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Empowering Rural Communities through Renewable Energy Initiatives: A Pathway to Sustainable Development

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Abstract
Access to reliable and sustainable energy is a key factor in improving the well-being of rural communities. This study highlights renewable energy's potential, challenges, and impacts in empowering rural communities towards sustainable development. The analysis shows that implementing solar, biomass, micro-hydro, and wind-based energy systems has increased electricity access by up to 85% in rural communities. In addition, adopting renewable energy has contributed to local economic growth by 70%, mainly through job creation and small business development. From an environmental perspective, using renewable energy has reduced carbon emissions by up to 40%, mainly through reduced dependence on biomass and fossil fuels. However, several challenges still hamper the sustainability of renewable energy implementation, including high initial costs (80%), lack of policy support (70%), lack of technical skills (65%), and limited energy infrastructure (60%). Strategies such as innovative financing models, increased policy incentives, technical training for communities, community-based microgrid development, and multi-sector collaboration need to be implemented more widely to overcome these obstacles. With proper policy implementation and cross-sector support, renewable energy can be a key solution in achieving 100% electrification in rural communities while driving inclusive and sustainable economic development.

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1. Introduction
Access to reliable and sustainable energy is a key factor in driving social and economic development in various parts of the world. Unfortunately, many rural communities, especially in developing countries, still face limitations in obtaining adequate energy sources. According to a report by the International Energy Agency (IEA), more than 700 million people live without access to adequate electricity, most of whom live in rural areas. This inequality creates significant barriers to sustainable development, hampering local economic growth, limiting access to education, and reducing people's quality of life. Therefore, renewable energy solutions are increasingly becoming a significant concern in the global development agenda. Various studies have shown that renewable energy has great potential to increase access to electricity in rural areas in a more environmentally friendly and economical way. Renewable energy-based energy systems, such as solar, micro-hydro, and biomass, can be effective solutions for remote areas not reached by conventional electricity grids [1–3]. Furthermore, renewable energy

projects implemented in a participatory manner in rural communities can increase community economic resilience and create new job opportunities [4–6].

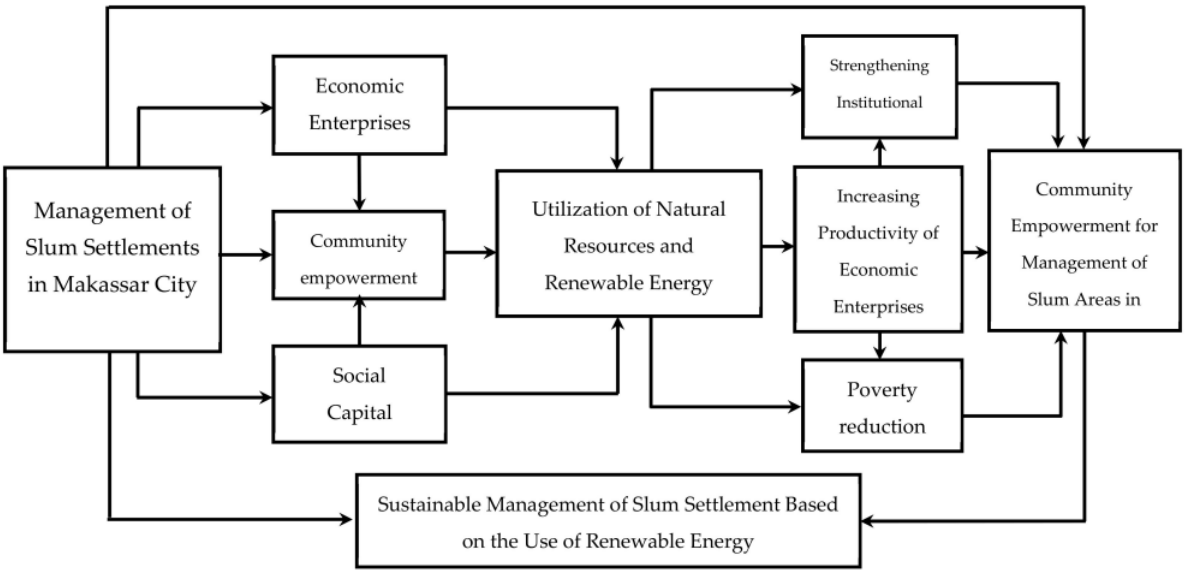

Figure 1: Conceptual framework for community empowerment and utilization of renewable energy based on handling slum settlements [4].

In addition to economic benefits, renewable energy reduces carbon emissions and negative environmental impacts from fossil fuel use. Using solar and biomass energy in rural communities can reduce dependence on firewood and coal, which have been the leading causes of deforestation and indoor air pollution [7–9]. Investment in renewable energy in rural areas could increase energy security and support achieving sustainable development goals (SDGs), especially in poverty alleviation and improving social welfare [10–12]. However, implementing renewable energy in rural communities still faces various challenges. Several significant obstacles to implementing renewable energy, including high initial costs, lack of technical knowledge, and limited government regulations and policy incentives [13–15]. In addition, several studies have also highlighted the importance of a community-based approach in renewable energy projects. For example, projects that involved communities in the planning and maintaining of energy systems had higher levels of sustainability than projects that relied solely on external assistance [16–18].

