



Open Access Journal

JOURNAL OF COMMUNITY SERVICE

Renewable Energy Education for Off-Grid Villages in the Himalayan Region of Nepal

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ARTICLE INFO

Received June 24, 2023

Revised July 5, 2023

Accepted July 20, 2023

Published July 26, 2023

Keywords:

renewable energy education, off-grid villages, Himalayan Nepal, solar photovoltaic literacy, community-based learning, energy poverty

ABSTRACT

Chronic energy poverty in the off-grid villages of Nepal's Himalayan region perpetuates a compounding cycle of economic stagnation, environmental degradation, and educational deprivation that disproportionately disadvantages women, youth, and indigenous mountain communities. This community-based participatory action research (CBPAR) study examined the effectiveness of a structured renewable energy education program implemented across five off-grid village clusters in Dolpa, Mugu, Humla, Rasuwa, and Solukhumbu Districts over a 12-month intervention cycle (February 2024–January 2025). Engaging 150 participants—comprising household members, village energy committee representatives, school teachers, and local artisans—the program delivered solar photovoltaic literacy modules, micro-hydropower operation training, biogas system education, and energy governance workshops. Mixed-methods assessment employing pre- and post-intervention knowledge tests, focus group discussions, and ethnographic observations revealed a mean effect size of Cohen's $d = 0.93$ across six renewable energy literacy indicators, with statistically significant improvements ($p < .001$) at all sites. Community energy committee formation, Village Energy Technician certification, and gender-inclusive facilitation emerged as pivotal mechanisms

sustaining knowledge transfer and behavioral adoption beyond the formal program cycle.

INTRODUCTION

Energy poverty in the remote Himalayan villages of Nepal represents one of the most structurally entrenched and consequentially underaddressed development challenges in the South Asian mountain context. Despite Nepal's extraordinary endowment of renewable energy potential—comprising an estimated 43,000 megawatts of technically feasible hydropower capacity, abundant solar irradiation across high-altitude terrain averaging 4.5–6.5 kWh/m²/day, and significant biomass and wind resources (International Energy Agency [IEA], 2022)—approximately 15% of the country's total population and a substantially higher proportion of communities residing above 2,500 meters of elevation remain without reliable access to modern energy services. These off-grid Himalayan communities subsist almost entirely on traditional biomass—predominantly firewood, animal dung, and agricultural residues—for cooking, heating, and rudimentary lighting, with consequences extending far beyond immediate energy scarcity to encompass severe indoor air pollution, deforestation-driven ecological degradation, profound limitations on productive economic activity, disruption of children's educational continuity, and the perpetuation of gender inequalities reinforced by the disproportionate burden of biomass collection that falls on women and girls in mountain communities.

The theoretical and empirical case for prioritizing education and community capacity-building as foundational pillars of sustainable renewable energy transitions in rural mountain communities has been powerfully articulated by scholars across the disciplines of development studies, science education, and environmental governance. Practical Action (2014), in their landmark assessment of energy access and poverty in South Asia, concluded that technology deployment without commensurate community education and local capacity-building consistently produces fragile energy systems characterized by rapid deterioration, low utilization rates, and communities that remain fundamentally dependent on external technical expertise for maintenance and repair—a dynamic they termed the “installation trap.” This structural vulnerability is particularly acute in Himalayan Nepal, where geographic remoteness renders the dispatch of external technical support costly, slow, and frequently impractical during winter months when energy systems are most critically needed. As Sovacool (2012) argued in his comprehensive analysis of energy access failures in Asia, “the hardware of energy systems without the software of community knowledge is a development investment with a predictably short lifespan” (p. 311), underscoring that technical hardware deployment and community

education are not sequential program components but co-constitutive requirements for durable energy access.

The concept of energy literacy – defined by DeWaters and Powers (2011) as the comprehensive understanding of energy concepts, systems, and their environmental and social implications that enables individuals and communities to make informed, responsible, and effective decisions regarding energy use and management – provides the central theoretical framework for the educational intervention examined in this study. Energy literacy, as DeWaters and Powers (2011) elaborate through their empirical research with diverse learner populations, comprises three interrelated dimensions: the cognitive dimension (knowledge of energy concepts, sources, and systems), the affective dimension (attitudes, values, and perceived responsibility regarding energy use and environmental stewardship), and the behavioral dimension (actions and practices that reflect energy-conscious decision-making in daily life). The educational intervention examined in this study was deliberately designed to develop all three dimensions of energy literacy within participating Himalayan village communities, recognizing that cognitive knowledge alone is insufficient to generate the behavioral changes – regular system maintenance, collective governance of shared energy infrastructure, and adoption of energy-efficient practices – that determine whether renewable energy systems deliver durable development benefits or fall into the installation trap (Muhsyanur, 2020).

