REVISTA INVECOM
ISSN en línea: 2739-0063

Electrification of rural areas: progress, challenges, and prospects toward sustainable development. A systematic review

Electrificación de las áreas rurales: progreso, desafíos y perspectivas hacia un desarrollo sostenible. Una revisión sistemática

Received: 18/04/2025 - **Accepted:** 15/08/2025

Víctor Antonio Hinojosa Gómez
https://orcid.org/0000-0003-3021-8548
Victor.hinojosa@hotmail.com
Universidad César Vallejo. Lima, Peru

Abstract

This article systematically analyzes the progress, challenges, and prospects for rural electrification within the framework of sustainable development, considering international, Latin American, and Ecuadorian experiences. Special attention is paid to the role of public policies, implemented technological models, community participation, and environmental sustainability, all aimed at contributing to universal energy access. The research adopts a qualitative approach based on a systematic literature review, following the PRISMA model, which encompasses four phases: search, evaluation, analysis, and synthesis. Fifteen scientific articles were selected from a total of 440 documents, between 2013 and 2025, using rigorous inclusion criteria and keywords related to rural electrification and sustainable development. The review highlights the progress achieved through decentralized models, the expansion of electricity grids, and the development of microgrids based on renewable energy, allowing for comparisons of results across various regions. Finally, the importance of effective public policies, the active involvement of local communities, and the incorporation of renewable technologies to ensure long-term sustainable impacts of rural electrification are highlighted.

Keywords: rural electrification, renewable energy, sustainable development.

Resumen

El presente artículo analiza de manera sistemática los avances, desafíos y perspectivas de la electrificación rural en el marco del desarrollo sostenible, considerando experiencias internacionales, latinoamericanas y ecuatorianas. Se presta especial atención al papel de las políticas públicas, los modelos tecnológicos implementados, la participación comunitaria y la sostenibilidad ambiental, con el fin de contribuir a la universalización del acceso energético. La investigación adopta un enfoque cualitativo basado en una revisión sistemática de la literatura, siguiendo el modelo PRISMA, que abarca cuatro fases: búsqueda, evaluación, análisis y síntesis. Se seleccionaron 15 artículos científicos entre 2013 y 2025, de un total de 440 documentos iniciales, empleando criterios de inclusión rigurosos y palabras clave vinculadas a la electrificación rural y el desarrollo sostenible. La revisión pone de manifiesto los avances logrados mediante modelos descentralizados, la ampliación de redes eléctricas y el desarrollo de microrredes basadas en energías renovables, permitiendo comparar resultados en diversas regiones del mundo. Finalmente, se destaca la importancia de las políticas públicas efectivas, el involucramiento activo de las comunidades locales y la incorporación de tecnologías renovables para garantizar impactos sostenibles a largo plazo en la electrificación rural.

Palabras clave: electrificación rural, energías renovables, desarrollo sostenible.

Introduction

Universal electric energy is a fundamental resource for human development and a key factor in reducing poverty. In this context, rural electrification represents a priority area in governmental and multilateral agency plans. According to a report by the International Energy Agency (IEA, 2023), approximately 675 million people worldwide lacked access to electricity in 2022, the majority of whom reside in rural areas. Reliable and sustainable electricity generation not only enhances household well-being but also boosts economic productivity, education, healthcare, and community resilience. However, the implementation of rural electrification projects remains a significant challenge, particularly in developing countries.

Rural electrification is thus a strategic element for the sustainable development of communities, directly impacting poverty reduction, educational improvement, healthcare access, and economic growth. In fact, the Banco Mundial et al. (2025) indicates that over 666 million people still lack electrical access, concentrated in rural regions of developing countries. This reality underscores that, despite technological advancements and energy policies implemented in recent decades, significant structural barriers persist that hinder universal energy access.

From a technical perspective, rural electrification programs face significant challenges, such as the geographic dispersion of settlements, low population density, and high costs associated with extending conventional electrical networks (Bhattacharyya & Palit, 2016). In response, decentralized solutions based on renewable energy, such as hybrid microgrids, home solar systems, and small hydroelectric plants, have recently been promoted, offering viable, sustainable alternatives tailored to rural contexts.