To address these challenges, various initiatives have been developed by governments, the private sector, and non-governmental organizations. Several case studies from Asia and Africa show that innovative financing schemes, such as community energy-based business models and cross-sector subsidy programs, can help accelerate the adoption of renewable energy in rural areas. For example, the energy-independent village project in India successfully combined solar power with micro-hydro to create a reliable and sustainable hybrid energy system [19–21]. Considering the potential and challenges, efforts to empower rural communities through renewable energy must be continuously promoted as part of a sustainable development strategy. A holistic approach, combining aspects of technology, policy, and community empowerment, is key to ensuring that renewable energy is not only a technical solution but also able to create real social and economic impacts for rural communities. This article will further explore the challenges and opportunities in renewable energy initiatives and how this approach can lead towards inclusive and sustainable development.

2. Energy Challenges in Rural Communities

Although renewable energy has great potential to improve rural communities' welfare, several challenges hinder its implementation. One of the main obstacles is the dependence on fossil fuels and traditional biomass, such as firewood and charcoal. Around 2.4 billion people worldwide still rely on traditional biomass for cooking and heating, negatively impacting public health and the environment

[7]. Biomass combustion produces high carbon emissions and contributes to indoor air pollution, which causes around 4 million deaths yearly from respiratory diseases [22]. In addition, dependence on imported fuels also increases the economic vulnerability of rural communities to fluctuations in global energy prices. Another obstacle is the limited availability of adequate energy infrastructure in rural areas. Around 85% of those without access to electricity live in rural areas, where constructing electricity grids is often uneconomical due to geographical factors and low population density [23]. A study by Bhattacharyya and Palit (2016) found that extending the electricity grid to rural areas can be twice as expensive as in urban areas, leaving many communities with unstable or no access to electricity. This exacerbates the development gap between urban and rural areas and hinders economic opportunities for local communities.

In addition to technical and economic aspects, another challenge is the lack of policy support and sustainable funding mechanisms. Although many countries have set energy transition targets, implementation at the rural level is still limited due to regulations that do not support small-scale renewable energy investments [24]. In addition, energy subsidy schemes in many countries still favour fossil fuels, which makes renewable energy prices less competitive. Only around 30% of total global renewable energy investment is allocated to small-scale projects in remote areas, so many rural communities still struggle to access the funding sources needed to build renewable energy systems [25]. Social and cultural challenges also play a role in inhibiting the adoption of renewable energy in rural communities. A lack of awareness and education about the benefits of renewable energy often makes people reluctant to switch from conventional energy systems [26]. Social factors, such as a lack of technical skills to operate and maintain renewable energy infrastructure, are also significant obstacles. In addition, the success of renewable energy projects is highly dependent on community participation in their planning and management, as highlighted in research [27]. If communities are not involved from the start, the project is at risk of being unsustainable in the long term.

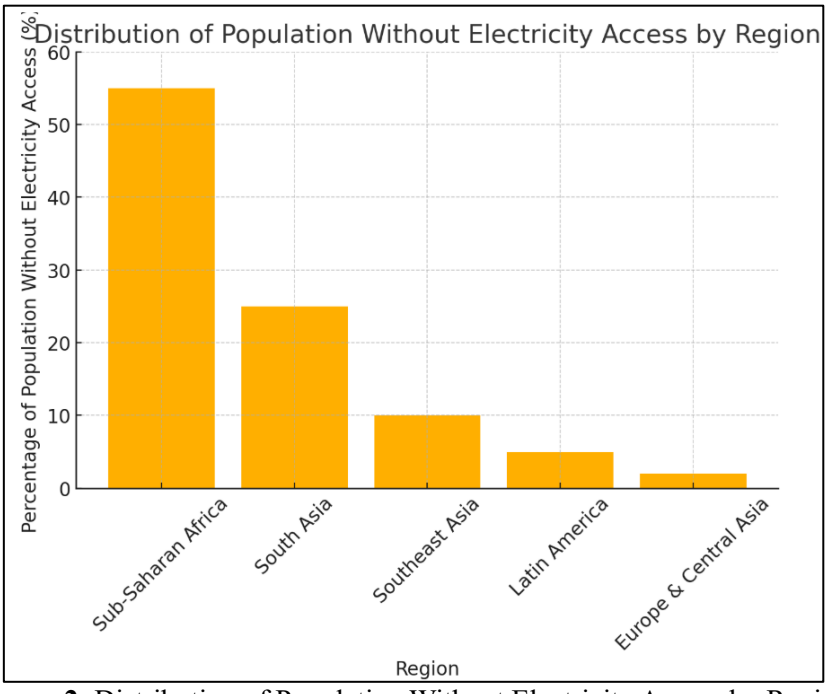

Figure 2: Distribution of Population Without Electricity Access by Region

Figure 2 shows the distribution of the population without access to electricity by region, with Sub-Saharan Africa having the highest percentage, at around 55% of the total population in the region. This reflects the enormous challenge of providing energy infrastructure to remote and hard-to-reach rural areas. South Asia also faces a similar challenge, albeit to a lesser extent, with around 25% of the population still living without electricity. Meanwhile, Southeast Asia and Latin America show lower figures, at around 10% and 5%, respectively, indicating progress in grid expansion and renewable energy initiatives. Europe and Central Asia have the smallest percentages, suggesting that most regions

have achieved near-full electrification. This data underscores the need for a more aggressive strategy to increase electricity access in the most affected areas, mainly through renewable energy-based solutions that can be implemented at a lower cost and faster than conventional grids.