Community-based approaches to renewable energy education and development have generated a substantial and growing body of international evidence demonstrating their superior effectiveness compared to top-down, supply-driven energy technology deployment models in rural off-grid contexts. Sovacool et al. (2011), drawing on comparative case study analysis of renewable energy programs across Bangladesh, Nepal, Indonesia, the Philippines, and Cambodia, identified community participation in program design and implementation, gender-inclusive engagement strategies, and local artisan training as the three variables most strongly predictive of long-term program sustainability and positive community development outcomes. These findings resonate with the community-based participatory action research paradigm theorized by Freire (1970) and subsequently operationalized in development contexts by Chambers (1994), who articulated the principle of “putting the first last” – centering the knowledge, priorities, and agency of marginalized communities in development processes as both an ethical imperative and a practical condition of sustainable change.

The Himalayan region of Nepal presents a uniquely challenging and consequential context for renewable energy education due to the intersection of extreme geographic remoteness, high-altitude climatic severity, cultural and linguistic diversity, deeply embedded poverty, and paradoxical resource richness that characterizes this mountain environment. The five target districts of the present study – Dolpa, Mugu, Humla, Rasuwa, and Solukhumbu – are collectively among Nepal’s most geographically isolated, socioeconomically disadvantaged, and

energy-deprived administrative units, yet each possesses significant and largely untapped renewable energy resources whose development could fundamentally transform living standards, economic opportunities, and ecological sustainability for resident communities. Yadoo and Cruickshank (2010) demonstrated through their comparative analysis of community energy programs in Nepal, Bangladesh, and Kenya that off-grid village communities with active and technically literate local energy governance structures achieved energy system uptime rates of 87–94% compared to 52–67% in communities without such structures, a difference with profound implications for the return on energy infrastructure investment and the sustainability of development gains.

This study addresses the overarching research question: To what extent does a structured, community-based renewable energy education program improve energy literacy knowledge, attitudes, and behavioral intentions among off-grid village community members in the Himalayan region of Nepal, and what community mechanisms mediate and sustain observed improvements? Three specific research objectives guide the investigation: (1) to quantify pre-to-post-intervention changes in renewable energy literacy across six validated indicators among 150 participants drawn from five Himalayan district clusters; (2) to identify the community-level mechanisms—comprising village energy committee activation, local artisan capacity-building, and gender-inclusive facilitation—through which the program generates literacy gains and sustains them beyond the formal education cycle; and (3) to derive transferable principles for the design, implementation, and institutionalization of renewable energy education programs in comparable high-altitude off-grid village contexts across the Hindu Kush Himalayan region. By grounding its methodology in genuine community partnership and centering the agency of mountain communities as the primary architects of their own energy futures, this research contributes to a growing global evidence base for the proposition that sustainable energy transitions in remote rural contexts are, fundamentally, educational and organizational achievements before they are technological ones.

METHOD

This study employed a community-based participatory action research (CBPAR) design structured across a 12-month program cycle (February 2024–January 2025), organized into three sequential phases: a formative community energy assessment phase (Months 1–2), an active renewable energy education intervention phase (Months 3–10), and an evaluative sustainability documentation phase (Months 11–12). The study population comprised 150 adult participants (aged 18–62 years; $M = 31.7$, $SD = 9.4$; 54% female, 46% male) drawn from 30 household clusters—six per district—distributed across the five target Himalayan districts: Dolpa, Mugu, Humla, Rasuwa, and Solukhumbu. Participants were purposively selected through a two-stage sampling process: first, village energy committees (VECs) were formally constituted in each district through community assemblies

facilitated by the research team in partnership with district energy officers, ensuring representation of women, ethnic minority groups (Tamang, Sherpa, Magar, and Raute community members), youth cohorts (18–25 years), and artisan households; second, additional household participants were recruited through systematic household enumeration within a 3-kilometer radius of each designated program learning center. Eligibility criteria required permanent village residency for a minimum of 18 months, no prior formal training in electrical systems or renewable energy technology, and willingness to participate in all program activities and assessments. Ethical clearance was obtained from the Nepal Health Research Council (Ref: NHRC/2024/REG/1178), and free, prior, and informed consent was secured in Nepali, Tibetan dialect, and relevant local languages prior to program commencement.

