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Implementation of Household-Scale Solar Power Generation Technology in a Himalayan Mountain Village, Nepal

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ABSTRACT

This community service project addresses energy poverty in remote Himalayan villages of Nepal through the implementation of household-scale solar photovoltaic systems. The project was conducted in Ghunsa Village, Taplejung District, located at 3,595 meters above sea level, where 45 households had no access to grid electricity. The initiative involved installation of 45 individual 500-watt solar power systems, technical training for local residents, and establishment of a community-based maintenance program. Pre-implementation assessment revealed that households relied solely on kerosene lamps and firewood, spending approximately USD 15-20 monthly on energy needs. Post-implementation evaluation after six months demonstrated 100% system functionality, with households gaining access to lighting, mobile phone charging, and small appliance operation. The project significantly improved quality of life, extended productive hours, enhanced children's educational opportunities, and reduced indoor air pollution. Community participation was integral to project sustainability, with 12 local technicians trained in basic solar system maintenance.

INTRODUCTION

Energy access remains one of the most critical challenges facing remote mountainous communities in developing nations, particularly in the Himalayan region where geographical barriers and economic constraints limit infrastructure development. Nepal, despite its abundant renewable energy potential, continues to struggle with energy poverty in rural areas, with approximately 8% of its population lacking access to electricity (International Energy Agency, 2023). The Himalayan mountain villages face unique challenges including extreme terrain, harsh weather conditions, limited road access, and sparse population distribution, making conventional grid extension economically unfeasible and technically challenging (Palit & Chaurey, 2021). These communities have historically relied on traditional biomass fuels and kerosene for their energy needs, resulting in health hazards from indoor air pollution, environmental degradation, and limited opportunities for economic development.

Solar photovoltaic technology presents a viable solution for addressing energy poverty in off-grid mountainous regions due to its modularity, declining costs, minimal maintenance requirements, and abundance of solar radiation at high altitudes (Bhattacharyya, 2022) and (Muhsyanur, 2024). The Himalayan region receives substantial solar irradiation throughout the year, with average daily solar radiation ranging from 4.5 to 6.5 kWh/m²/day, making it particularly suitable for solar energy applications (Pandey et al., 2020). However, the successful implementation of solar technology in remote communities requires more than technical installation; it necessitates comprehensive community engagement, capacity building, and culturally appropriate approaches that ensure long-term sustainability (Ulsrud et al., 2021).

Previous studies have documented both successes and failures of renewable energy interventions in developing countries, highlighting the importance of community participation and local ownership in ensuring project longevity (Sovacool et al., 2022). Technical training and knowledge transfer to local communities have been identified as critical factors in maintaining solar systems beyond the initial installation phase (Katre & Tozzi, 2020). Furthermore, the socio-economic impacts of electrification extend beyond mere access to lighting, encompassing improvements in education, health, income generation, and overall quality of life (Khandker et al., 2021).

This community service project was developed in response to direct requests from the Ghunsa Village community in the Taplejung District of eastern Nepal, where residents expressed urgent need for reliable electricity access to improve their living conditions and economic opportunities. The village, situated at 3,595 meters above sea level along the Kanchenjunga Conservation Area, represents a typical remote Himalayan settlement with 45 households, predominantly engaged in agriculture, livestock rearing, and seasonal tourism. The nearest grid connection point lies approximately 65 kilometers away through challenging mountainous

terrain, making grid extension economically prohibitive with estimated costs exceeding USD 25,000 per kilometer (Asian Development Bank, 2022).

The primary objective of this project was to implement sustainable household-scale solar power systems that would provide basic electricity access while building local capacity for system maintenance and management. Secondary objectives included improving indoor air quality by reducing kerosene lamp usage, extending productive hours for income-generating activities, enhancing educational opportunities for children through adequate lighting, and demonstrating a replicable model for similar communities across the Himalayan region. The project adopted a participatory approach, engaging community members in all phases from planning through implementation and establishing community-based institutions for long-term system sustainability.

This article documents the comprehensive process of implementing solar technology in Ghunsa Village, presenting the methodological approach, technical specifications, community engagement strategies, and outcomes achieved. The findings contribute to the growing body of knowledge on community-based renewable energy interventions in challenging geographical contexts and offer practical insights for organizations and practitioners working in rural energy access. By examining both technical and social dimensions of the project, this documentation provides evidence for the transformative potential of appropriately designed and implemented solar energy solutions in addressing energy poverty in remote mountainous regions.

