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Does Renewable Energy (RE) Contribute to Rural Livelihood? Evidence from Nepal

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Abstract

This study examines the contribution of renewable energy (RE) on rural livelihoods in Nepal using a mixed-methods approach with the consideration of socio-economic development and environmental sustainability. Data were gathered through household surveys, key informant interviews, and focus group discussions across various local levels in Nepal. The findings indicate that the adoption of RE technologies, particularly solar energy, has significantly improved agricultural productivity, income levels, and overall living standards. Solar-powered irrigation systems have enabled farmers to increase crop yields, enhancing food security and income diversification. The study highlights the essential role of community involvement and local governance in the successful implementation and sustainability of RE projects. Despite the initial high costs of RE technologies, the long-term benefits, including reduced energy costs and enhanced environmental sustainability, outweigh these challenges. The reduction in the use of traditional biomass fuels has led to improved air quality and health outcomes in rural households. This research highlights the potential of renewable energy to transform rural livelihoods in Nepal,

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advocating for continued support and investment in RE initiatives to ensure sustainable development in remote and underserved regions.
Keywords*:* renewable energy, contribution, rural communities, solar system

Introduction

Renewable Energy (RE) has emerged as a critical component in the development strategies of rural areas worldwide, significantly contributing to improving livelihoods by providing access to modern energy services, enhancing productivity, and fostering economic growth (Bhandari & Stadler, 2011). The deployment of RE technologies, such as solar, wind, and small-scale hydropower, offers a sustainable solution to the energy challenges faced by rural communities, particularly in regions with limited access to conventional energy sources (Bhattacharyya, 2013). Access to reliable and affordable energy is essential for achieving various developmental goals, including poverty reduction, improved health outcomes, and education (Modi et al., 2005).

The relationship between RE and rural livelihoods is complex and multifaceted. It encompasses the enhancement of agricultural productivity, the creation of new income-generating opportunities, and the overall improvement of living standards (Chaurey et al., 2004). For example, solar-powered irrigation systems have allowed farmers to boost crop yields by providing a reliable water supply, thereby reducing the adverse effects of unpredictable rainfall patterns (Burney et al., 2010). Furthermore, the implementation of decentralized energy systems, such as microgrids, has empowered rural communities by delivering dependable electricity for lighting, communication, and small businesses. This access to reliable energy has led to significant economic empowerment and social transformation (Bhattacharyya & Palit, 2014).

The RE initiatives in rural areas significantly contribute to environmental sustainability by reducing reliance on fossil fuels, lowering greenhouse gas emissions, and encouraging the use of clean energy alternatives (Panwar et al., 2011). The adoption of RE technologies is especially important in remote regions where extending national grids is often not economically viable (Zerriffi, 2010). In these contexts, decentralized RE systems provide a practical solution for ensuring energy access while promoting local development (Sovacool, 2012).

However, the impact of RE on rural livelihoods is not uniform and varies based on factors such as geographical location, socio-economic conditions, and the type of RE technology employed (Heltberg, 2004). Studies have shown that while RE can significantly enhance livelihoods, its effectiveness depends on proper implementation, community involvement, and supportive policies (Urmee & Gyamfi, 2014). For example, the success of solar home systems in improving household energy access in rural Bangladesh was largely due to the active participation of local communities in the planning and implementation process (Komatsu et al., 2013).

The transition to RE in rural areas often encounters challenges such as high upfront investment, limited technical capacity, and the need for sustained maintenance and support (Yadoo

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& Cruickshank, 2012). Overcoming these challenges requires a comprehensive approach that includes capacity building, financial incentives, and the establishment of robust institutional frameworks (Karekezi & Kithyoma, 2002). This paper explores the various ways in which RE contributes to rural livelihoods, drawing on case studies and empirical evidence from different regions.

The Government of Nepal (GoN) actively promotes the use of renewable energy sources to sustainably meet the country's energy needs. It emphasizes increasing the share of renewable energy in the national energy mix and supports rural energy access. The Rural Energy Policy of 2006 focuses on the development and application of renewable technologies, providing a framework for financial mechanisms, technical support, and capacity building.