3. Renewable Energy Potential for Rural Areas

Renewable energy has great potential to increase access to electricity in rural areas not yet covered by conventional electricity grids. Distributed energy systems based on renewable energy, such as solar, biomass, micro-hydro, and wind, can effectively solve rural electrification [28]. One of the main advantages of renewable energy is its flexibility and adaptability to local geographic conditions and resources. For example, off-grid Solar Power Plants (PLTS) systems can be an economical and sustainable solution in areas with high solar radiation levels. In addition to solar power, biomass and bioenergy have great potential, especially in rural areas rich in agricultural and plantation waste. Biomass for energy can reduce dependence on fossil fuels and increase the energy independence of rural communities, according to a report from the International Renewable Energy Agency [29]. Agricultural waste conversion projects into biogas and bioenergy in several developing countries have succeeded in increasing electrification in remote villages [30]. In addition to providing electricity, this technology also helps reduce greenhouse gas emissions and improve food security by managing organic waste more efficiently.

Micro Hydro Power Plants (MHP) are a beautiful alternative in areas with sufficient water flow potential. Micro-hydro can provide sustainable electricity to rural communities at lower operating costs than diesel fuel [31]. In addition, micro hydro systems have a long service life and can operate without relying on external fuels. Examples of successful micro hydro applications are in several Asian countries, such as Nepal and Indonesia, where micro hydro-based electrification programs have increased electricity access for thousands of households in remote areas. In addition to the technologies mentioned, the potential of wind energy cannot be ignored, especially in rural areas with reasonably high wind speeds. Small-scale wind turbines can effectively provide energy solutions for coastal and highland regions with stable wind patterns [32]. Although the initial investment for wind turbines is relatively high, this technology can provide a reliable electricity supply with low operating costs in the long term. By combining various renewable energy sources, hybrid energy systems can be developed to improve electricity reliability in rural communities, ensure sustainable energy availability, and reduce dependence on fossil fuels.

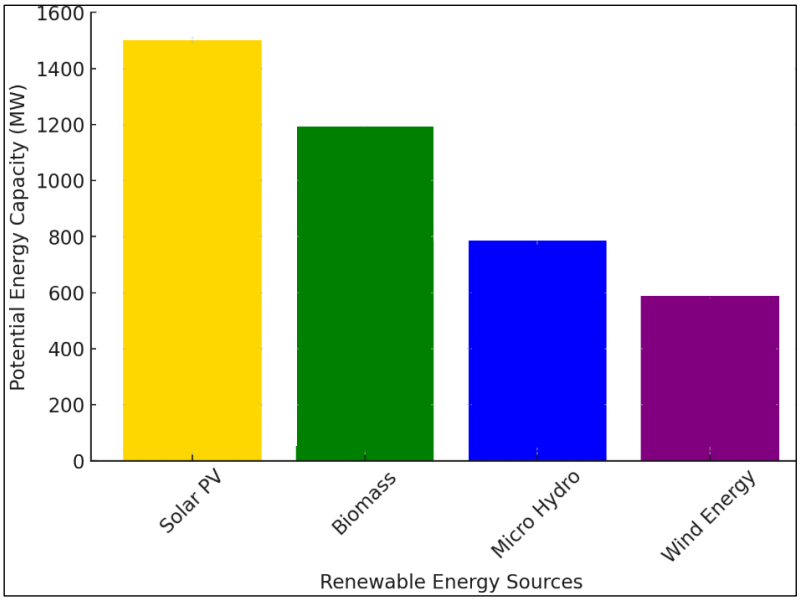

Figure 3: Estimated Renewable Energy Potential for Rural Areas

Figure 3 shows the estimated energy production capacity of various renewable energy sources for rural areas. Solar PV has the highest potential, with a capacity of around 1,500 MW, followed by biomass with 1,200 MW. Micro-hydro also offers significant opportunities with 800 MW, especially for areas

with stable water sources. Meanwhile, wind energy has a lower capacity, around 600 MW, but is still an energy source that can be utilized in areas with reasonably high wind speeds. These data underline the importance of a local resource-based approach in developing renewable energy for rural communities.

4. Renewable Energy Initiatives and Implementation Models

Various renewable energy initiatives have been developed to increase access to electricity in rural areas through government policies, private programs, or collaboration between multiple parties. Developing countries that have successfully increased rural electrification generally implement a hybrid model that combines government subsidies, fiscal incentives, and private sector investment [33]. For example, the "Saubhagya Scheme" program in India has succeeded in providing electricity to more than 26 million households in five years through a combination of solar energy and distributed power grids. In addition, the Bangladesh Rural Electrification Board (BREB) has developed a Solar Home Systems (SHS) system that provides electricity to more than 4 million households with a micro-installment payment system. In addition to government programs, community-based business models are an effective strategy for implementing renewable energy in remote areas. The community-based energy model approach applied in Nepal and Indonesia has increased the sustainability of renewable energy projects [34]. In this model, communities are involved in the planning, managing, and maintaining of energy systems, creating a strong sense of ownership. For example, the Energy Independent Village project in Indonesia is developing micro-hydro power plants that are collectively managed by local communities, with the resulting electricity used not only for household needs but also for economic activities such as agricultural processing and small businesses.