Socially, access to electricity in rural areas generates profound transformations: it improves educational outcomes, facilitates healthcare service delivery, fosters local entrepreneurship, and strengthens the empowerment of vulnerable groups, particularly women and youth (Barnes, 2007). However, recent research highlights that the success of electrification projects does not solely depend on technical or economic aspects but also on political and community participation. It is essential for individuals to be actively involved through local training and for initiatives to have financial sustainability (Arthur et al., 2025).

The analysis of international, Latin American, and Ecuadorian experiences allows for the identification of best practices, common obstacles, and valuable lessons in expanding energy access in rural areas. Therefore, this article conducts a critical review of these experiences, aiming to contribute to the formulation of strategies that help achieve the goals of "Sustainable Development Goal 7: ensure access to affordable, reliable, sustainable, and modern energy for all" (Organización de las Naciones Unidas, 2023). Access to energy is an essential right for human development and poverty reduction.

In particular, rural electrification is a priority on governmental and multilateral agendas. Reliable and balanced electricity availability not only supports internal progress but also strengthens local economies, education, healthcare, and social stability. Nevertheless, the implementation of electrical projects in remote communities faces barriers that do not exist in developed countries, where successful models address the needs of these areas (La Camera, 2025).

Regarding the traditional model of electrification in rural areas, it is based on the expansion of the national grid, a strategy suitable for regions with low geographic dispersion and moderate population density. This approach has been successful in countries like China and India, where the rapid expansion of the grid achieved nearly 100% coverage in record time. However, high infrastructure investment, maintenance costs, and low demand in remote areas limit its effectiveness in more isolated zones (Almeshqab & Selim, 2019).

On the other hand, isolated and decentralized electrical systems have advanced due to the development of renewable technologies and hybrid systems. Microgrids and distributed solutions provide flexible energy tailored to local needs, reducing dependence on centralized infrastructure. Among the most common technologies are:

- Standalone photovoltaic systems (SHS), ideal for individual households.
- Hybrid microgrids that combine solar, wind, and diesel generators with batteries.
- Small hydroelectric plants in areas with stable water resources.

The adoption of these technologies facilitates access to isolated areas, decreases the carbon footprint, and strengthens community belonging (Paz, 2016). Regarding policies and financial schemes, it is crucial to design clear and stable legal frameworks that incentivize investment in rural electrification, including subsidies, differentiated tariffs, and technical regulations that ensure safety and economic viability. Countries such as Ethiopia and Nepal have developed national strategies that combine centralized planning with decentralized decision-making, promoting expansion through public-private partnerships and international collaboration (Banco Mundial, 2024). Additionally, to address the limited profitability of various rural projects, mixed financial models are being implemented, such as:

- Direct state subsidies.
- "Pay-As-You-Go" (PAYG) payment modalities that allow payments based on availability.
- Rural electrification funds (FER) that stimulate private investment.
- Local energy cooperatives that help reduce financial risks and improve project stability.

In social and economic terms, rural electrification has a multiplicative effect on human development. Among the most notable benefits are:

- Education: Enables night training and access to digital technologies and the Internet.
- Health: Improves refrigerated storage of medicines and equipment, as well as lighting in medical centers for 24-hour care.
- Local economy: Facilitates agricultural mechanization and diversifies commercial activities.
- Gender equality: Reduces manual domestic tasks and strengthens economic autonomy and capabilities of women through microenterprises.

Various studies also indicate that electrification reduces forced migration and strengthens social cohesion, improving rural living conditions (Peters & Sievert, 2016). In relation to challenges and opportunities, energy expansion must be balanced with environmental sustainability and stability. The selection of renewable technologies minimizes greenhouse gas emissions and reduces dependence on fossil fuels, aligning with the global energy transition. However, challenges persist, such as:

- The lack of infrastructure for the proper recycling of components like solar panels and batteries.
- The need for buildings and infrastructure capable of withstanding severe climatic phenomena.
- Limitations in community management, which at times impede the passage of installations through certain territories.

Regarding community participation, social stability is vital for the success of projects. International experience shows that joint planning with communities, prior to operation, significantly enhances the prospects for sustainable long-term outcomes. Technical training, technological support, and the creation of local maintenance networks are essential to ensure the autonomy and proper functioning of systems.