The Sustainable Energy for All (SE for ALL) initiative, launched by the United Nations, supports global efforts to ensure universal access to modern energy services and increase the use of renewable energy. This initiative aligns with national policies by fostering collaboration and setting targets. Various policies collectively enhance the deployment and integration of renewable energy technologies, contributing to sustainable development and improved energy access.

Methodology

The study employed a mixed-methods approach, combining quantitative and qualitative data to understand the impact of RE uses on rural livelihoods. Data were collected through household surveys, key informant interviews (KIIs), and focus group discussions (FGDs) across various rural areas. The household surveys gathered information on functional status and its role on rural livelihood after the adoption of RETs. KIIs with local government officials, community leaders, and RE organization representatives provided insights into the implementation processes, challenges, and benefits of RETs. FGDs with community members offered diverse perspectives on the socio-economic dimensions of RE adoption.

The study team examined the functional status and impact on rural livelihoods of twenty micro-hydro projects (MHPs) in Baglung, Rolpa, Rukum, Achham and Bajura Districts. Additionally, the Gutu Solar Mini grid Project in the Surkhet District was included in the study to assess its community-level impact. Study team observed five numbers of small solar irrigation pumping system during the site visits. The study also involved direct observation of twelve Improved Water Mills in the Sindhuli District, revealed that many of these mills were in poor physical condition, with owners attempting to transition to electric mills. During the research process, the team visited around 50 households with domestic biogas plants in Sundarbazar Municipality of the Lamjung District. The study also incorporated the impacts of those biogas plants that were functional. Furthermore, the study comprehensively covered the impact of improved cookstoves, electric stoves, and other renewable energy technologies. Field-level assessments and data collection were conducted between November 2023 and June 2024. The

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sample used in this study may not fully represent or encompass the entire range of related technologies. A brief analysis of RE uses and their impact on livelihoods is discussed in next section.

Results

RE is increasingly recognized as a vital component of global efforts to combat climate change and promote sustainable development. Globally, renewable energy sources such as solar, wind, hydro, and biomass have seen significant growth. As of 2023, RE accounts for approximately 29% of global electricity generation, with solar and wind contributing the largest shares (IRENA, 2023). This growth has been driven by technological advancements, decreasing costs, and supportive policies aimed at reducing greenhouse gas emissions and enhancing energy security (IEA, 2023).

In Asia, RE deployment has been particularly notable due to the region's rapid economic growth and energy demands. Countries like China and India are leading the way in renewable energy investments, with China being the largest producer and consumer of RE globally. India has also made substantial progress, aiming to achieve 500 GW of RE capacity by 2030 (IEA, 2023). Overall, Asia contributes significantly to the global RE capacity, with substantial investments in solar and wind power infrastructure.

In Nepal, RE is crucial for meeting the energy needs of its predominantly last-mile population. Despite a limited resource base, Nepal has made significant progress in harnessing hydropower, which is the country's primary RE source, accounting for nearly 90% of the total installed capacity (NEA, 2023). Additionally, Nepal has been expanding its use of solar energy through various initiatives that support the installation of solar home systems and community scale solar mini-grids (AEPC, 2023). The GoN aims to enhance RE adoption and improve energy access in remote areas, reflecting a broader commitment to sustainable development and energy security.

Role of Studied MHPs on Rural Livelihood

Many rural areas, typically situated in challenging geographical locations and having minimal energy needs, are often left out of mainstream electrification initiatives (Van Ruijven et al., 2012). RE based off-grid solutions present a more feasible alternative for these communities, significantly contributing to their economic, social, and environmental development (Kaygusuz, 2011). In Nepal, micro-hydro schemes, particularly "Run of the River" hydro projects with capacities up to 100 kW, are widely used to supply electricity to rural areas. These schemes have proven crucial for rural electrification, reducing laborious tasks, and, to some extent, generating income in Nepal's rural regions, which face challenging geographical conditions and have limited prospects for national grid expansion.

The field assessment revealed that approximately 40% of the MHPs were non-functional. MHPs with poor functional status typically operated for 7 to 14 hours with low load factors,

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whereas systems with good functional status operated for 9 to 20 hours, with load factors ranging from low to high. Satisfactory systems operated for 7 to 14 hours with low to medium load factors.