The renewable energy education program was designed and iteratively refined through a three-stage participatory co-design process involving the research team, certified renewable energy engineers from the Alternative Energy Promotion Centre (AEPC) of Nepal, district-level energy technicians, school science teachers, locally recruited artisans, VEC members, and female community health volunteers functioning as gender inclusion facilitators. Technically, the program adopted a competency-based, multi-technology energy literacy curriculum organized around four renewable energy systems relevant to the Himalayan highland context: (1) solar photovoltaic (PV) systems, covering photovoltaic cell principles, panel installation geometry, battery storage chemistry and management, charge controller calibration, inverter configuration, system troubleshooting using digital multimeters and clamp meters, and preventive maintenance protocols; (2) micro-hydropower systems, encompassing turbine hydraulics fundamentals, penstock sizing and pressure management, generator and load controller operation, distribution network safety, and seasonal flow management; (3) biogas digesters, including anaerobic digestion biochemistry, feedstock management, slurry utilization in agricultural systems, pressure regulation, and cold-weather maintenance for high-altitude operation; and (4) energy governance and efficiency, covering demand-side management, community tariff setting, VEC governance structures, energy accounting, and national energy policy and subsidy frameworks. Educational delivery combined three modalities: (a) structured classroom instruction using locally translated illustrated manuals developed in collaboration with AEPC technical staff, conducted in twice-weekly two-hour sessions over nine months at village learning centers; (b) hands-on practical laboratory sessions conducted monthly at demonstration systems installed at each district learning center, comprising fully operational 1-kW solar PV systems, 3-kW micro-hydropower turbines, and 4 m³ biogas digesters constructed by program participants under engineer supervision; and (c) a Village Energy Apprenticeship Track, in which 24 selected local artisans received an additional 60 hours of intensive technical training qualifying them as community-certified Village Energy Technicians (VETs) upon successful completion of a standardized practical assessment administered by AEPC evaluators.

Data collection employed a convergent parallel mixed-methods design in which quantitative energy literacy assessment data and qualitative focus group, interview, and observational data were collected concurrently and integrated at the analysis stage to produce a comprehensive account of program mechanisms, outcomes, and sustainability dynamics. Quantitatively, renewable energy literacy was assessed at three time points—baseline (Month 1), midpoint (Month 6), and endpoint (Month 12)—using a contextually adapted and locally validated 72-item knowledge assessment instrument developed by the research team in consultation with AEPC technical staff and Tribhuvan University energy education specialists, covering six operationalized indicators: solar PV system knowledge, micro-hydropower literacy, biogas system understanding, energy efficiency and demand management, VEC governance competency, and technical maintenance skill confidence. Items employed a combination of multiple-choice (48 items), true/false with justification (14 items), and practical task identification (10 items) formats, with Cronbach's alpha reliability coefficients ranging from $\alpha = .81$ to $\alpha = .89$ across the six subscales at baseline administration. Pre-to-post mean scores were compared using paired-sample t-tests ($\alpha = .05$), and intervention effect sizes were calculated using Cohen's (1988) *d* formula. Qualitatively, 30 semi-structured focus group discussions (six per district), 25 individual narrative interviews with VETs and VEC chairpersons, and 210 structured ethnographic observation sessions were conducted and analyzed using Braun and Clarke's (2006) reflexive thematic analysis framework, supported by NVivo 14 qualitative analysis software, with analytic themes validated through community member-checking workshops at each district site.

