EXPLORING MICROGRIDS AS A PROMISING SOLUTION FOR EQUITABLE ELECTRICITY ACCESSIBILITY

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Ensuring fair access to electricity in urban areas is a major challenge that calls for a fresh perspective on urban development. One promising approach is to explore innovative solutions, like improving electrical infrastructure using distributed energy systems such as microgrids. The first step toward creating novel distributed solutions is to better understand the equity problem and identify potential implementation challenges. This study addresses this, taking a two-step approach. First, using historical data, the potential association between people's socioeconomic backgrounds and their access to electricity is investigated. This will help to determine if current electrical systems are serving all citizens equitably. Second, insights from experts were gathered through a semi-structured interview to uncover potential challenges in implementing widespread distributed energy systems and equitable energy solutions. By combining the findings from the data analysis and expert input, this study sets the groundwork for future research. This research will focus on identifying new potential solutions to improve equitable access to electricity in urban areas. The results of this study will provide valuable information to decision-makers, helping them identify opportunities and challenges in implementing distributed energy solutions, ultimately leading to a more equitable urban electricity infrastructure.

Keywords: Equity, Electricity access, Distributed energy systems, Socioeconomic background.

1 INTRODUCTION

The pursuit of equitable infrastructure development is a cornerstone of a just and sustainable society. It upholds the principle that essential resources and services, such as electricity, should be readily accessible to all individuals, regardless of their economic status, racial identity, or geographic location. It is a pivotal element in shaping a future marked by both equity and sustainability. As the global urban population continues to expand, the demand for electricity intensifies, underscoring the necessity of establishing equitable electricity infrastructure systems. Moreover, given the exacerbating effects of climate change, ensuring equitable access to reliable and affordable energy resources is critical. An illustrative example of the life-threatening consequences of climate change which necessitates having an equitable electricity infrastructure is the escalating frequency and intensity of global heat waves that more than any other natural disaster claim lives (Chow 2022). Heatwaves underscore the urgent need for accessible cooling mechanisms during heat waves (Mastrucci et al. 2022), highlighting the life-saving role of electrical infrastructures. Despite growing awareness of the importance of equitable urban infrastructure,
there remains a limited understanding of the issue's magnitude. The primary objective of this study is to empirically examine the accessibility of electricity for individuals across diverse socio-economic backgrounds.

Addressing the intricate challenge of equitable electricity access may necessitate a comprehensive reevaluation of core approaches to city planning, infrastructure design, resource management, and construction methods. An underexplored avenue involves investigating decentralized energy infrastructures, such as microgrids, as a potential solution to ensure reliable and equitable access to electric power in urban settings. Despite extensive investigations into decentralized energy solutions, the prevailing literature predominantly focuses on environmental impacts (Zhang et al., 2022), financial benefits discussed by the National Academies of Sciences, Engineering, and Medicine (2023), electrification of isolated rural areas (Chakravarty and Roy 2021), and resilience (Dharmasena et al. 2022). A promising avenue for addressing equity issues lies in the augmentation of microgrids to centralized grid systems to provide more reliable and equitable energy access, particularly in areas prone to grid failures during extreme events. However, there is insufficient understanding of developing, and evaluating distributed solutions such as microgrids to address energy equity issues. The second study objective aims to bridge this knowledge gap by identifying potential challenges through a semi-structured interview with experts working in the area of distributed energy systems.

This study aims to contribute to offer insights to guide the development of fair and sustainable urban energy systems. It's a crucial step toward realizing a future where electricity access is not only equitable but also resilient, inclusive, and responsive to the needs of all urban residents, regardless of their background or circumstance.

This study is designed with two main objectives. First, using historical data collected from New York City (NYC), this study empirically examined whether there is a statistically significant association between citizens’ socioeconomic background and their access to electricity. Second, this study investigated how emerging technologies of decentralized electricity infrastructures, such as microgrids, can address equity issues. More specifically, this study aims to address the following interrelated questions. (1) Is there any statistically significant association between citizens’ socioeconomic background and their access to electricity? and (2) What are the potential benefits and challenges of adopting distributed energy systems such as microgrids in the electricity infrastructure systems to address the electricity equity issue?

In this study, the first question is addressed using a series of statistical analyses using publicly available data. The second question is investigated through a series of semi-structured interviews with subject-matter experts. The primary contribution of this study to the body of knowledge is to empirically understand and analyze equity issues in the existing electricity infrastructure systems and how microgrids can solve this problem. The outcomes of this study will help researchers and decision-makers better understand the problems and potential solutions related to equitable electricity infrastructure systems.

