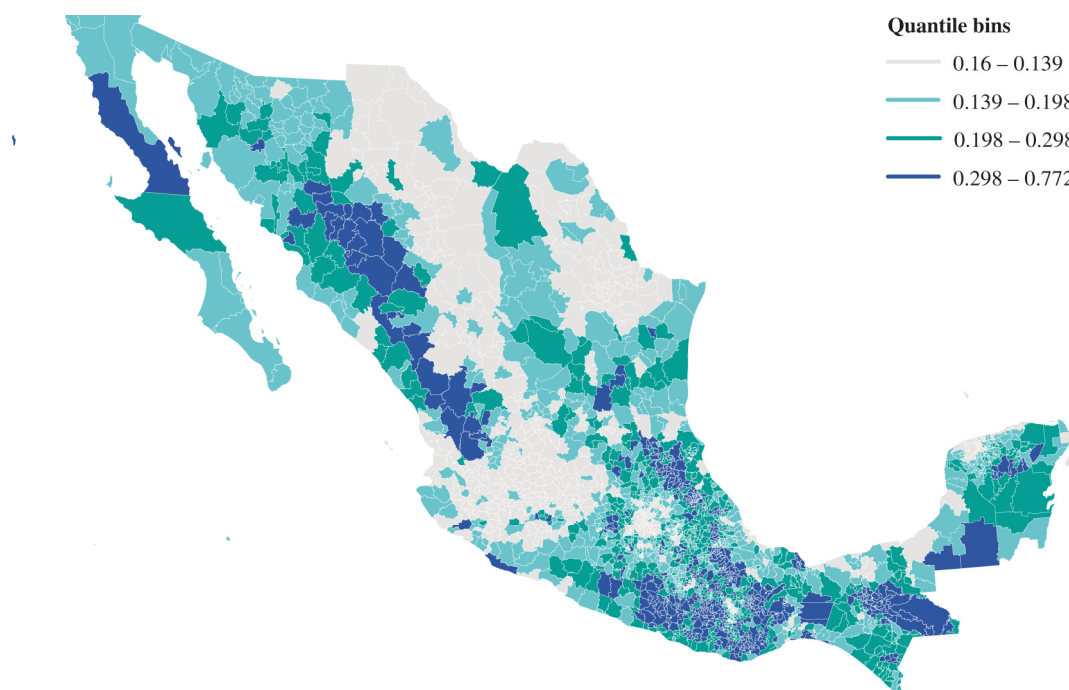
Source: self-made with data from INEGI (Census 2020 and ENIGH 2020), using R and Python.

Meanwhile, Figure 5 shows the computed index at a municipal level. Municipal-level results highlight granular disparities that further illuminate the challenges of energy poverty. In states like Chiapas, municipalities such as Ocosingo and Chilón exhibit acute energy deprivation. These findings resonate with similar patterns observed in rural and remote areas globally, where geographic isolation and limited infrastructure investment exacerbate energy poverty (Hong *et al.*, 2022). Accessibility and availability are particularly constrained in mountainous regions, such as the Sierra Madre Occidental, where infrastructure development faces significant logistical challenges.

Note that, while there are similarities, the patterns shown in Figure 5 differ from the ones in Figure 1. While figure 1 correlates to poverty and geography, Figure 5 distinguishes with greater clarity those municipalities with a more urgent need for an intervention, as the index indicates. Also note that accessibility and availability dimensions are more pronounced in rural and remote areas, underscoring the need for infrastructure development and the adoption of decentralized energy solutions, such as solar or wind energy systems.

On the other hand, consider the contrast between urban and rural areas in light of the multidimensional nature of energy poverty. While urban centers like Mexico City benefit from dense infrastructure networks and higher average incomes, rural municipalities often face compounded challenges. These disparities align with findings from studies on Latin American and global contexts, where rural areas consistently demonstrate higher levels of energy deprivation due to infrastructural and economic constraints (Cedano, *et al.*, 2021; Siksnyte-Butkiene, *et al.*, 2021).

Figure 5
Choropleth map of the LUMEN Index at a municipal level



Note: the darker shades indicate a higher degree of energy poverty, as calculated by the Lumen index. The shades are separated by equal sized quartiles.

Source: self-made with data from INEGI (Census 2020 and ENIGH 2020), using R and QGIS.