Financial health across the studied MHPs was similarly inconsistent, with irregularities in tariff collection practices. For instance, the Malagad III MHP employed a structured, energy-based tariff system and reported a 95% collection rate, leading to a healthy financial balance. In contrast, underperforming projects with flat-rate tariffs recorded less than 50% collection, severely impacting their financial viability. Most user committees did not maintain bookkeeping, contingency funds for operation and maintenance (O&M), or conduct audits. Specifically, user committees often lacked bookkeeping and contingency funds and rarely performed audits. Conversely, MHP cooperatives generally maintained manual bookkeeping, had contingency funds for O&M, and conducted audits. The introduction of cooperative or lease-out management models was a significant reform across several MHPs, enhancing community ownership and operational efficiency.

The electrification of rural communities through MHPs spurred the development of small and medium enterprises (SMEs). The number and type of SMEs varied greatly across the micro-hydro communities. Baseline data indicated that there were very few enterprises in most of these communities, with 32 end-uses in 12 micro-hydro serving communities at the time of project commencement. Field assessment data reported that a total of 340 small enterprises are currently operational in studied project locations. These local enterprises can be grouped into two broad categories: common enterprises/businesses like agro-processing mills, sawmills, poultry farms, and bakeries, and specialized businesses like hotels/restaurants, noodles and computer centers. The share of revenue from SMEs increased substantially, accounting for up to 50% of total project revenue in some cases. This growth in energy demand from productive uses reflects the catalytic role of electricity in fostering economic development, particularly in agro-based industries. Existing diesel and/or water mills are generally converted to electric power once electricity reaches the village.

The establishment of SMEs is crucial for the success of MHPs and significantly contributes to rural livelihoods. Common enterprises such as poultry farms and agro-processing mills often emerge following the installation of MHPs. The growth of these businesses is influenced by factors such as local demographics, community proactiveness, availability of credit facilities, effective post-installation support, and the synergistic efforts of local NGOs. Electrification, even though lighting alone, has been noted to precipitate positive impacts on household health, hygiene, education, awareness levels, communication, and access to information. Moreover, the incorporation of productive end uses of electricity through various enterprises has the potential to bring about compounded socio-economic benefits to MHP communities.

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Role of Solar Minigrid on Rural Livelihood

The Gutu Solar Mini Grid (SMG) Project, with a capacity of 100 kWp, was located in Ward No. 8 of Chaukune Rural Municipality in Surkhet District. The SMG provided electricity to 288 households, with around two-thirds of these households belonging to Brahmin/Chhetri ethnic groups. Additionally, 59 households (20.48%) belonged to the Dalit community, and 32 households (14.23%) belonged to Janajati and other minority ethnic groups. The SMG also supplied electricity to 30 productive energy use applications, with another 4 enterprises awaiting 3-phase connections. Furthermore, 9 social institutions, including 3 schools, 4 cooperatives, a health post, and a commercial bank, relied on the SMG for their electricity needs.

Since the installation of the SMG, significant socio-economic impacts were observed at the community level. During the COVID-19 pandemic, the vaccine storage facilities at the local Gutu Health Post played a crucial role in the local government's response. The project also led to drudgery reduction, particularly for women, increased community participation in animal husbandry, improved proximity and reduced costs of services, and enhanced access to distance education for children.

Electricity supply was sometimes disrupted during extended periods of rainfall, along with fluctuations in voltage. Consumers were generally satisfied with the regularity of electricity supply, with more than 75% of respondents perceiving the supply to be regular apart from unexpected disruptions. One key issue identified for the sustainability of the plant was battery replacement. The battery had a limited lifespan, and its efficiency decreased over time. The cost of battery replacement, estimated at NPR 18 million, is beyond the capacity of the local villagers.

Many enterprises emerged in and around the vicinity of Gutu Bazaar after the mini grid's installation. The electricity users' cooperative started saving and credit activities in January 2020 with monthly saving schemes, expanding to daily saving schemes in September 2020. The SMG powered 45 refrigerators (each 18W), 5 ironing machines (each 1,000W), and 4 electrical sewing machines (each fitted with 1 HP motors) within the served community. Extensive use of fans was noted during hot summers. Various SMEs, including furniture industries, grill workshops, and garment industries, were established after the mini grid's installation. Previously, local people had to travel to Birendranagar for welding, but now the facility is available in the village. The traveling distance for agro-processing is significantly reduced as agro-mills became available locally, reducing the time required for agro-processing works. Other facilities like photocopy and photo studios are newly established, reducing service fees and charges.