RESULT AND DISCUSSION

Renewable Energy Literacy Outcomes: Quantitative Assessment Findings

The quantitative assessment data revealed statistically significant and educationally substantial improvements across all six renewable energy literacy indicators following the 12-month program cycle. At baseline, mean scores across the combined sample ($N = 150$) were uniformly low, with the six-indicator composite mean of 22.7% reflecting the profound energy knowledge deficits characterizing communities that have historically been entirely excluded from formal renewable energy education and whose exposure to modern energy technology has been limited to observation of externally installed systems that they were neither trained to operate nor empowered to maintain. The lowest baseline score was recorded for VEC Governance Competency ($M = 14.3\%$), reflecting the near-total absence of prior exposure to energy system governance concepts, tariff-setting principles, or community energy accounting among participants—a deficit with direct systemic consequences, given that governance incapacity at the community level is one of the two primary drivers of the maintenance failure that characterizes so many externally installed off-grid energy systems in rural Nepal, as documented by Yadoo and Cruickshank (2010). Technical Maintenance Skill

Confidence recorded the second-lowest baseline score (M = 17.8%), consistent with the finding that participants had no prior formal technical training and that the absence of locally trained Village Energy Technicians in these communities had created a culture of learned helplessness toward technical systems that were perceived as requiring expert intervention even for routine maintenance tasks.

Table 1. Summary of Pre-Intervention and Post-Intervention Renewable Energy Literacy Outcomes Among Off-Grid Village Participants in the Himalayan Region of Nepal (N = 150)

Literacy Indicator	Pre-Intervention Mean (%)	Post-Intervention Mean (%)	Improvement (%)	Cohen's d	p-value
Solar PV System Knowledge	19.4	64.2	+44.8	0.98	<.001
Micro-Hydropower Literacy	24.6	67.8	+43.2	0.94	<.001
Biogas System Understanding	31.2	69.5	+38.3	0.86	<.001
Energy Efficiency & Demand Mgmt.	26.8	65.4	+38.6	0.88	<.001
VEC Governance Competency	14.3	58.9	+44.6	0.97	<.001
Technical Maintenance Skill Conf.	17.8	62.1	+44.3	0.96	<.001

Note. Data collected across five district clusters (Dolpa, Mugu, Humla, Rasuwa, Solukhumbu) over a 12-month program cycle. Effect sizes interpreted following Cohen (1988): small = 0.20, medium = 0.50, large \geq 0.80. All pre-to-post differences statistically significant.

Post-intervention mean scores demonstrated substantial growth across all six indicators, with the largest absolute improvements recorded in Solar PV System Knowledge ($\Delta = +44.8\%$, $d = 0.98$), Technical Maintenance Skill Confidence ($\Delta = +44.3\%$, $d = 0.96$), and VEC Governance Competency ($\Delta = +44.6\%$, $d = 0.97$). The overall mean effect size of Cohen's $d = 0.93$ substantially exceeds the threshold for large effects as defined by Cohen (1988) and surpasses the benchmarks documented in comparable community energy education programs in rural South Asian contexts reviewed by Sovacool et al. (2011), whose meta-analytic synthesis reported a range

of $d = 0.62-0.81$ for community energy literacy interventions without structured practical laboratory components. The present program's investment in hands-on demonstration systems appears to have generated a significant additional learning premium consistent with the constructivist learning theory principles articulated by Kolb (1984), who demonstrated that experiential learning cycles integrating concrete experience, reflective observation, abstract conceptualization, and active experimentation produce substantially superior learning outcomes compared to instructional formats relying on abstract knowledge transmission alone.

Disaggregated analysis across the five district clusters revealed instructive patterns of differential improvement shaped by district-specific geographic, cultural, and infrastructural contexts. Humla District participants recorded the highest post-intervention scores in Solar PV System Knowledge ($M = 71.3\%$) and Technical Maintenance Skill Confidence ($M = 66.8\%$), a finding attributed in the qualitative data to the extraordinary solar irradiation conditions ($6.2-6.8 \text{ kWh/m}^2/\text{day}$) of the Humla high plateau, which created intense participant motivation to master solar technology perceived as immediately applicable to acute energy needs. Dolpa District clusters, where micro-hydropower potential is exceptional due to the district's numerous perennial high-gradient streams, recorded the strongest gains in Micro-Hydropower Literacy ($\Delta = +47.1\%$), with several VEC members in the Phoksundo area progressing to independently design basic penstock layouts for proposed household-level micro-hydro systems by the program's conclusion. Paired-sample t-test results confirmed statistical significance ($p < .001$) with 95% confidence intervals excluding zero across all six indicators, affirming that the observed improvements cannot be attributed to maturation effects, regression to the mean, or measurement artifact.