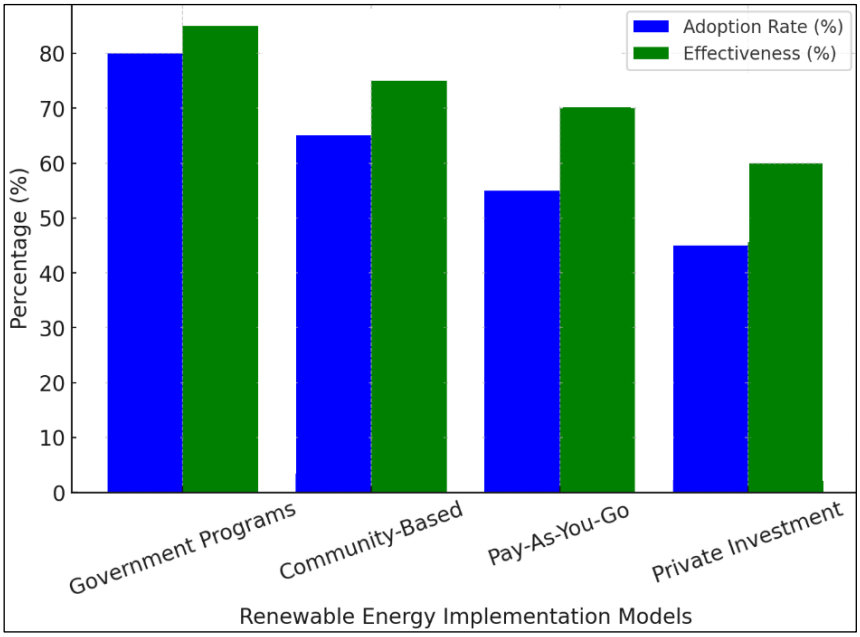

Figure 4: Adoption Rate and Effectiveness of Renewable Energy Models

Innovative financing schemes also play a significant role in accelerating the adoption of renewable energy in rural areas. The “pay-as-you-go” (PAYG) scheme has become one of the financial solutions that enable low-income communities to gain access to renewable energy-based electricity [35]. This scheme allows users to pay for electricity in small instalments using a digital payment system without needing a significant initial investment. Kenya and Tanzania are successful examples of implementing the PAYG model to purchase household solar power systems, which have helped more than 2 million households gain access to electricity. In addition, the availability of grants and low-interest loans from international financial institutions also further support the expansion of renewable energy in rural areas. Although various initiatives have had a positive impact, the challenges in implementing renewable energy in rural communities are still significant. The lack of technical skills, weak regulations, and minimal investment incentives are the main obstacles to the expansion of renewable energy [36].

Therefore, the sustainability of this program requires a multi-sectoral approach involving the government, the private sector, non-governmental organizations (NGOs), and local communities in the planning and implementation process. With the right combination of policies, innovative funding schemes and active community participation, renewable energy can be a long-term solution to improving the welfare of rural communities and driving sustainable development.

Figure 4 shows the adoption and effectiveness of various renewable energy implementation models in rural communities. Government programs have the highest adoption rate (80%) and high effectiveness (85%), indicating that policies supported by regulations and subsidies can accelerate rural electrification. Community-based models are also quite successful, with adoption rates (65%) and effectiveness (75%) reflecting the importance of community participation in renewable energy management. Pay-As-You-Go (PAYG) schemes have 55% adoption and 70% effectiveness, demonstrating that innovative financing models can help address the economic constraints of rural communities. Meanwhile, private investment has the lowest adoption rate (45%) but is still effective (60%), indicating that the private sector plays an important role but requires policy support for broader implementation.

5. Positive Impact on Rural Communities

The implementation of renewable energy in rural communities has significantly impacted various aspects of life, including social, economic and environmental welfare. Renewable energy-based electrification has increased access to health services, education, and communication, directly improving people's quality of life [37]. In several developing countries such as Bangladesh and Kenya, Solar Home Systems (SHS) projects have enabled thousands of households to access electricity for lighting, charging communication devices, and supporting the operation of local health facilities. This directly contributes to reducing the infrastructure gap between rural and urban areas. In addition to increasing access to electricity, renewable energy also positively impacts local economic growth. Renewable energy projects have created new job opportunities in the installation, maintenance, and management of energy systems [16]. For example, in India, the "Ujala" program, which focuses on distributing energy-efficient LED lamps and solar power plants, has created more than 200,000 jobs in the renewable energy sector. In addition, the community-based microgrid model has encouraged the development of small and medium enterprises (SMEs), such as electric rice milling, agricultural product processing, and food storage using solar energy-based cooling.