Gutu Bazaar, a key local market, became busier with increased mobility of people from surrounding areas. Lack of quality electricity access had previously limited-service delivery in local hotels, but the mini grid's electricity supply improved services for travelers and locals. Access to banking and financial services also significantly improved. During community discussions, one major impact of electricity was its contribution to education and communication,

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especially during the COVID-19 pandemic. Children could study later due to lighting, and access to electricity facilitated internet use for video calls and online classes. Students from Kathmandu and other cities returned home during the lockdown and attended online classes from home.

Electricity access also improved the health sector, particularly in maternity and child care. Previously, child delivery at night was difficult and risky, but the situation improved significantly. Vaccine storage facilities in the village provided vaccination services locally, and the local health post supplied stored vaccines to remote health posts without electricity access. The regular vaccination program of Chaukune Rural Municipality continued smoothly due to the vaccine storage facility at the Gutu Health Post. Street lighting improved safety and security, reducing the risk of snake bites at night.

Electricity access significantly increased women's roles. The Executive Committee included 5 women, and women played crucial roles in operating and managing some enterprises. Women led saving and credit groups and were the majority of members. Increased involvement in these groups encouraged women to attend skill development training and participate in local economic activities, leading to more women engaging in commercial activities and contributing to family income. Women demanded equal representation and opportunities in all programs and institutions.

Similarly, the participation and livelihood of disadvantaged groups improved significantly after the solar mini grid's installation. The socio-economic status of Dalits and other disadvantaged groups improved due to increased productivity and efficiency in their livelihood options. Tailoring businesses thrived with electric irons and sewing machines, allowing bulk orders previously made outside the village. Jewelry workshops and other enterprises like masala industries utilized electricity, and involvement in saving and credit groups increased access to finance and financial security.

Role of Solar Irrigation Pumping (SIP) on Agriculture

In various parts of Nepal, particularly in the Terai region, solar pumping systems are used to pump underground water for irrigation. The demand for this technology is high in areas where the national electricity distribution line has not yet reached. Even in locations where the distribution line is available, farmers are often compelled to use diesel pumps due to poor voltage quality and frequent power cuts. During the study, the researcher team observed the SIPs in several locations in the Terai. It was noted that small systems, ranging from 2 to 3 kilowatts, which pumped 70,000 to 100,000 liters of water daily, had significantly benefited individual farmers. The demand for these systems is high because consumers are responsible for constructing civil structures, while the electromechanical components are provided as government subsidies. For farmers who struggled to pay their energy meter bills, this technology proved to be a boon. The development of this technology, which reduced carbon emissions and decreased diesel usage, enabled the benefiting farmers to increase productivity in their fields.

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Role of Improved Water Mill (IWM) on Rural Livelihood

This study assessed the operational and functional status of the surveyed improved water mills (IWMs). The survey was conducted purposively in 12 different IWMs in the Sindhuli District. Only 41.67%, or 5 IWMs, were operational. It was observed that the average daily operating duration of the long shaft type of IWM was 6 hours per day with a standard deviation (SD) of 0.18, while that of the short shaft type was 5 hours with an SD of 1.82. According to users' perceptions, IWMs generally operated for 265 days annually on average. However, the average agro-processing capacity of the surveyed IWMs varied according to the crop type. The major common crops processed in the surveyed area were maize, wheat, and millet. Although the processing capacity varied significantly, the agro-processing capacity of the long shaft was notably higher than that of the short shaft.

The tariff for agro-processing was accepted both in terms of cash and kind. It was observed that the tariff for agro-processing varied according to crop type and IWM type. The tariff was comparatively cheaper for the long shaft, irrespective of the crop type. The tariff rates per kilogram for maize, wheat, and millet were NRs. 2.50, NRs. 2.50, and NRs. 2.59, respectively, for the short shaft, while the tariff rate per kilogram for both maize and millet was NRs. 2 for the long shaft.