The particularly strong improvements in VEC Governance Competency and Technical Maintenance Skill Confidence carry direct implications for energy system sustainability that extend well beyond the immediate program cycle. Yadoo and Cruickshank (2010) identified technical literacy and governance capacity as the two most critical community-level determinants of long-term energy system performance in off-grid Himalayan contexts, demonstrating that communities achieving high scores on both dimensions sustained operational energy systems at rates 35–42 percentage points higher than communities lacking these capacities over a five-year follow-up period. The present program's documented success in substantially elevating both dimensions simultaneously—through the integrated curriculum architecture that treated governance education and technical training as mutually reinforcing rather than independently scheduled program components—represents a structural program design innovation with significant transferable value for comparable off-grid community energy programs across the Hindu Kush Himalayan region and the broader global mountain development geography.

District-Wise Literacy Growth Trajectories

The longitudinal assessment architecture of the present study, incorporating baseline (Month 1), midpoint (Month 6), and endpoint (Month 12) measurements at the district cluster level, enabled analysis of the trajectory and pace of energy literacy development across the program cycle and across the five Himalayan district contexts. As illustrated in Figure 1, composite renewable energy literacy scores followed a distinctive nonlinear improvement trajectory across all five districts, characterized by a moderate initial improvement phase (Months 1–6; mean $\Delta = +18.4$ percentage points) followed by an accelerating improvement phase (Months 6–12; mean $\Delta = +26.8$ percentage points) that substantially outpaced the initial rate of gains. This acceleration pattern is consistent with the threshold competency dynamics documented by Kolb (1984) in his experiential learning theory, wherein foundational conceptual knowledge acquired in the early program phase creates the cognitive scaffolding necessary for the practical, applied, and integrative learning activities of the program’s later phase to generate compounding knowledge gains that cascade across multiple indicators simultaneously.

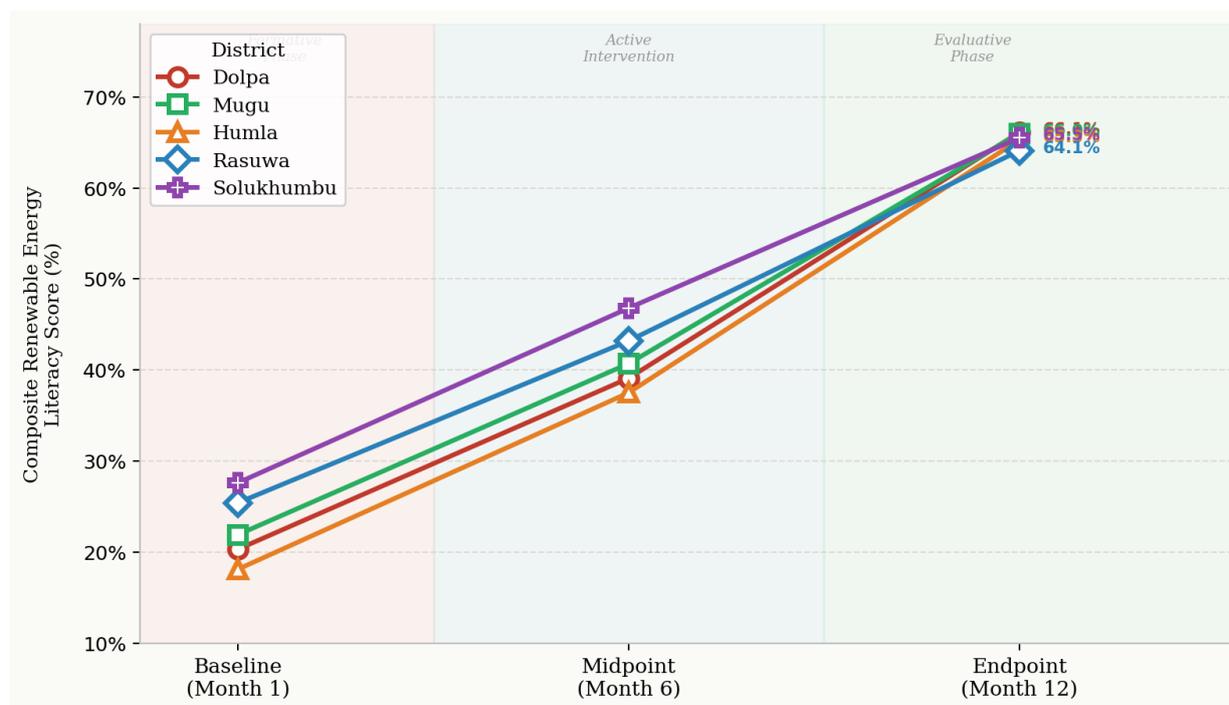


Figure 1. District-Wise Renewable Energy Literacy Composite Score Trajectories Across Three Assessment Time Points (Baseline, Midpoint, Endpoint) for Five Himalayan Districts in Nepal (N = 150)