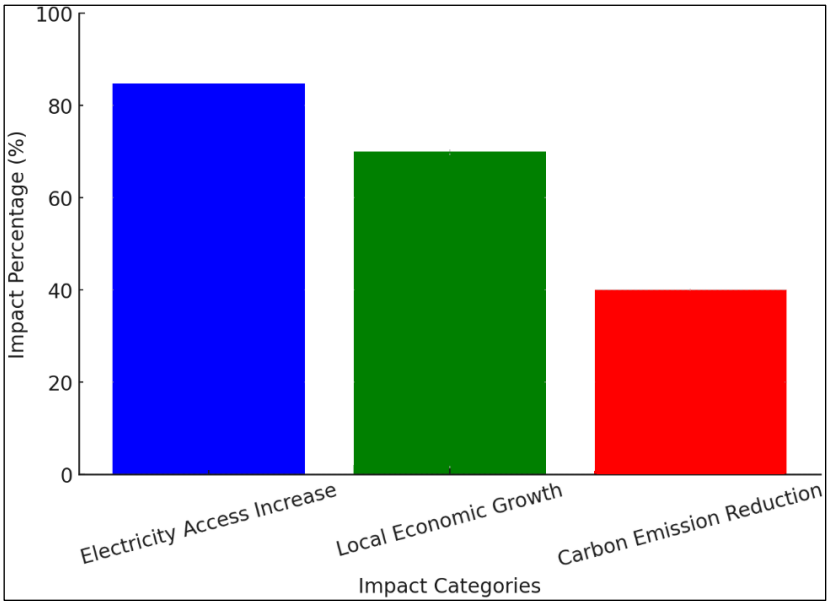

Figure 5: Impact of Renewable Energy on Rural Communities

Environmentally, renewable energy helps reduce dependence on fossil fuels and traditional biomass, often the leading causes of deforestation and air pollution. Implementing biogas and biomass in rural communities in South Asia has reduced carbon emissions by up to 40% compared to using firewood

and charcoal [38]. This has a direct impact on improving public health, especially for women and children who are often exposed to toxic fumes from using traditional stoves. In addition, micro-hydro projects in Nepal and Indonesia have also contributed to preserving river ecosystems, as small-scale hydropower does not cause significant ecosystem changes like large dams. In the long term, the sustainability of renewable energy can accelerate the achievement of the Sustainable Development Goals (SDGs), especially in terms of poverty eradication (SDG 1), increasing access to affordable energy (SDG 7), and mitigating climate change (SDG 13). Countries that have successfully developed renewable energy systems in rural areas tend to experience faster local economic growth compared to countries that still rely on fossil fuels [39]. Thus, developing renewable energy is a technical solution for providing electricity and a catalyst for sustainable economic and social development in rural communities.

Figure 5 shows the impact of renewable energy in three main aspects in rural communities. Increasing access to electricity has the highest impact, with 85% of rural communities experiencing a significant increase in electrification after implementing renewable energy. Local economic growth also shows a significant effect (70%), primarily through job creation and support for small businesses that depend on electricity. Meanwhile, carbon emissions reductions reached 40%, indicating that the transition to renewable energy can help reduce the environmental impact of burning biomass and fossil fuels. These data confirm that renewable energy provides technical benefits and has significant economic and ecological implications for rural communities.

6. Sustainability Challenges and Strategies

Although renewable energy has great potential to improve the welfare of rural communities, several challenges still hamper its sustainability. One of the main challenges is limited infrastructure and high initial costs. Many rural communities, especially in developing countries, still struggle to access renewable energy technologies due to expensive initial investments [40]. For example, although solar power has become more affordable, installing a household-scale solar panel system still requires relatively high costs for low-income communities. In addition, limited electricity distribution networks in remote areas make it difficult for many small-scale renewable energy projects to integrate their resources into the broader energy system. Another challenge is the lack of policy support and incentives for renewable energy in rural areas. Although many countries have set ambitious targets for energy transition, the implementation of policies supporting renewable energy development in rural areas is still limited [24]. Energy subsidies in many countries still favour fossil fuels, making renewable energy prices less competitive. In addition, complex licensing and regulations often hinder investment in this sector. The lack of government involvement in providing fiscal incentives and investment facilities for renewable energy projects in rural areas is also a significant obstacle to ensuring the sustainability of this program.