Before the use of IWMs, traditional water mills were predominantly used for agro-processing, with a few users also utilizing home-based agro-processing and diesel mills. Most IWM users felt that there was a reduction in drudgery after the installation of IWMs. All users perceived that there had been significant savings in agro-processing time due to the use of IWMs. Generally, it was seen that agro-processing time had been reduced by half after the improvement of water mills. The users seemed to be satisfied or more with the technology. They perceived that IWM technology had brought about positive changes in their income-generating activities, mainly due to the availability of spare time resulting from faster processing times through IWMs and presumably cheaper processing costs associated with the technology. It was observed that adults (both male and female) were saving an average of around 1 hour for agro-processing. Utilizing the saved time due to faster agro-processing was also a critical aspect of the technology. Most users utilized the saved time for agriculture, with many also using it for household activities and income-generating activities. With the benefits that users had been enjoying with IWMs, the majority felt that IWMs had helped in avoiding diesel mills for agro-processing. However, the rising popularity of electric mills, particularly domestic grinders, posed a threat to IWM technology. Therefore, special consideration and post-installation support were deemed essential for its sustainability.

Role of Domestic Biogas Plants (DBG) on Rural Livelihood

A total of 50 biogas plants were visited for the field assessment, and only 15 (30%) digesters were found to be functional at the time of the survey. The survey revealed that households did not rely on a single source of alternative fuel but rather used a mix of alternative fuels. Firewood was the predominant alternative fuel, although the use of LPG was also notably

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observed. FGD participants indicated that road network expansions, easy handling, market accessibility, and social prestige could be the reasons for the increasing trend of LPG use in semi-urban or rural parts of Nepal.

Regarding the responsibility for fuelwood collection, it was observed that in 48% of cases, both adult members of the family shared this responsibility. However, in many households, this responsibility still fell primarily on women. The normal operating hours of the biogas digesters, as per the design, were 2.5 to 3.0 hours a day. Compared to this standard, the survey showed that the biogas digesters were performing reasonably well to meet the cooking needs of the households.

The study also collected information on households' perceptions of sustainable development indicators. Questions related to indoor smoke, time-saving, slurry use, and toilet use along with biogas were asked. A higher percentage (66.66%) of households perceived that indoor smoke had drastically reduced, while 26.66% reported a perceived reduction in indoor smoke. Some respondents (6.66%) were not familiar with the impact of biogas on indoor air pollution. All respondents were asked about their perception of the reduction in specific health issues after the installation and use of biogas digesters. The majority indicated that the use of biogas plants drastically reduced fire or smoke-related diseases. More than 93.33% of households reported a reduction in the incidence of eye infections and respiratory diseases.

Bio-slurry, the only by-product of the biogas digester, is rich in nitrogen content and can be utilized as farmyard manure in agricultural applications. Bio-slurry has the potential to reduce the need for chemical fertilizers and is a key contributor to sustainable development in biogas technology. The study captured the status of bio-slurry application in farmyard settings. Most households (86.66%) reported using bio-slurry as manure. The majority of households stated that the application of slurry manure had increased crop productivity.

Study also examined the displacement of chemical fertilizers and traditional farmyard manure (in the form of fresh dung) with the introduction of bio-slurry. Due to its high nitrogen content, bio-slurry is a potent replacement for urea. The survey results indicated that, on average, the use of farmyard manure, urea, DAP, and potash had decreased after the utilization of bio-slurry, while the use of bio-slurry had increased.

The construction and use of toilets reflect the status of sanitation in households. Biogas user households were recommended to construct toilets and connect them to their biogas digesters if they did not already have one. If they did, they were advised to connect the toilet to the biogas digester to improve the quantity of feeding materials. The survey revealed that all households had toilets, indicating good sanitation conditions among biogas user households.

Role of Improved Cookstoves on Rural Livelihood

The rural population of Nepal predominantly relies on traditional energy sources, particularly for cooking. Traditional cooking stove technologies are often characterized by poor quality and low efficiency, leading to numerous adverse effects on users' health and the

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environment. The increasing demand for fuelwood exacerbates deforestation and environmental degradation, highlighting the urgent need for promoting improved cookstoves (ICS) and electric cooking solutions in rural Nepal. The AEPC, in collaboration with various governmental, non-governmental, and private organizations, has been actively involved in the development and promotion of different types of ICS in Nepal. To date, over 700,000 improved cook stoves have been installed across the country (AEPC, 2024).

The adoption of improved cookstoves and electric cooking technologies can significantly reduce firewood consumption, thereby mitigating deforestation and aiding forest conservation efforts. Additionally, these technologies help minimize indoor air pollution, contributing to a healthier living environment and overall environmental protection.

