INPLASY

The impact of mini-grid solutions on energy access in rural communities of developing countries: A systematic review

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ADMINISTRATIVE INFORMATION

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 9 January 2025 and was last updated on 9 January 2025.

INTRODUCTION

Review question / Objective Review Question: To what extent do mini-grid solutions improve energy access in rural areas of developing countries, according to academic literature?
Objectives:
To review and provide an overview of the existing literature characteristics, including research trends, key authors, geographical focus, types of mini-grid systems, methodological approaches, and research themes, for studies conducted between 01/01/2010 and 30/07/2024.
To assess the impact of mini-grid solutions on energy access by evaluating key energy metrics such as electrification rate, electricity availability, reliability, hours of supply, affordability, and power supply consistency in rural developing countries.

Rationale The rationale for the study is grounded in addressing the significant challenges of energy access in rural areas of developing countries. One of the key points supporting this rationale is the persistent energy poverty that affects many people around the world. Despite progress in global electrification, as of 2023, 746 million individuals still lacked access to electricity, with 80% of them residing in Sub-Saharan Africa. This statistic underscores the urgent need for solutions that are specifically tailored to rural and underserved regions.
In addition to energy poverty, there is a considerable dependence on inefficient energy sources in these areas. Traditional energy sources such as biomass, kerosene, and diesel generators dominate the rural energy landscape. This reliance leads to severe health issues, contributes to environmental degradation, and hampers economic growth.
Furthermore, the potential of mini-grid solutions presents a promising avenue for addressing these challenges. Mini-grid systems that are powered by renewable energy sources, such as solar, wind, and hydro, are emerging as decentralized alternatives to conventional central grid systems.

These systems offer sustainable, reliable, and context-specific energy generation opportunities that can significantly benefit rural communities.

Condition being studied The condition being studied in this systematic review is the lack of adequate energy access in rural areas of developing countries. Specifically, the study focuses on several key issues.
First, energy poverty is a significant concern, as a large portion of rural populations in these regions lacks access to reliable and sustainable electricity. This inadequate energy access leads to a heavy reliance on traditional and inefficient energy sources such as biomass, kerosene, and diesel generators.
Second, challenges in energy metrics are prevalent. Limited electrification rates, unreliable power supply, insufficient electricity hours, high energy costs, and inconsistent power supply all contribute to the difficulties faced by these communities.
Finally, there are considerable barriers to infrastructure development. The high costs associated with extending central grid systems to remote areas, along with various regulatory hurdles and maintenance challenges, exacerbate the energy access condition.
This study investigates how mini-grid solutions, as a decentralised alternative, can effectively address these conditions and enhance key energy access metrics such as electrification rates and electricity availability in rural areas.

METHODS

Search strategy ScienceDirect: (“mini-grid” OR “microgrid”) AND (“energy access”) AND (“rural areas” OR “off-grid” OR “developing countries” OR “low-income countries” OR “global south” OR “underdeveloped regions”)
Web of Science: (“mini-grid” OR “microgrid” OR “mini grid” OR “micro grid” OR “renewable energy system” OR “distributed generation” OR “decentralised energy” OR “off-grid system”) AND (“rural” OR “remote” OR “rural communities” OR “rural areas” OR “off-grid” OR “developing countries” OR “low-income countries” OR “global south” OR “underdeveloped regions”) AND (“energy access” OR “electrification” OR “energy poverty” OR “energy supply” OR “electricity access” OR “power supply”)
SCOPUS: (“mini-grid” OR “microgrid” OR “mini grid” OR “micro grid” OR “renewable energy system” OR “distributed generation” OR “decentralised energy” OR “off-grid system”) AND (“rural” OR “remote” OR “rural communities” OR “rural areas” OR “off-grid” OR “developing countries” OR “low-income countries” OR “global south” OR “underdeveloped regions”) AND (“energy access” OR “electrification” OR “energy poverty” OR “energy supply” OR “electricity access” OR “power supply”).

Participant or population Rural communities in developing countries.

Intervention Mini-grid solutions.

Comparator Rural communities with mini-grid solutions in various geographical regions.

Study designs to be included The systematic review follows PRISMA 2020 guidelines, focusing on rural developing communities. A comprehensive search in databases (ScienceDirect, Web of Science, SCOPUS) was conducted for studies from 2010-2024. Guided by the PICO framework, it analyzed rural communities, mini-grid interventions (solar, hybrid, etc.), comparisons with non-electrified areas, and energy metrics (reliability, affordability). Inclusion criteria emphasized peer-reviewed articles; data were extracted on methodologies (62% quantitative, 15% qualitative, 22% mixed-method) and energy access metrics.

Eligibility criteria No additional inclusion or exclusion criteria not defined in the PICOS sections.