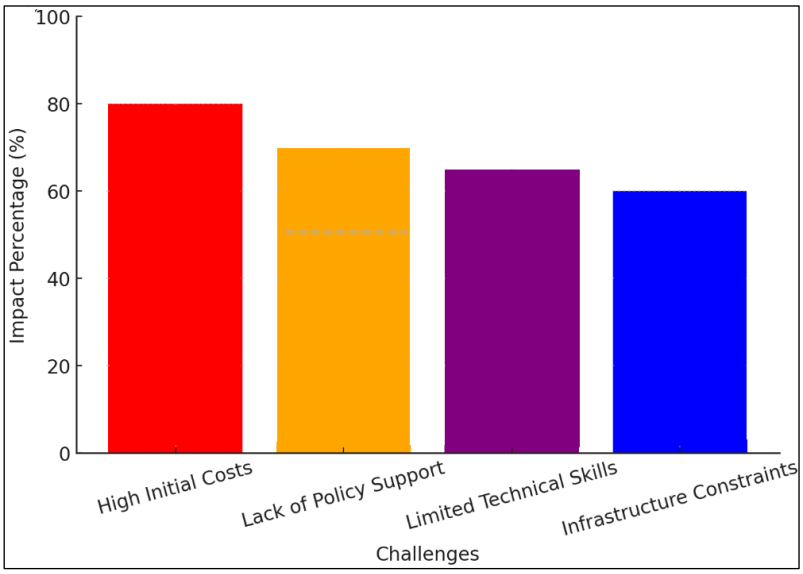

Figure 6: Key Challenges in Renewable Energy Implementation in Rural Areas

From a social perspective, lack of community awareness and technical skills are significant challenges. Rural electrification programs based on renewable energy often face obstacles due to a lack of understanding of this technology's benefits and how to operate it [41]. In several micro-hydro and biomass projects in South Asia, for example, low levels of technical training have caused many energy systems to fail in the long term due to a lack of adequate maintenance and management. Therefore, efforts are needed to increase the capacity of communities to manage and maintain renewable energy systems independently so that these projects can be sustainable. To address these challenges, various studies have proposed several sustainability strategies. The importance of innovative financing models, such as "Pay-As-You-Go" (PAYG) schemes and microcredit, to support energy access for low-income communities was emphasized in a survey [42]. In addition, providing more incentives for renewable energy through subsidy policies and investment facilitation was suggested [43]. From a social perspective, technical education and training programs need to be strengthened to ensure that communities can actively participate in managing their energy systems. Collaboration between government, private sector and non-governmental organizations is also a key factor in ensuring sustainable renewable energy transition in rural areas.

Figure 6 shows the main challenges to implementing renewable energy in rural communities. High initial costs are the most significant challenge, with an impact of 80%, indicating that expensive initial investments hamper many renewable energy projects. Lack of policy support is also an important barrier (70%), suggesting that unsupportive regulations and subsidies that favour fossil fuels hinder renewable energy development. Lack of technical skills impacts 65%, highlighting the lack of community capacity to manage and maintain energy infrastructure. Infrastructure limitations are at 60%, reflecting that many rural communities do not have access to adequate electricity distribution networks. These data underscore the importance of a holistic strategy to address these challenges, including policy incentives, increased technical education, and more flexible financing models.

7. Conclusion and Recommendations

Based on the previous discussion, renewable energy has great potential to improve the welfare of rural communities, especially in areas not yet covered by conventional electricity networks. Implementing solar, biomass, micro-hydro, and wind-based energy systems has increased electricity access by up to 85% in rural communities. In addition, renewable energy initiatives also encourage local economic growth by creating job opportunities and increasing the productivity of small businesses, which contributes to the economic development of 70% in rural areas that have adopted green energy systems. In terms of the environment, the transition to renewable energy has helped reduce carbon emissions by up to 40%, mainly through reducing dependence on fossil fuels and traditional biomass. However, despite the significant benefits, there are still various challenges in implementing and sustaining renewable energy in rural communities. High initial costs (80%) are the main obstacles that prevent many people from switching to renewable energy. In addition, the lack of supporting policies (70%), minimal technical skills (65%), and limited energy infrastructure (60%) are also inhibiting factors in the development of green energy projects in remote areas. Therefore, a more comprehensive and collaborative strategy is needed to ensure the sustainability of the energy transition in rural communities.

To address these challenges, some key recommendations can be considered:

a. Innovative Financing Models: To overcome the high initial cost barrier, governments and financial institutions need to develop more flexible financing schemes, such as "Pay-As-You-Go" (PAYG) systems and microcredit. These models have proven successful in Kenya and India, enabling low-income communities to access renewable energy with small instalment payments.
b. Policy Support and Incentives: Governments should strengthen regulations and provide more favourable subsidies for renewable energy. Only about 30% of global renewable energy investment is allocated to small-scale projects in remote areas. Increasing fiscal incentives and facilitating licensing for renewable energy projects can accelerate the adoption of this technology in rural communities.

c. Community Capacity Building: Technical training and education on renewable energy need to be expanded to enable communities to independently manage and maintain their energy systems. Studies have shown that community-based projects have a higher level of sustainability, as they involve communities in managing and maintaining their own energy infrastructure.
d. Integrated Infrastructure Development: To overcome the limitations of the distribution network, the government and private sector need to develop community-based microgrids that can connect various renewable energy sources in remote areas. Microgrids have been proven to improve the stability of electricity supply and expand the scope of electrification in different developing countries.
e. Multi-sector Collaboration: The government, private sector, non-governmental organizations (NGOs), and local communities must work together to design and implement sustainable renewable energy projects. The public-private partnership model has successfully accelerated the adoption of renewable energy by sharing responsibilities in financing, management, and technology innovation.

With the right strategy, renewable energy can be a significant solution in achieving 100% electrification in rural communities while supporting inclusive economic development and climate change mitigation. If the steps recommended above can be appropriately implemented, renewable energy will be an alternative resource and a major driver of sustainable development in remote areas.