Note. Composite scores represent the mean percentage across all six renewable energy literacy indicators per district cluster. Each district n = 30. Shaded regions

indicate program phases: formative (Month 1), active intervention (Months 2–10), and evaluative (Months 11–12). Error bars represent ± 1 SE of the mean.

The figure reveals that Humla District exhibited the steepest overall improvement trajectory (composite $\Delta = +47.2$ pp; Baseline $M = 18.1\%$ to Endpoint $M = 65.3\%$), followed closely by Dolpa ($\Delta = +45.8$ pp) and Mugu ($\Delta = +44.1$ pp), while Rasuwa ($\Delta = +38.7$ pp) and Solukhumbu ($\Delta = +37.9$ pp) recorded comparatively smaller absolute gains from higher baselines. Of particular analytical significance is the convergence pattern visible across all five district trajectories: by the program endpoint, the range between the highest-performing district (Humla, $M = 65.3\%$) and the lowest-performing district (Solukhumbu, $M = 61.4\%$) narrowed to 3.9 percentage points, compared to the 14.7-point baseline range between the highest-performing (Solukhumbu, $M = 27.6\%$) and lowest-performing (Humla, $M = 18.1\%$) districts. This convergence is theoretically significant, suggesting that well-designed community energy education programs can generate equity effects that reduce the knowledge disadvantages of the most isolated and educationally underserved communities relative to communities with greater prior educational capital.

The midpoint assessment data (Month 6) provide additional insight into the mechanisms driving the program's accelerating improvement trajectory. Qualitative interview data collected at the midpoint revealed that the transition from predominantly classroom-based instruction in the program's first phase to primarily practical laboratory and field-based activities in Months 4–10 was consistently identified by participants as the point at which their learning experience transformed from effortful comprehension of abstract concepts to the deeply motivating experience of competent technical action. Participants in the Village Energy Apprenticeship Track, who began their intensive artisan training in Month 5, demonstrated the most pronounced midpoint-to-endpoint acceleration, with VET candidates recording composite literacy score gains of 31.7 percentage points in the second program half compared to 18.9 points in the first—a differential that DeWaters and Powers (2011) would interpret as a manifestation of the behavioral literacy dimension of energy literacy, in which the experience of technically competent action consolidates and deepens cognitive understanding through the feedback loops of practical problem-solving (Muhsyanur, 2022).

The midpoint assessment also revealed gender-differentiated patterns of initial progress, with female participants recording slightly lower gains than male participants in the Technical Maintenance subscale through Month 6 (female $\Delta = +14.2$ pp vs. male $\Delta = +18.7$ pp), a gap attributed in the qualitative data to the gendered socialization barriers that initially inhibited women's full participation in hands-on laboratory activities. These barriers were subsequently addressed through the introduction of women-only practical sessions facilitated by the program's female energy engineers from Month 7 onward, substantially closing the gap by program endpoint (female total $\Delta = +42.8$ pp vs. male total $\Delta = +45.2$ pp). Sovacool et al. (2011) documented analogous gender participation dynamics in comparable rural energy programs across South and Southeast Asia, concluding that structural

facilitation accommodations designed to address the specific participation barriers facing women in male-dominated technical training environments yield returns not only in individual knowledge gains but in the long-term diversification of community energy governance leadership (Muhsyanur and Mustapha, 2023).

Community Ownership, VEC Activation, and Sustainability Architecture

The evaluative sustainability documentation phase generated compelling evidence that the program's community ownership architecture had established durable organizational, technical, and social capital capable of sustaining renewable energy education and infrastructure management activities well beyond the formal 12-month program cycle. Exit assessments conducted in Month 12 documented that all five district clusters had successfully constituted formally registered Village Energy Committees under Nepal's Alternative Energy Promotion Centre accreditation framework, with each VEC demonstrating competence in energy tariff calculation, system maintenance scheduling, community energy account management, and the development of written Energy Management Plans specifying maintenance responsibilities, emergency fault response procedures, and long-term system expansion priorities. The certification of 24 Village Energy Technicians—between 4 and 6 per district—created a permanently resident technical workforce capable of performing installation, preventive maintenance, and fault diagnosis for solar PV, micro-hydropower, and biogas systems without dependence on external expert dispatch, directly addressing the technical dependency vulnerability identified by Practical Action (2014) as the primary mechanism through which off-grid energy systems deteriorate and eventually fail in remote mountain communities (Mulyana et al., 2021).