Information sources The systematic review utilized several information sources to identify relevant studies. First, electronic databases such as ScienceDirect were employed to access peer-reviewed journal articles and research papers that focus on mini-grid solutions and energy access. Additionally, Web of Science offered comprehensive coverage of multidisciplinary studies and citation analysis, while SCOPUS was used to identify a broad range of articles and reviews from both technical and social science fields.
To effectively extract studies that aligned with the research objectives, specific search queries incorporating Boolean operators and keywords were applied. Keywords included terms such as "mini-grid," "microgrid," "energy access," "rural areas," and "developing countries."
The timeframe for the studies considered in the review spanned from January 1, 2010, to July 30, 2024, which allowed for the capture of recent developments in the field. Furthermore, only peer-reviewed journal articles, case studies, and systematic reviews published in English were included to ensure the credibility and relevance of the selected sources.

Lastly, non-relevant sources were systematically excluded from consideration to maintain the focus and quality of the review.

Main outcome(s) A review of energy access metrics reveals that 92% of studies reported improved electrification rates, particularly in rural areas, and a similar percentage noted enhanced electricity availability through mini-grids, though this varied by region. Affordability improved in 95% of studies, while reliability showed mixed results, with 84% noting stable power supply but only 37% discussing daily supply hours. Hybrid systems were the most studied technology at 64%, followed by solar-based systems at 25%, with research predominantly from Asia (43%) and Africa (35%).
Quantitative methods were used in 62% of studies, with gaps identified in econometric models, exploration of underrepresented regions like Latin America, and socio-cultural impacts. Mini-grids hold potential for sustainable energy access in rural areas, but success depends on addressing affordability and reliability challenges. Future research should combine socio-technical analysis with statistical modelling to better understand mini-grid impacts.

Additional outcome(s) N/A.

Data management The data management process for the systematic review followed a structured approach to ensure accuracy, transparency, and reproducibility:
Data Collection:
1. Database Selection: Data were collected from ScienceDirect, Web of Science, and SCOPUS using predefined search queries.
2. Search Strategy: Boolean operators and keywords were employed to extract relevant studies based on the inclusion and exclusion criteria.
Screening and Selection:
3. PRISMA Flow Diagram: The PRISMA guidelines were used to document the identification, screening, eligibility, and inclusion process for studies.
4. Duplicates Removal: Duplicate records were removed before the screening phase.
5. Eligibility Assessment: Titles, abstracts, and full-text articles were reviewed against the predefined inclusion criteria.
Data Extraction:
6. Key Information Extracted: Study characteristics (e.g., authors, year, geographical focus), Mini-grid types (e.g., solar, hybrid), and Energy metrics (e.g., electrification rates, reliability, affordability).
Data Storage:
7. Storage and Organization: Data were systematically stored in spreadsheets or databases to facilitate analysis. Each study was assigned a unique identifier for traceability.
Quality Control:
8. Validation: The extracted data were cross-checked multiple times to minimise errors and ensure consistency.
Analysis:
9. Synthesis: The data were synthesised quantitatively (e.g., percentages for energy metrics) and qualitatively (e.g., thematic analysis).
Data Security:
10. Confidentiality: Access to data was unrestricted to authorised reviewers, and there were no sensitive information issues and in compliance with ethical standards.

Quality assessment / Risk of bias analysis
Quality Assessment:
The quality assessment process for the systematic review ensures rigour and relevance through several key components. It employs the PICO framework (Population, Intervention, Comparison, and Outcome) to define the research scope, focusing on mini-grid solutions for energy access in rural communities of developing countries. Inclusion criteria target peer-reviewed articles, systematic reviews, and case studies published from 2010 to 2024, while exclusion criteria remove studies unrelated to energy access, those focusing on urban areas, non-peer-reviewed materials, or those not in English. A comprehensive search strategy using Boolean queries in databases like ScienceDirect, Web of Science, and SCOPUS was implemented to extract relevant studies. The PRISMA protocol was applied to ensure a systematic and transparent study selection process. Selected studies were categorized by geographical focus, mini-grid technology, methodologies, and key themes, ensuring a mix of quantitative, qualitative, and mixed-method approaches. Finally, studies were assessed based on energy metrics such as electrification rates and reliability. This thorough quality assessment enables the review to synthesize high-quality research, address existing gaps, and provide actionable insights.