The remainder of this paper is structured as follows. First, the first research question is addressed by presenting the data, proposed methodology, and results. Next, the second research question is discussed using the outcomes of the semi-structured interview, and the potential directions for future studies are discussed. Finally, in the conclusion section, the findings and contributions of this study to the body of knowledge and state of practice are summarized.

2 STATISTICAL ANALYSIS OF EQUITABLE ACCESS TO ELECTRICITY

In this section, the study begins with a detailed review of the dataset employed to analyze access to electricity. Following that, the methodology used in this study is outlined. Finally, a
A comprehensive discussion of the results and findings is provided, explaining a deeper understanding of the conclusions drawn from the research.

2.1 Data

For this study, an analysis was carried out using various socioeconomic factors within New York City. These factors encompassed elements such as the city's population, per capita income, unemployment rate, the percentage of the educated population, and the percentage of the non-white population. Data for this analysis was sourced from publications by the United States Census Bureau (2017), the American Community Survey 5-Year Estimates, with a focus on zip code-level granularity.

Furthermore, citizens’ access to electricity is investigated using the number of power outages at the zip code level of granularity. The study incorporated data regarding power outages in New York City, including their frequency and distribution at the zip code level. This data was collected as part of a National Science Foundation-funded project (Eckstrom et al. 2022). The project’s scope included the real-time monitoring and collection of data on power outages occurring in NYC.

2.2 Methodology

To investigate a potential association between socioeconomic factors and the frequency of power outages, a linear regression analysis is employed. The primary objective of this analysis was to ascertain whether there exists a linear association between our dependent variable, which is the number of power outages, and the chosen independent variables of interest which are the previously mentioned socioeconomic factors. To determine any potential linear association, using the regression model represented by Eq. (1), the analysis is conducted.

\[ y = \beta_0 + \beta_1 x + \epsilon \]  

(1)

Where \( y \) is the dependent variable, \( \beta_0 \) is the intercept, \( \beta_1 \) is the regression coefficient or the slope of the regression line, \( x \) is the independent variable, and \( \epsilon \) is the random error (Su et al. 2012).

2.3 Statistical Analysis Results

The linear regression analysis conducted at a 5% significance level unveiled significant associations between the number of power outages and several key socioeconomic factors, including population, per capita income, unemployment rate, the percentage of the educated population, and the percentage of non-white residents. Here, a detailed breakdown of these findings is provided.

In the context of this analysis, Table 1 presents the results of the analysis of the associations between the chosen socioeconomic factors and the occurrence of power outages. In this table, \( P \)-values are written in the first row of results, while regression coefficients are encapsulated within parentheses. These findings provide valuable insights into the associations between socioeconomic factors and power outage frequency. Considering the results included in Table 1, it becomes evident that zip codes characterized by larger populations, higher unemployment rates, a higher percentage of non-white residents, experience more frequent power outages. In contrast, in those zip codes with higher per capita income, a greater percentage of educated residents generally encounter a lower frequency of power outages.
Table 1. Linear regression results of analyzing the association between socioeconomic factors and the number of power outages.

<table>
<thead>
<tr>
<th>Socioeconomic Factors</th>
<th>Population</th>
<th>Per Capita Income</th>
<th>Unemployment Rate (%)</th>
<th>Education (%)</th>
<th>Race (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Power Outages</td>
<td>9.538E-07</td>
<td>2.296E-25</td>
<td>5.740E-07</td>
<td>7.403E-23</td>
<td>6.844E-05</td>
</tr>
<tr>
<td>(0.0031)</td>
<td>(-0.0038)</td>
<td>(632.5481)</td>
<td>(-606.9010)</td>
<td>(208.3803)</td>
<td></td>
</tr>
</tbody>
</table>

3 MICROGRID’S POTENTIAL BENEFITS AND CHALLENGES

In the quest for equitable access to electricity, distributed energy systems such as microgrids, emerge as a promising solution. However, to fully grasp their potential, one must investigate the challenges and benefits of their utilization. Having a semi-structured interview with three experts working in the area of distributed energy systems, the intricate interplay of perspectives and challenges that define this realm is discovered. Energy equity in terms of access to electricity is currently a vital concern, while it is argued that this issue remains underestimated in planners' agendas. This duality sparks questions about the awareness and prioritization of the problem. A common thread running through the conversations is the absence of universally accepted metrics for measuring equitable electricity access.