References

[1] P. Malik, M. Awasthi, S. Sinha, Biomass-based gaseous fuel for hybrid renewable energy systems: an overview and future research opportunities, Int. J. Energy Res. 45 (2021) 3464–3494.
[2] D.F. Fitriyana, R. Rusiyanto, W. Maawa, Renewable Energy Application Research Using VOSviewer software: Bibliometric Analysis, Int. J. Sci. Adv. Technol. 1 (2025) 92–107.
[3] B. Bahagia, M. Nizar, M.H.M. Yasin, S.M. Rosdi, M. Faisal, Advancements in Communication and Information Technologies for Smart Energy Systems and Renewable Energy Transition: A Review, Int. J. Eng. Technol. 1 (2025) 1–29.
[4] B. Surya, S. Suriani, F. Menne, H. Abubakar, M. Idris, E.S. Rasyidi, H. Remmang, Community empowerment and utilization of renewable energy: Entrepreneurial perspective for community resilience based on sustainable management of slum settlements in Makassar City, Indonesia, Sustainability. 13 (2021) 3178.
[5] S.M. Rosdi, G. Maghfirah, E. Erdiwansyah, S. Syafrizal, M. Muhibbuddin, Bibliometric Study of Renewable Energy Technology Development: Application of VOSviewer in Identifying Global Trends, Int. J. Sci. Adv. Technol. 1 (2025) 71–80.
[6] A. Gani, S. Saisa, M. Muhtadin, B. Bahagia, E. Erdiwansyah, Y. Lisafitri, Optimisation of home grid-connected photovoltaic systems: performance analysis and energy implications, Int. J. Eng. Technol. 1 (2025) 63–74.
[7] U. Abdela, Review on Environmental and Social Impacts of Rural Household Traditional Biomass Energy Utilization, J. Energy Technol. Policy. 9 (2019) 1–13.
[8] M. Muhibbuddin, M.A. Hamidi, D.F. Fitriyana, Bibliometric Analysis of Renewable Energy Technologies Using VOSviewer: Mapping Innovations and Applications, Int. J. Sci. Adv. Technol. 1 (2025) 81–91.
[9] S. Yana, A.A. Mufti, S. Hasiany, V. Viena, M. Mahyudin, Overview of biomass-based waste to renewable energy technology, socioeconomic, and environmental impact, Int. J. Eng. Technol. 1 (2025) 30–62.
[10] C. Brunet, O. Savadogo, P. Baptiste, M.A. Bouchard, C. Cholez, F. Rosei, C. Gendron, B. Sinclair-Desgagné, N. Merveille, Does solar energy reduce poverty or increase energy security? A comparative analysis of sustainability impacts of on-grid power plants in Burkina Faso, Madagascar, Morocco, Rwanda, Senegal and South Africa, Energy Res. Soc. Sci. 87 (2022) 102212. https://doi.org/https://doi.org/10.1016/j.erss.2021.102212.
[11] Erdiwansyah, A. Gani, M. Zaki, R. Mamat, M. Nizar, S.M. Rosdi, S. Yana, R.E. Sarjono, Analysis of technological developments and potential of biomass gasification as a viable industrial process: A review, Case Stud. Chem. Environ. Eng. 8 (2023) 100439.

https://doi.org/https://doi.org/10.1016/j.cscee.2023.100439.
[12] D. Chirambo, Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030, Renew. Sustain. Energy Rev. 94 (2018) 600–608. https://doi.org/https://doi.org/10.1016/j.rser.2018.06.025.
[13] O. Juszczyk, J. Juszczyk, S. Juszczyk, J. Takala, Barriers for renewable energy technologies diffusion: Empirical evidence from Finland and Poland, Energies. 15 (2022) 527.
[14] A. Gani, Adisalamun, M.R. Arkan D, Suhendrayatna, M. Reza, Erdiwansyah, Saiful, H. Desvita, Proximate and ultimate analysis of corncob biomass waste as raw material for biocoke fuel production, Case Stud. Chem. Environ. Eng. 8 (2023) 100525. https://doi.org/https://doi.org/10.1016/j.cscee.2023.100525.
[15] K. Malik, S.M. Rahman, A.N. Khondaker, I.R. Abubakar, Y.A. Aina, M.A. Hasan, Renewable energy utilization to promote sustainability in GCC countries: policies, drivers, and barriers, Environ. Sci. Pollut. Res. 26 (2019) 20798–20814.
[16] H. Lund, Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modeling of Fully Decarbonized Societies, Elsevier, 2024.
[17] M.G. Gebreslassie, G. Bekele, S.T. Bahta, A.H. Mebrahtu, A. Assefa, F.F. Nurhussien, D. Habtu, A. Lake, V.C. Broto, Y. Mulugetta, Developing community energy systems to facilitate Ethiopia's transition to sustainable energy, Energy Res. Soc. Sci. 117 (2024) 103713. https://doi.org/https://doi.org/10.1016/j.erss.2024.103713.
[18] E. Erdiwansyah, A. Gani, R. Mamat, M. Mahidin, K. Sudhakar, S.M. Rosdi, H. Husin, Biomass and wind energy as sources of renewable energy for a more sustainable environment in Indonesia: A review, Arch. Environ. Prot. 48 (2022) 57–69. https://doi.org/10.24425/aep.2022.142690.
[19] M. Rumbayan, R. Rumbayan, Feasibility study of a micro hydro power plant for rural electrification in Lalumpe village, North Sulawesi, Indonesia, Sustainability. 15 (2023) 14285.
[20] Erdiwansyah, A. Gani, R. Mamat, Bahagia, M. Nizar, S. Yana, M.H. Mat Yasin, Muhibbuddin, S.M. Rosdi, Prospects for renewable energy sources from biomass waste in Indonesia, Case Stud. Chem. Environ. Eng. 10 (2024) 100880. https://doi.org/https://doi.org/10.1016/j.cscee.2024.100880.
[21] Y. Lv, Transitioning to sustainable energy: opportunities, challenges, and the potential of blockchain technology, Front. Energy Res. 11 (2023) 1258044.
[22] A.S. Tomlin, Air quality and climate impacts of biomass use as an energy source: a review, Energy & Fuels. 35 (2021) 14213–14240.
[23] O.O. Babayomi, B. Olubayo, I.H. Denwigwe, T.E. Somefun, O.S. Adedoja, C.T. Somefun, K. Olukayode, A. Attah, A review of renewable off-grid mini-grids in Sub-Saharan Africa, Front. Energy Res. 10 (2023) 1089025.
[24] M.M.V. Cantarero, Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries, Energy Res. Soc. Sci. 70 (2020) 101716.
[25] P. Blechinger, C. Cader, P. Bertheau, H. Huyskens, R. Seguin, C. Breyer, Global analysis of the techno-economic potential of renewable energy hybrid systems on small islands, Energy Policy. 98 (2016) 674–687. https://doi.org/https://doi.org/10.1016/j.enpol.2016.03.043.
[26] T. Ahmad, R. Madonski, D. Zhang, C. Huang, A. Mujeeb, Data-driven probabilistic machine learning in sustainable smart energy/smart energy systems: Key developments, challenges, and future research opportunities in the context of smart grid paradigm, Renew. Sustain. Energy Rev. 160 (2022) 112128. https://doi.org/https://doi.org/10.1016/j.rser.2022.112128.
[27] B. Liu, Y. Hu, A. Wang, Z. Yu, J. Yu, X. Wu, Critical factors of effective public participation in sustainable energy projects, J. Manag. Eng. 34 (2018) 4018029.
[28] V.S.K.V. Harish, N. Anwer, A. Kumar, Applications, planning and socio-techno-economic analysis of distributed energy systems for rural electrification in India and other countries: A review, Sustain. Energy Technol. Assessments. 52 (2022) 102032. https://doi.org/https://doi.org/10.1016/j.seta.2022.102032.
[29] L. Janota, K. Vávrová, R. Bízková, Methodology for strengthening energy resilience with SMART solution approach of rural areas: Local production of alternative biomass fuel within