METHODE

The project employed a participatory action research approach, integrating community engagement with technical implementation to ensure cultural appropriateness and long-term sustainability. The methodology was structured in three distinct phases: pre-implementation assessment and planning, installation and capacity building, and post-implementation monitoring and evaluation. This comprehensive approach aligns with best practices in community development projects, where stakeholder participation and local ownership are essential for success (Chambers, 2020). The participatory framework enabled the project team to incorporate indigenous knowledge, respect local social structures, and adapt technical solutions to community-specific needs and priorities.

The pre-implementation phase, conducted over eight weeks from March to April 2024, involved detailed community needs assessment through household surveys, focus group discussions, and key informant interviews with village leaders, women's groups, and youth representatives. The assessment utilized mixed-methods data collection, combining quantitative surveys of 45 households with qualitative ethnographic observations to understand energy consumption patterns, economic activities, social structures, and community aspirations (Creswell & Creswell, 2021). Technical site assessment included solar resource measurement using pyranometers, structural evaluation of housing for panel mounting, and load calculation for each

household based on anticipated electricity usage. This baseline data collection was critical for system design specifications and provided benchmarks for subsequent impact evaluation (Sovacool & Dworkin, 2023). Community mapping exercises identified existing social networks and leadership structures that would support project implementation, while participatory planning workshops engaged residents in decision-making regarding system specifications, installation priorities, and maintenance arrangements (Cornwall & Jewkes, 2020).

The implementation phase spanned twelve weeks from May to July 2024, combining technical installation with intensive capacity-building activities designed to transfer knowledge and skills to community members. Solar photovoltaic systems were standardized at 500 watts per household, consisting of two 250-watt polycrystalline panels, a 40-amp charge controller, a 200-amp-hour deep-cycle battery, a 1000-watt pure sine wave inverter, and LED lighting fixtures with mobile charging points. Installation followed a community-based approach where trained technicians worked alongside selected local residents, providing hands-on training in mounting procedures, electrical connections, safety protocols, and basic troubleshooting (Katre & Tozzi, 2020). Twelve community members, including three women, completed a comprehensive 40-hour training program covering solar technology fundamentals, system maintenance, battery care, common problem diagnosis, and simple repairs. The training curriculum incorporated adult learning principles with practical demonstrations, visual aids in the local language, and progressive skill-building exercises that accommodated varying literacy levels (Ulstrup et al., 2021). A community-based management committee was established and formalized through village consensus, with clearly defined roles for system monitoring, fee collection for replacement parts, and coordination with external technical support when necessary. Post-implementation monitoring continued for six months through monthly household visits, quarterly satisfaction surveys, technical performance assessments, and documentation of challenges encountered, creating a robust evidence base for impact evaluation and adaptive management (Chambers, 2020).

RESULT AND DISCUSSION

Technical Performance and System Reliability

The implementation of 45 household solar photovoltaic systems achieved 100% installation success rate within the planned timeframe, with all systems becoming operational by July 2024. Technical performance monitoring over the six-month evaluation period revealed exceptional system reliability, with only three minor technical issues reported, all successfully resolved by trained community technicians without external intervention. This outcome significantly exceeds typical performance benchmarks for solar home systems in developing countries, where technical failure rates often range from 15-30% within the first year due to inadequate maintenance and quality control issues (Palit & Chaurey, 2021). The high reliability achieved in Ghunsa Village can be attributed to several factors: rigorous

quality assurance during procurement, proper installation supervised by certified technicians, comprehensive user training, and establishment of preventive maintenance protocols. Average daily energy generation across all systems measured 1.8-2.3 kWh per household during optimal seasons, with slight variations during monsoon months when cloud cover reduced solar irradiation by approximately 20-25%.

Battery performance emerged as the most critical component requiring careful management, particularly given the extreme temperature variations experienced at high altitude, ranging from -10°C in winter to 25°C in summer. Deep-cycle batteries were protected through insulated battery boxes and user education on proper charging and discharging practices to prevent premature degradation. Monitoring data indicated that batteries maintained 85-90% of their rated capacity after six months, suggesting good management practices and appropriate system sizing (Bhattacharyya, 2022). The charge controllers effectively prevented overcharging and deep discharge, two primary causes of battery failure in solar systems. Voltage regulation remained stable across all installations, with inverters providing clean sine wave output suitable for sensitive electronics including mobile phones, radios, and small appliances.

Solar panel orientation and tilt angles were optimized for the village's latitude (27.7°N), with panels mounted at 28-30° angles facing south to maximize annual energy capture. The high-altitude location provided advantages in solar energy harvesting, with reduced atmospheric attenuation and cooler operating temperatures that enhanced photovoltaic efficiency by approximately 10-12% compared to sea-level installations (Pandey et al., 2020). However, this advantage was partially offset during winter months when heavy snowfall necessitated manual snow clearing from panels, a maintenance task readily adopted by households who recognized its importance for system performance. The project incorporated innovative mounting solutions adapted to traditional stone and wood housing structures, using reinforced brackets that distributed weight loads while maintaining structural integrity of older buildings.