Finally, innovative technologies, such as artificial intelligence for predicting failures, monitoring storage systems, and optimizing distribution, are transforming the traditional perception of rural electrification. These tools allow for cost reduction and increased reliability, opening new perspectives for communities (Poudineh, 2025).

In summary, this article aims to systematically analyze the advances, challenges, and perspectives of rural electrification within the framework of sustainable development. International, Latin American, and Ecuadorian experiences will be considered, with a particular emphasis on the role of public policies, implemented technological models, community participation, and environmental sustainability, thereby contributing to the universalization of energy access.

Methodology

This research adopts a qualitative approach, based on a systematic literature review, with the aim of rigorously and systematically analyzing the advances, challenges, and opportunities in rural electrification processes related to sustainable development. The PRISMA methodological model was used as a reference, which encompasses four fundamental phases: search, evaluation, analysis, and synthesis.

1. Search phase

A documentary search was conducted in recognized scientific databases, such as Scopus, Scielo, Dialnet, Google Scholar, and ScienceDirect. The keywords used were: "rural electrification," "renewable energies," "sustainable development," "energy access," and "energy public policies." Articles published between 2013 and 2025 were selected to include both current approaches and relevant foundations from the last decade. Studies in both Spanish and English were considered, including systematic reviews, case studies, and comparative analyses. Conversely, theses, institutional reports, and non-indexed documents were excluded.

2. Evaluation phase

After the initial gathering, the titles, abstracts, and thematic indexes of the documents were evaluated to determine their relevance concerning the stated objectives. The inclusion criteria were: a) direct relation to rural energy access; b) incorporation of renewable energies in isolated communities; c) analysis of the social, environmental, or economic implications of electricity access. Duplicate documents, articles with fewer than six pages, and those lacking in-depth analysis of rural electrification were discarded.

3. Analysis phase

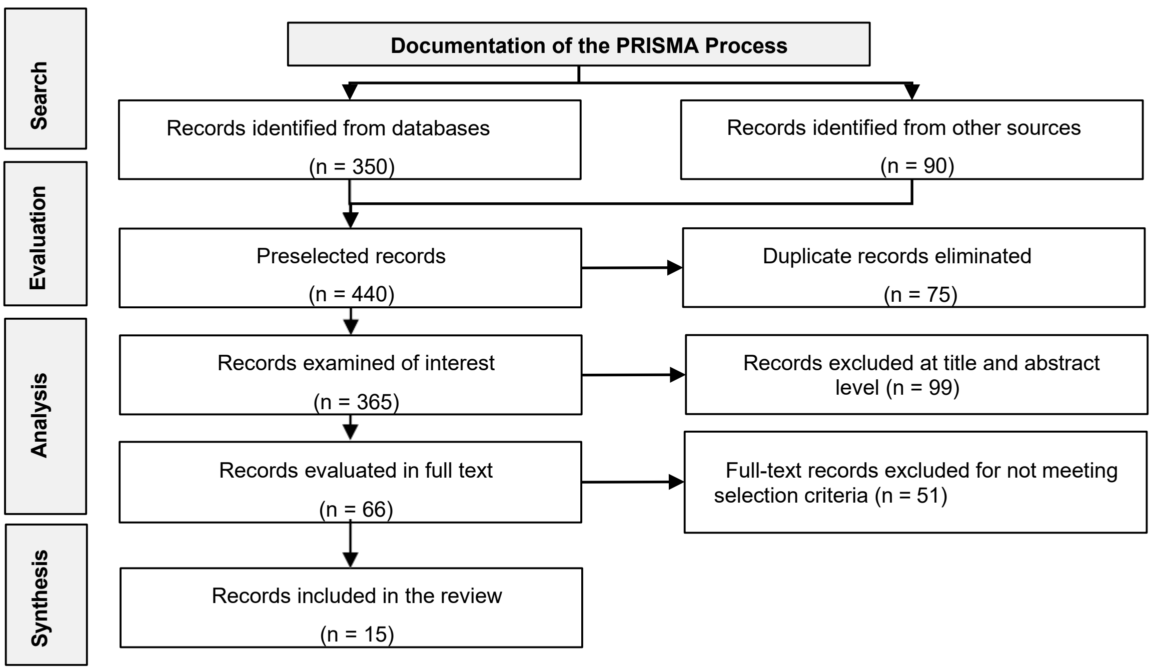
The selected articles underwent detailed critical reading, extracting relevant information on: electrification models (conventional vs. decentralized), social impacts, technical and regulatory barriers, international experiences, community participation, environmental sustainability, and public policy proposals. The data were organized into thematic tables that facilitated the identification of recurring patterns, regional differences, and innovative elements.