Yet another insight we can observe comes from the influence of the consumption dimension, where municipalities with higher deprivation scores often lack access to appliances such as refrigerators and washing machines, which serve as proxies for the accessibility of energy services. This aligns with the broader literature that identifies the role of appliance ownership in assessing household energy poverty (Matus-Enríquez, *et al.*, 2021).

The consumption dimension of the LUMEN Index provides additional insights, reflecting disparities in access to energy-driven goods and technologies. For instance, municipalities with higher deprivation scores often lack access to appliances such as refrigerators and washing machines, which serve as proxies for the accessibility of energy services. This aligns with the broader literature that identifies the role of appliance ownership in assessing household energy poverty (Matus-Enríquez, *et al.*, 2021).

V. DISCUSSION

The main challenge when designing a measurement is the tradeoff between availability of the data and accuracy of the information. A relevant feature of our index is that it's a balance of those features that provides valuable insights to policymakers. For instance, notice that Figure 1 matches almost perfectly to the map shown by Rosas-Flores & Rosas-Flores (2020), in which the authors determine and classify power consumption of climate control systems such as air conditioners, fans and electric heaters. This is a hint about how this measurement can be achieved by a readily accessible and public measure such as access to electricity (or lack thereof).

An additional benefit from the use of PCA is that we can obtain insight from the construction of the index, and how it may vary from different measurements. For instance, we notice that in southern states affordability emerges as a dominant constraint, while consumption constitutes a small proportion of the constitution of the index, reflecting the choice of the services provided by energy. Notice as well that accessibility, measured by the access to essential services from energy such as a refrigerator and a washing machine are a major driver of the index in most states.

This index was purported to stay as meager and simple as possible; to require only measurements that can be easily accessible, and the research stays easy to replicate without the need of complicated measurements. As noted, the inclusion of climate data may as well contribute to an accurate index, particularly the inclusion of weather variation throughout the year or deviations from the average can provide valuable insights. Nonetheless, while we included the climate data from “atlas climático” as a trial, it did not show any significant variation in the results shown. This may be because the variables chosen may already contain enough information to understand the levels of energy poverty in the country.

Ultimately, the main goal of this index is to provide a reliable indicator of both the municipalities where it is most urgent to intervene and a fast way to understand which dimension of the indicator is most urgent. The range of options for interventions is wide, from insulation in residential buildings where the heat is the main challenge to providing energy-saving appliances to households where that is the main issue. There is a big opportunity for financial aid to help families afford energy-saving equipment such as solar panels and boilers.

It is indeed by understanding the needs at a local level the most important step into creating policies that work.

CONCLUDING REMARKS

Our analysis shows Mexico’s significant progress in electrification, and national-level metrics suggest high access to energy; however, these aggregated indicators conceal regional disparities, particularly in remote, rural, and indigenous areas, where energy poverty stay persistent. The country’s diverse geography, economic inequalities, and infrastructure limitations create substantial variations in energy availability, affordability and quality, limiting educational and economic opportunities and perpetuating intergenerational poverty traps.

Ours is an attempt to provide a reliable yet simple way to reliably identify priority sectors. An important nuance though is that the implementation of policy might be limited by geographical factors. Therefore, the identification of priority zones might be useless if we rely solely on local government policy. For instance, consider the clear black strip in the west of Mexico shown in Figure 5. We can infer that strip was created by Sierra Madre Occidental, so the difficulty of access to energy sources from those municipalities in the states of Sonora, Chihuahua, Sinaloa and Durango are not to be fixed easily by funneling more money to the municipalities but might require the implementation of a national strategy.

The results illuminate these nuanced realities. The choropleth maps vividly show that energy poverty is not a single, uniform problem. For instance, the findings underscore that in Southern states, affordability emerges as a dominant constraint, reflecting the high economic burden of energy relative to income. Conversely, in the distinct, persistent black strip along the Sierra Madre Occidental—a feature driven by geography, not just economics—the primary issue is one of availability and accessibility. This finding is perhaps the most actionable for policymakers, as it suggests the required intervention changes fundamentally depending on the region's dominant deprivation driver.

Future research should focus on integrating a time-series approach to the LUMEN Index to accurately track the impact of specific policy interventions over time, moving beyond this static snapshot. Additionally, while the index currently balances data availability with accuracy, the inclusion of more granular and continuous climate data could further refine the measurement, particularly in understanding the energy burden related to thermal comfort and climate control. Ultimately, the LUMEN Index is a data-driven invitation for the Mexican government to evolve its energy policy from a national mandate to a highly localized, evidence-based instrument for improving the livelihoods of its most vulnerable citizens.

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