User satisfaction with system performance was remarkably high, with 43 of 45 households (95.6%) rating their systems as "excellent" or "very good" in quarterly surveys. The two neutral responses related not to technical performance but to desires for expanded capacity to operate larger appliances such as rice cookers and electric heaters, which exceeded the designed system capacity. This feedback indicated high acceptance and growing energy demand, suggesting potential for system upgrades in future phases. The technical success demonstrated that appropriately designed and maintained solar home systems can reliably serve basic electricity needs in extreme mountainous environments, challenging assumptions that such contexts are unsuitable for photovoltaic technology.

Table 1: Technical Performance Indicators of Solar Home Systems (6-Month Period)

Performance Indicator Measurement Target Achievement System Functionality Rate % operational 90% 100% Average Daily Generation kWh/household 1.5-2.0 1.8-2.3 Battery Capacity Retention % of rated capacity 80% 85-90% Technical Failure Rate incidents/system <0.5 0.067 User Satisfaction Score scale 1-5 4.0 4.6 Maintenance Response Time hours <24 6.5 Community Technician Resolution Rate % resolved locally 70% 100%

Table 1. Technical Performance Indicators of Solar Home Systems (6-Month Period)

Performance Indicator	Measurement	Target	Achievement
System Functionality Rate	% operational	90%	100%
Average Daily Generation	kWh/household	1.5-2.0	1.8-2.3
Battery Capacity Retention	% of rated capacity	80%	85-90%
Technical Failure Rate	incidents/system	<0.5	0.067
User Satisfaction Score	scale 1-5	4.0	4.6
Maintenance Response Time	hours	<24	6.5
Community Technician Resolution Rate	% resolved locally	70%	100%

Socio-Economic Impact and Quality of Life Improvements

The introduction of reliable electricity access catalyzed profound socio-economic transformations within Ghunsa Village, extending far beyond the basic provision of lighting. Households reported dramatic improvements in quality of life across multiple dimensions, with impacts particularly pronounced in education, health, economic productivity, and social connectivity. Prior to the solar installation, families spent an average of USD 18 monthly on kerosene for lamps and candles, plus additional costs for battery-powered devices and mobile phone charging requiring travel to the nearest market town. Post-implementation economic analysis revealed net savings of approximately USD 12-15 per household monthly after accounting for minimal system maintenance costs, representing 3-4% of average household income and creating tangible financial benefits (Khandker et al., 2021).

Educational outcomes showed remarkable improvement, particularly for school-age children who previously struggled with inadequate lighting for evening study. Parents reported that children's study time increased by an average of 2.3 hours per day, with homework completion rates improving significantly. Teachers from the village school noted better academic performance and attendance, particularly during winter months when shortened daylight hours previously limited study opportunities. Adult literacy classes, previously impossible to conduct after sunset, were successfully initiated with 18 adults participating in evening educational programs. These findings align with broader literature documenting strong correlations between household electrification and educational attainment in rural developing contexts (Khandker et al., 2021). The availability of reliable lighting

enabled establishment of a small community library with evening hours, fostering knowledge sharing and cultural preservation activities.

Health impacts were equally significant, with dramatic reduction in indoor air pollution from eliminated kerosene lamp usage. Baseline health surveys documented high incidence of respiratory symptoms, eye irritation, and headaches associated with kerosene fume exposure, particularly affecting women and children who spent more time indoors. Six-month follow-up assessments revealed 76% reduction in reported respiratory symptoms and 82% decrease in eye irritation complaints, consistent with research on health benefits of clean lighting technologies (Sovacool et al., 2022). The local health post reported fewer respiratory illness cases during the monitoring period, though longer-term epidemiological studies would be necessary to establish definitive causal relationships. Additionally, mobile phone access enabled better health communication, with families able to contact distant health facilities for advice and emergency coordination, effectively reducing isolation during medical emergencies.

Economic productivity expanded through extended working hours for income-generating activities including handicraft production, weaving, and small-scale food processing. Women's groups reported particular benefits, with evening handicraft work increasing by 15-20 hours weekly per household, directly translating to income increases of USD 25-40 monthly. Small shop owners extended operating hours, serving tourists and community members into evening hours and increasing revenue by estimated 30-35%. The tourism sector, representing seasonal income for many households, benefited from ability to offer basic electricity amenities to trekkers, enhancing the village's competitiveness along the Kanchenjunga trekking route. These economic multiplier effects demonstrate how basic energy access serves as catalyst for broader economic development, confirming theories of energy as enabler of productive activities rather than mere consumption commodity (Sovacool & Dworkin, 2023).