renewable energy community, Energy Reports. 10 (2023) 1211–1227. https://doi.org/https://doi.org/10.1016/j.egyr.2023.07.057.
[30] M. Pilloni, T.A. Hamed, Small-size biogas technology applications for rural areas in the context of developing countries, Anaerob. Dig. Built Environ. 10 (2021) 70–72.
[31] N. Sanjel, B. Baral, Modelling and analysis of decentralized energy systems with photovoltaic, micro-hydro, battery and diesel technology for remote areas of Nepal, Clean Energy. 5 (2021) 690–703.
[32] V. Magar, A. Peña, A.N. Hahmann, D.A. Pacheco-Rojas, L.S. García-Hernández, M.S. Gross, Wind energy and the energy transition: challenges and opportunities for Mexico, Sustainability. 15 (2023) 5496.
[33] M.M. Rafique, H.M.S. Bahaidarah, M.K. Anwar, Enabling private sector investment in off-grid electrification for cleaner production: Optimum designing and achievable rate of unit electricity, J. Clean. Prod. 206 (2019) 508–523. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.09.123.
[34] H.S. Fathoni, A.B. Setyowati, J. Prest, Is community renewable energy always just? Examining energy injustices and inequalities in rural Indonesia, Energy Res. Soc. Sci. 71 (2021) 101825. https://doi.org/https://doi.org/10.1016/j.erss.2020.101825.
[35] R. Besner, K. Mehta, W. Zörner, How to enhance energy services in informal settlements? Qualitative comparison of renewable energy solutions, Energies. 16 (2023) 4687.
[36] M. Majid, Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities, Energy. Sustain. Soc. 10 (2020) 1–36.
[37] E.A. Soto, A. Hernandez-Guzman, A. Vizcarrondo-Ortega, A. McNealey, L.B. Bosman, Solar energy implementation for health-care facilities in developing and underdeveloped countries: Overview, opportunities, and challenges, Energies. 15 (2022) 8602.
[38] T. Kefalew, B. Tilinti, M. Betemariyam, The potential of biogas technology in fuelwood saving and carbon emission reduction in Central Rift Valley, Ethiopia, Heliyon. 7 (2021).
[39] S. Tabrizian, Technological innovation to achieve sustainable development—Renewable energy technologies diffusion in developing countries, Sustain. Dev. 27 (2019) 537–544.
[40] K. Ukoba, K.O. Yoro, O. Eterigho-Ikelegbe, C. Ibegbulam, T.-C. Jen, Adaptation of solar power in the Global south: Prospects, challenges and opportunities, Heliyon. (2024).
[41] M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum, A. Peacock, Blockchain technology in the energy sector: A systematic review of challenges and opportunities, Renew. Sustain. Energy Rev. 100 (2019) 143–174. https://doi.org/https://doi.org/10.1016/j.rser.2018.10.014.
[42] G. Adwek, S. Boxiong, P.O. Ndolo, Z.O. Siagi, C. Chepsaigutt, C.M. Kemunto, M. Arowo, J. Shimmon, P. Simiyu, A.C. Yabo, The solar energy access in Kenya: a review focusing on Pay-As-You-Go solar home system, Environ. Dev. Sustain. 22 (2020) 3897–3938.
[43] X. Shi, X. Liu, L. Yao, Assessment of instruments in facilitating investment in off-grid renewable energy projects, Energy Policy. 95 (2016) 437–446. https://doi.org/https://doi.org/10.1016/j.enpol.2016.02.001.