4. Synthesis phase

Finally, the findings were integrated around three main thematic axes: a) models and technologies applied in rural electrification; b) economic and social impact of energy access; c) role of policies and financing programs. Additionally, studies that demonstrated the success of participatory and sustainable approaches were highlighted, contrasting them with those reflecting structural limitations. This synthesis allowed for the formulation of solid conclusions about the current state of the topic and generated valuable recommendations for researchers, decision-makers, and stakeholders involved in rural development.

Figure 1

Flow diagram summarizing the selection and refinement process of studies, according to the PRISMA methodology



In total, 440 documents were reviewed, of which 15 scientific articles met all inclusion criteria.

Results and discussion

1. Comparison of influence

- **Reduction of energy poverty**: All reviewed studies agree that electrification of rural areas significantly contributes to reducing energy poverty, although the magnitude of impact varies by context and the model employed to electrify communities. In particular, decentralized models, such as those implemented in Bangladesh according to Samad & Zhang (2017), have proven effective in increasing access to basic energy services in areas far from the main grid. These systems enable households to have lighting, refrigeration, and communication means, thereby improving quality of life. Additionally, they foster the development of productive and educational activities, which are key factors in breaking the long-term cycle of energy poverty.
- **Impact on education and health**: Research highlights a positive effect on access to education by allowing schools and homes to have lighting at night. For example, Lenz et al. (2017) documented significant improvements in educational outcomes in Ethiopia following the implementation of hybrid electrification systems.
- **Local economic development**: Results in this area are consistent, though nuanced. Peters & Sievert (2016) and Lenz et al. (2017) note that while electrification improves living conditions, its direct impact on family income or economic outcomes in the initial years is often limited unless complemented by parallel development or economic training programs.
- **Financial stability**: Samad & Zhang (2017) emphasize the potential of pay-as-you-go (PAYG) models in developing countries, where initial costs represent a significant barrier to energy access. This approach offers greater financial stability compared to traditional solutions.