The eCooking solutions are smoke free, which can substantially reduce respiratory infections, eye irritations, and headaches among users. These technologies also lower the risk of fire hazards in kitchens and improve overall sanitation and health conditions within households.

The introduction of improved cookstoves and electric cooking can save women considerable time spent on cooking, washing utensils, and collecting firewood. This time-saving aspect allows for greater participation of men in kitchen work due to the cleaner environment. Moreover, smokeless kitchens contribute to the better health of kitchen workers. Training local promoters in ICS technology serves as an excellent example of promoting gender equity.

Implementing modern clean cooking technologies in rural Nepal requires a thorough understanding of the socio-cultural environment, religious beliefs, and cultural taboos related to fuelwood types and cooking systems. Without this understanding, it is challenging to achieve widespread adoption of these technologies.

Factors such as lack of knowledge, limited decision-making power among rural housewives, and socio-cultural values hinder the motivation to adopt ICS. To address these challenges, it is crucial to actively involve women and socially disadvantaged groups in ICS promotional activities. Demonstrating and promoting ICS technology through awareness campaigns about its health, environmental, and firewood-saving benefits can significantly enhance its adoption on a larger scale. These technologies offer substantial environmental, health, and gender benefits, contributing to the overall improvement of rural livelihoods. Addressing socio-cultural barriers and enhancing awareness are critical steps towards achieving widespread adoption and realizing the full potential of these clean cooking solutions.

Discussion

The overall findings of this study indicate that RE has significantly improved rural livelihoods across various regions of Nepal. Households that adopted solar energy for lighting and small-scale irrigation reported increased agricultural productivity, higher incomes, and enhanced

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living standards. The use of solar-powered pumps for irrigation enabled farmers to cultivate additional crops, leading to greater food security and income diversification in several rural areas.

Key informant interviews across different areas emphasized the importance of community involvement and local governance in the successful implementation of RE projects. Stakeholders emphasized that the sustainability of these projects depends on continuous support, capacity building, and the establishment of maintenance systems tailored to local needs.

Focus group discussions from multiple communities revealed that, despite the high initial costs of RE technologies, the long-term benefits in terms of reduced energy costs and improved livelihoods outweigh these challenges. Participants across the study area also noted the positive impact of RE on environmental sustainability, with a significant reduction in the use of traditional biomass fuels, leading to improved air quality and health outcomes in rural households. The findings of this study align with existing literature on the positive impact of renewable energy on rural livelihoods. However, the successful implementation of RE projects requires a holistic approach that includes community involvement, capacity building, and supportive policies.

The study also highlights the importance of addressing the challenges associated with the adoption of RE technologies, particularly in remote areas. High initial costs, limited technical capacity, and the need for sustained maintenance and support are significant barriers that must be overcome to ensure the long-term success of RE initiatives.

Conclusion and Recommendation

This study demonstrates that RE has a profound and positive impact on rural livelihoods across Nepal, contributing to significant improvements in agricultural productivity, income generation, and overall quality of life. The adoption of RE technologies, particularly micro-hydro and solar energy, has empowered rural communities by providing reliable and sustainable energy solutions that address both economic and environmental challenges.

Key factors in the success of RE initiatives include active community participation, strong local governance, and continuous support in the form of capacity building and maintenance systems. While the initial investment in RE technologies can be substantial, the long-term benefits, such as reduced energy costs, increased food security, and improved health outcomes, far outweigh the challenges. Moreover, the environmental benefits, including a reduction in greenhouse gas emissions and decreased reliance on traditional biomass fuels, contribute to the overall sustainability of rural development.

There is immense potential for RE and its applications in driving socio-economic transformation in Nepal's rural areas. To fully realize this potential, it is essential to foster supportive policies, encourage community engagement, and ensure that RE projects are adapted to local needs and conditions. Continued investment in the RE sector is not only crucial for

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enhancing rural livelihoods but also for advancing Nepal's broader goals of sustainable development and environmental stewardship.

Author Contributions

Conceptualization, Methodology design, Editing and finalizing the manuscript: BBK, Literature review, Data collection, and Writing-original draft: BKN.

Data Availability Statement

The dataset used in the study is available upon request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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