Considering equity issues in terms of access to electricity, the advantages of distributed energy systems, particularly microgrids, as a potential solution come into sharp focus. Experts agreed on the ability of these distributed systems to promote equity and offer financial benefits to users. However, these benefits coexist with concerns about limitations and the intricacies of integrating them with existing grids. Moreover, among the discussions about these systems' potential benefits for equity purposes, there was some concern about the limitations and challenges of distributed energy systems' large-scale implementation. Among the challenges, one that was considered a vital concern is the development of new policies that can facilitate the large-scale adoption of distributed electricity. To address this, incentive programs should be designed to make these technologies financially viable for all, especially those with limited income. Additionally, political leaders' understanding of the potential benefits offered by these systems is recognized as crucial for a smoother transition. However, it is believed that there is a need for clear technical solutions to precede policy development. The technological readiness for distributed energy systems is a subject of lively debate. While some experts view the current state favorably, others highlight technology gaps and the financial burden associated with storage and microgrid technologies. One technology gap is the variability in the daily electricity generation from intermittent sources, such as solar panels, raising challenges for their large-scale implementation. The solution may lie in the augmentation of distributed energy systems to the conventional grid instead of the full replacement of these systems with the grid. This approach can be helpful during peak hours, reducing pressure on the grid and costs.

Resistance from electrical companies that own centralized grid systems, to switch to more decentralized systems is often driven by financial considerations, overshadowing equity concerns. Ownership becomes the basis for shaping their stance. On the other hand, there are some concerns about the resistance to the adoption of these newly emerged technologies from the electricity user side and their acceptance level. Skepticism endures among the public regarding the reliability of
decentralized electricity generation. A general lack of consumer knowledge contributes to this skepticism. This highlights the importance of raising awareness and enhancing consumer understanding. Incentive programs emerge as powerful tools to promote decentralized energy systems to increase public acceptance. However, their success is greatly influenced by the geographic dynamics of specific locations, reflecting the intricate nature of the market. Additionally, there are concerns that emerge subsequent to reaching a level of social acceptance. These concerns are regarding users’ electricity consumption behavior after the implementation of distributed energy systems. From one point of view, it is believed that the possibility of reducing energy consumption through the adoption of decentralized energy systems depends on consumer awareness and there might be a few numbers of electricity users that will reduce their consumption. From another point of view, individuals are more likely to adopt energy-saving practices when they can see a direct financial benefit like the financial benefit coming from selling energy to the grid. However, the development of real-time electricity pricing mechanisms and ensuring cybersecurity for peer-to-peer trading emerges as a challenge. Despite cybersecurity concerns, the benefits of this trading mode are recognized as beneficial for both utilities and consumers.

In densely urbanized areas, spatial constraints pose significant challenges to the large-scale implementation of distributed electricity systems, particularly microgrids. However, the emergence of more efficient panels might hold the promise of mitigating these constraints to some extent. Moreover, the concern regarding the short life cycle and waste management of photovoltaic panels is of interest. Experts display less apprehension in this regard, with the possible presence of recycling companies dedicated to managing PV panel waste, offering a promising perspective. Moreover, the eco-friendly nature of PV panels alleviates some concerns.

The primary concern revolves around the cost implications of microgrid solutions, given that the associated technologies have historically accrued substantial expenses. Nevertheless, there is a noticeable trend indicating a gradual reduction in these costs. Maintenance, including battery replacements, adds a recurring cost. However, Microgrids offer a self-contained energy solution with lower maintenance costs compared to traditional fossil fuels.

While the concept of augmenting centralized grids with distributed microgrids in vulnerable areas is conceptually a good solution for equity issues, practicality unveils its own set of questions. Transforming this concept into reality demands more reliable technology and thoughtful space considerations. It becomes apparent that the path to equitable electricity access is marked by both challenges and opportunities. The intricate interplay of factors and diverse perspectives enriches the understanding of this complex landscape.

4 CONCLUSION

This paper underscores the urgent need for equitable electricity access particularly for vulnerable urban populations. The empirical analysis of New York City’s socioeconomic data reveals significant associations between citizens' socioeconomic backgrounds and the frequency of power outages. This insight into disparities across zip codes lays the groundwork for targeted interventions and highlights the critical role of equitable infrastructure in mitigating life-threatening consequences.

Furthermore, the study delves into the potential of decentralized energy systems, such as microgrids, to address electricity access equity issues. While acknowledging the promise of distributed systems in promoting equity and offering financial benefits, the research emphasizes challenges such as these systems’ integration with existing grids, policy development, and public acceptance. The findings stress the need for clear technical solutions, increased awareness, and thoughtful policy measures to pave the way for a transition to more decentralized energy systems.
Despite the complexities, the study contributes valuable insights to guide researchers, policymakers, and urban planners in fostering fair and sustainable energy systems for all urban residents.

References