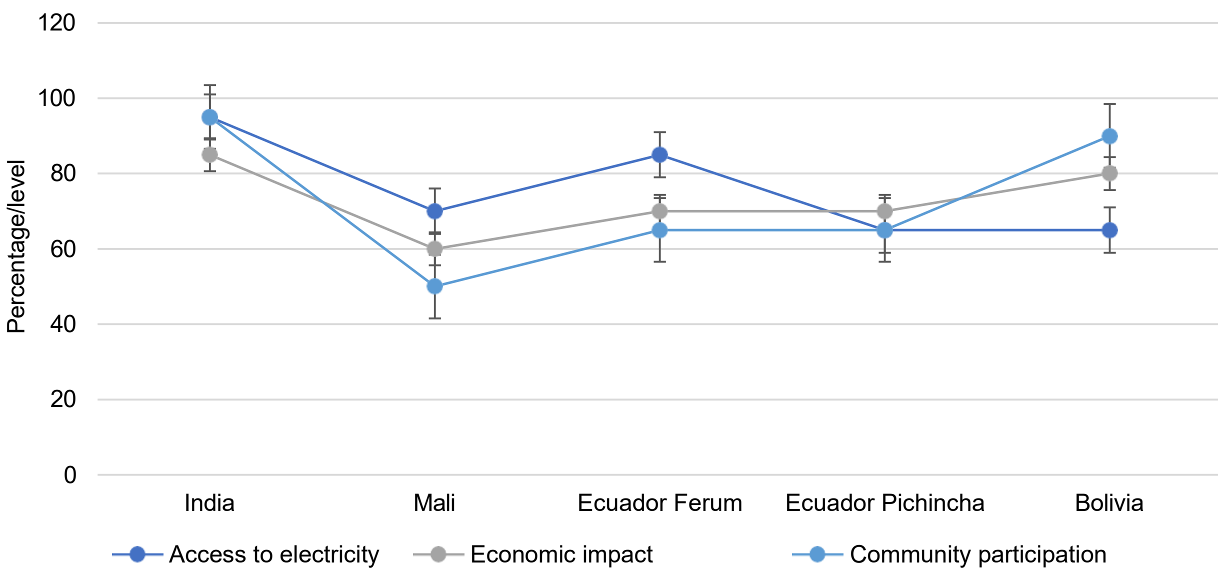
2. International experience

The following table presents a comparison based on specific cases of rural electrification in Africa, Asia, and Latin America, emphasizing their social, economic, and technical impacts:

Author(s)	Year	Region	Electrification Model	Relevant Results
Peters & Sievert	2016	Sub-Saharan Africa	Grid Extension	Moderate poverty reduction, limited impact on agricultural production, high costs associated with domestic consumption.
Bhattacharyya & Palit	2016	Asia (India and Bangladesh)	Renewable Microgrids	Improvement in education and commercial activities, high social recognition, but limitations in outreach capacity.
Samad & Zhang	2017	Bangladesh	PAYG and microfinance for solar systems	Marked reduction in energy poverty, rapid response, and positive economic impacts in rural microenterprises.
Lenz et al.	2017	Ethiopia	Decentralized hybrid electrification (solar-diesel)	Significant improvements in education and continuous access; limited economic benefits in initial stages due to low demand.
Ávila et al.	2023	Latin America (Ecuador)	Photovoltaic solar systems	Reduction of pollution; viability depends on subsidies and public policies.

Figure 2

Comparison of rural electrification indicators



3. Discussion: studied levels

A comparative analysis allows to draw the following conclusions:

- The expansion of the electrical grid, according to Peters & Sievert (2016), is effective in ensuring supply stability, but its high costs hinder implementation in dispersed areas, and its economic impact tends to be limited.
- Photovoltaic solar systems, according to Ávila et al. (2023), and renewable microgrids (Bhattacharyya, 2016), offer lower costs, rapid adaptability, and flexibility in diverse geographical contexts, although they require careful planning for future scalability.
- Hybrid and flexible payment models, according to Samad & Zhang (2017), demonstrate that community integration is crucial for long-term sustainability, regardless of the technology applied.

Similarly, in relation to the graph (Figure 2), a comparison of three key indicators—electricity access, economic impact, and community participation—in rural electrification projects at the international level, in Latin America, and in Ecuador is presented, with a special emphasis on the FERUM program and the province of Pichincha.

1. **India (Barefoot College):** Notable for its high indicators in access, community participation, and economic benefits, reflecting a comprehensive model that combines coverage, community training, and direct income generation.
2. **Mali (VLight):** Shows moderate access to electricity, with stability issues and limited community participation, resulting in indirect economic impact and highlighting the need for complementary policies and programs for local development.
3. **Ecuador (FERUM):** Achieved wide coverage in electrical access thanks to state investment, although economic and social indicators remain average due to low community participation, indicating that electrification must be articulated with productive development policies.
4. **Ecuador (Pichincha):** Exhibits high participation and innovative management approaches, though with moderate economic impact; suggesting that electrification alone does not guarantee socioeconomic development, requiring technical support and training.
5. **Bolivia**: Has achieved notable community empowerment through home photovoltaic systems, although access levels and economic impact remain average due to technical limitations and policy design issues.

Conclusions

Electrification of rural areas goes beyond a technical process; it stands as a key tool for reducing inequality gaps and advancing toward sustainable development. The combination of integrated state policies, innovative business models, and clean technologies is essential to ensure real and sustainable energy access in the long term. The accumulated experience demonstrates that addressing social, environmental, and economic aspects simultaneously is the most appropriate approach to achieving the objectives of universal electrification.

Furthermore, rural electrification should be considered a public policy implemented alongside adaptive technologies, accessible financial programs, and active participation from beneficiary communities. The study shows that there is no one-size-fits-all solution applicable in every context; rather, the effectiveness of each model depends on the economic, geographic, and social environment in which it develops, thereby ensuring that energy access is a universal basic service.