Community Capacity Building and Sustainability Mechanisms

The project's emphasis on community capacity building and institutional development proved critical for ensuring long-term sustainability beyond external support. The training of 12 local technicians, including three women, represented strategic investment in human capital that would sustain the systems far beyond the initial implementation period. Trainees demonstrated high competency levels, successfully resolving 100% of technical issues during the monitoring period without requiring external technical assistance. This achievement exceeded project expectations and validated the training methodology's effectiveness (Ulsrud et al., 2021). The inclusion of women technicians challenged traditional gender roles and created new economic opportunities, with female technicians reporting increased social status and respect within the community.

The Community Solar Management Committee, established through participatory process and formalized through village consensus, demonstrated

effective governance and resource mobilization. The committee implemented a modest monthly fee collection system (USD 2 per household) to build a maintenance fund for component replacements and future system upgrades. Within six months, the fund accumulated USD 540, sufficient for replacing approximately three battery sets if needed. This financial sustainability mechanism addressed one of the most common failure points in community energy projects: absence of resources for component replacement when parts reach end of life (Katre & Tozzi, 2020). The committee also developed clear operational guidelines, conflict resolution procedures, and transparent accounting systems that built trust and accountability.

Knowledge transfer extended beyond technical skills to include understanding of solar technology principles, energy conservation practices, and load management strategies. Educational sessions conducted in local language using culturally appropriate communication methods ensured comprehension across different literacy levels. Community members demonstrated strong understanding of system operation, with 89% of surveyed households able to correctly identify and explain basic troubleshooting procedures. This knowledge diffusion represented fundamental shift from passive technology recipients to active system managers, embodying principles of technology democratization (Chambers, 2020). Children showed particular enthusiasm for learning about renewable energy, with the local school integrating solar technology into science curriculum, potentially inspiring future generation of renewable energy advocates and practitioners.

Social cohesion and collective efficacy strengthened through the project process, with community members expressing pride in their renewable energy village status. The success attracted visits from neighboring villages interested in replicating the model, positioning Ghunsa as a demonstration site and knowledge hub for the region. This peer-to-peer learning mechanism holds potential for organic scaling of the intervention beyond project boundaries. The community articulated clear vision for future expansion, including solar-powered water pumping, improved telecommunications access, and small-scale cold storage for agricultural products. This forward-looking perspective indicated internalization of renewable energy benefits and commitment to sustainable development pathway (Ulsrud et al., 2021). The transformation from energy-poor to energy-secure village occurred not merely through technology transfer but through holistic process of empowerment, capacity building, and institutional development that positioned the community as agents of their own development.

Documentation of the implementation process, including challenges encountered and solutions developed, created valuable knowledge resources. A detailed operations and maintenance manual was developed in Nepali with visual instructions, and video documentation captured installation procedures and maintenance practices. These materials serve as learning resources for both Ghunsa residents and other communities considering similar projects. The project's participatory approach, technical success, and community ownership demonstrated that remote mountainous communities, when provided with appropriate support

and resources, possess the capability and commitment to manage sophisticated renewable energy systems, challenging deficit-based narratives that often characterize development discourse about rural populations.

CONCLUSION

This community service project successfully demonstrated the technical viability, economic feasibility, and social acceptability of household-scale solar photovoltaic systems in remote Himalayan villages, providing a replicable model for addressing energy poverty in challenging geographical contexts. The implementation of 45 solar home systems in Ghunsa Village, Nepal, achieved 100% technical success rate while generating substantial improvements in quality of life, economic productivity, educational opportunities, and health outcomes. The project's emphasis on participatory approaches, comprehensive capacity building, and community-based institutional development ensured sustainability beyond external support, with trained local technicians successfully maintaining all systems throughout the monitoring period. Financial sustainability mechanisms established through community savings funds demonstrated local ownership and commitment to long-term system maintenance. The transformation experienced by Ghunsa Village validates the potential of decentralized renewable energy solutions to catalyze rural development, reduce environmental impacts of traditional fuel use, and enhance resilience of mountain communities. Key success factors included rigorous community engagement, appropriate technology selection, quality installation, comprehensive training, and establishment of local governance structures. This documentation provides evidence-based guidance for practitioners, policymakers, and development organizations working to expand energy access in off-grid regions, demonstrating that with proper design and implementation, solar energy can effectively serve as foundation for sustainable rural development in the world's most challenging terrains.

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