Risk of Bias Analysis:
This analysis of bias risks in studies on mini-grids in rural developing countries. Selection bias was mitigated using well-defined inclusion criteria focused on peer-reviewed studies published between 2010 and 2024, guided by the PRISMA protocol. Publication bias was addressed by restricting the review to high-quality literature, though this risked excluding valuable gray

literature. Future reviews could include sensitivity analyses to assess this exclusion. Language bias was a concern, as only English-language studies were included, potentially overlooking research from Latin America and non-Anglophone regions. Temporal bias was partially addressed by selecting a broad timeframe, although earlier foundational research may have been excluded. There was also methodological bias due to the predominance of quantitative studies (62%), which may overshadow qualitative insights. While mixed-method approaches (22%) were included, future research should seek to expand methodological diversity. To mitigate these biases, a comprehensive search strategy used Boolean operators across multiple databases and defined clear inclusion/exclusion criteria based on the PICO framework. The review aimed for methodological diversity but mainly featured quantitative studies. Data extraction involved categorizing studies by geography, technology, energy metrics, and methodology, with cross-referencing to validate findings and identify gaps. In summary, the review acknowledges potential bias from excluding non-peer-reviewed studies and non-English literature and suggests that reliance on highly cited work may overlook innovative research. Future efforts should address these biases for a more holistic understanding of mini-grid solutions in energy access.

Strategy of data synthesis The strategy for data synthesis in the systematic review includes several key components:
The review primarily utilized quantitative synthesis to assess energy access metrics such as electrification rates, electricity availability, affordability, reliability, supply hours, and power consistency, while qualitative synthesis examined socio-cultural and contextual factors influencing mini-grid implementation.
Studies were categorized by geographical focus (e.g., Asia, Africa, Latin America), technological focus (e.g., hybrid systems, solar-based systems), and research methodologies (quantitative, qualitative, mixed). Key themes regarding socio-economic impact, technical feasibility, and policy implications were analyzed using thematic frameworks.
A focused evaluation synthesized results on key energy access metrics, providing summary statistics to highlight trends. The PRISMA protocol was employed to ensure systematic study selection, documented through a PRISMA flowchart.
Findings from individual studies were aggregated to identify commonalities and trends, with real-world examples contextualizing variations in electricity availability and reliability. Visual tools, such as Sankey diagrams and thematic maps, supported the data synthesis.
Additionally, critical appraisal of methodologies and findings identified gaps, such as limited use of econometric models and underexplored regions. Overall, this synthesis offered insights into the impact of mini-grids on energy access in rural developing countries.

Subgroup analysis The subgroup analysis in the systematic review was performed to explore variations in the findings and provide deeper insights into how mini-grid solutions impact energy access in different contexts.
1. Subgroup Categories:
The analysis was conducted based on the following subgroups:
• Geographical Regions:
o Africa, Asia, and Latin America were compared to identify regional differences in mini-grid adoption, effectiveness, and challenges.
• Types of Mini-Grids:
o Solar, hybrid, biomass, and other configurations were analysed to evaluate their specific contributions to energy access metrics.
• Energy Metrics:
o Electrification rates, reliability, affordability, hours of supply, and power consistency were analysed individually.
• Study Methodologies:
o Quantitative, qualitative, and mixed-method studies were compared to examine differences in the depth and scope of findings.
• Year of Publication:
o Trends over time (2010–2024) were assessed to identify evolving research priorities and the influence of global energy policies like the Paris Agreement.

2. Analysis Goals:
• Regional Disparities:
o Highlighted differences in mini-grid performance due to geographic, socio-economic, and policy environments.
o For example, Africa and Asia showed higher research focus, while Latin America had fewer studies due to better-existing energy access.
• Technological Focus:
o Solar and hybrid systems dominated the literature, whereas biomass and hydro systems were underexplored, indicating potential areas for future research.
• Variability in Outcomes:
o Explored how mini-grids performed in specific contexts, such as electrification rates (e.g., 98% in China vs. 17–18% in Sub-Saharan Africa over a decade).
• Methodological Insights:

o Quantitative studies focused on techno-economic aspects, while qualitative studies provided insights into community engagement and socio-cultural impacts.
3. Findings from Subgroups:
• Energy Metrics:
o Electrification and affordability were the most frequently studied, with reliability and hours of supply being less explored.
• Geographical Focus:
o Studies in Africa highlighted high reliance on external funding, while Asia emphasised hybrid systems' scalability and affordability.
• Technology Types:
o Hybrid systems showed the highest potential for reliable and consistent power supply, while solar was more widely adopted due to its simplicity and lower cost.

4. Limitations:
• Subgroup analyses were constrained by limited studies in specific regions (e.g., Latin America) or technologies (e.g., biomass).
• Variability in methodological quality across studies could influence subgroup findings.
This subgroup analysis helped identify disparities and focused on tailoring recommendations to regional and technological contexts.

Sensitivity analysis N/A.

Language restriction N/A.

Country(ies) involved United Kingdom.

Keywords Mini-grids, Energy Access, Rural Electrification, Renewable Energy, Developing Countries.

Dissemination plans
Journal Publications
Conference Presentations
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