Data reflect that models based on renewable sources, managed through microprograms with strong local involvement, are highly effective in expanding access and reducing energy shortages in isolated areas. These initiatives directly contribute to sustainable development goals, positioning rural electrification as an essential fight against the lack of basic services and as a driver for promoting sustainable communities.

Although significant advances have been made in the last two decades, it is imperative to strengthen policies for universal access, promote the implementation of long-term vision technologies, and safeguard the social, economic, and environmental sustainability of deployed systems.

References

Agencia Internacional de Energía. (2023). *Perspectivas de la energía mundial 2023*. https://www.iea.org/reports/world-energy-outlook-2023

Almeshqab, F., & Selim, T. (2019). Lessons learned from rural electrification initiatives in developing countries: Insights for technical, social, financial and public policy aspects. *Renewable and Sustainable Energy Reviews, 109*, 532–539. https://doi.org/10.1016/j.rser.2018.11.035

Arthur, J. L., Kporha, D. C. E., & Arthur, S. D. (2025). Rural electrification as a catalyst for sustainable development. *Discover Environment, 3*(39). https://doi.org/10.1007/s44274-025-00225-7

Ávila, M. V., Flores, E. T., Cobos, J. C., & Álvarez, M. S. (2023). Sistemas fotovoltaicos en sectores del Ecuador con difícil acceso y/o desprovistos de servicio eléctrico: Un estudio desde las experiencias latinoamericanas. *Revista Latinoamericana de Estudios Sociales, 21*(2), 1–25. https://dialnet.unirioja.es/descarga/articulo/9278342.pdf

Banco Mundial. (2024, 3 de abril). Energizar Etiopía: Un nuevo programa del Banco Mundial amplía el acceso a la electricidad. *Fomento al Desarrollo*. https://fomento.eu/noticias/energizar-etiopia-un-nuevo-programa-del-banco-mundial-amplia-el-acceso-a-la-electricidad

Banco Mundial, Agencia Internacional de Energía, Agencia Internacional de Energías Renovables, Organización Mundial de la Salud, & División de Estadística de las Naciones Unidas. (2025). *Seguimiento del ODS 7: Informe de progreso energético 2025*. Naciones Unidas. https://news.un.org/es/story/2025/06/1539826

Barnes, D. (2007). *The challenge of rural electrification: Strategies for developing countries* (1st ed.). Routledge. https://doi.org/10.4324/9781936331697

Bhattacharyya, S., & Palit, D. (2016). Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? *Energy Policy, 94*, 166–178. https://doi.org/10.1016/j.enpol.2016.04.010

La Cámara, F. (2025, 23 de abril). The powerful role in geopolitics is to manage the energy transition. *Agencia Internacional de Energías Renovables (IRENA)*. https://www.irena.org/News/expertinsights/2025/Apr/The-Powerful-Role-in-Geopolitics-is-to-Manage-the-Energy-Transition

Lenz, L., Munyehirwe, A., Peters, J., & Sievert, M. (2017). Does large-scale infrastructure investment alleviate poverty? Impacts of Rwanda's electricity access roll-out program. *World Development, 89*, 88–103. https://doi.org/10.1016/j.worlddev.2016.08.003

Organización de las Naciones Unidas. (2023). Energía – Desarrollo sostenible. Naciones Unidas. https://www.un.org/sustainabledevelopment/es/energy/

Paz, M. (2016). Redes transnacionales de organizaciones indígenas. Análisis del uso de las redes en conflictos socioambientales. *Revista de Estudios Sociales, 1*(55), 63–72. https://doi.org/10.7440/res55.2016.04

Peters, J., & Sievert, M. (2016). Impacts of rural electrification revisited – the African context. *Journal of Development Effectiveness, 8*(3), 327–345. https://doi.org/10.1080/19439342.2016.1178320

Poudineh, R. (2025). Artificial intelligence and its implications for electricity systems (Issue 145). *Oxford Energy Forum*. Oxford Institute for Energy Studies. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2025/05/OEF-145.pdf

Samad, H., & Zhang, F. (2017). Heterogeneous effects of rural electrification: Evidence from Bangladesh. *World Bank Policy Research Working Paper No. 8102*. Banco Mundial. https://www.researchgate.net/publication/317588429_Heterogeneous_effects_of_rural_electrification_evidence_from_Bangladesh