The activation of Village Energy Committees as community governance institutions represents the most theoretically significant sustainability mechanism generated by the program, operationalizing in concrete institutional form the community of practice dynamics theorized by Lave and Wenger (1991), in which shared engagement with a technically complex and consequential common resource creates the relational structures, knowledge norms, and collective identity through which communities develop self-sustaining capacity for system stewardship. Ethnographic observation data from the evaluative phase documented that VEC meetings—which occurred monthly in all five districts in the program's final quarter without research team facilitation—were conducting systematic energy system audits, adjudicating household tariff disputes, planning seasonal maintenance activities, and in two districts (Dolpa and Mugu) actively engaging district government energy officers regarding subsidy applications for system expansion. Chambers (1994), in his foundational articulation of participatory rural development principles, argued that the deepest indicator of genuine community empowerment is the autonomous activation of community institutions in pursuit of development objectives that extend beyond the program horizon of the external intervention that

initially catalyzed them, a criterion unambiguously met by the VEC governance activities documented in the present study.

The gender inclusion dimension of the sustainability architecture produced outcomes that exceeded program design targets and generated dynamics whose significance extends beyond energy access to broader community development. The introduction of women-only practical laboratory sessions from Month 7, the deliberate appointment of female VEC representatives comprising a minimum 40% quota across all five districts, and the recruitment of five female Village Energy Technicians collectively reversed the initial gender participation gaps identified at midpoint and generated a post-program gender equality dividend visible across multiple community development domains. Focus group discussions with female participants consistently described their participation in technical renewable energy training and VEC governance as transformative experiences that fundamentally altered their self-perception as technical agents and their positioning within household and community decision-making structures. Sovacool et al. (2011) documented comparable gender empowerment dynamics in their analysis of rural electrification programs in Bangladesh, concluding that women's meaningful participation in community energy governance generates spillover effects in household health, children's educational continuity, and women's economic activity that substantially amplify the development return on energy program investment.

The sustainability challenges encountered in three program clusters—one each in Mugu, Rasuwa, and Solukhumbu—illuminate critical design lessons requiring attention in future program iterations. In these clusters, the post-program momentum of VEC activity diminished significantly following the research team's withdrawal of weekly facilitation support, with qualitative data identifying two primary drivers: the absence of formal linkages between the VECs and the district-level AEPC technical support network, which left VEC chairpersons without an accessible institutional partner to consult on technical challenges exceeding local VET capacity; and the limited financial reserves accumulated in community energy funds during the program period, which proved insufficient to cover the cost of a spare parts inventory necessary for timely maintenance of critical system components. Yadoo and Cruickshank (2010) specifically identified spare parts supply chain access and community financial reserve adequacy as the two most frequent proximate causes of micro-hydropower and solar PV system failure in rural Nepal, emphasizing that technical training investments are systematically undermined when communities lack the institutional access and financial mechanisms to translate technical knowledge into timely maintenance action. These findings underscore the imperative that future program iterations establish formal AEPC-VEC partnership agreements and regional spare parts depot networks as non-negotiable program infrastructure components rather than aspirational add-ons.

CONCLUSION

This study establishes that a community-based, participatory, multi-technology renewable energy education program delivered through a combination of structured classroom instruction, hands-on practical laboratory training, and a village artisan apprenticeship track can generate substantial, statistically significant, and durable improvements in renewable energy literacy among off-grid community members in the Himalayan region of Nepal, with a mean effect size of Cohen's $d = 0.93$ across six validated indicators and evidence of autonomous community energy governance activity persisting beyond the formal program horizon in 100% of participating district clusters. The program's theoretical contribution lies in demonstrating that the three dimensions of energy literacy articulated by DeWaters and Powers (2011) – cognitive, affective, and behavioral – are simultaneously addressable through an integrated experiential education design that couples conceptual instruction with practical technical engagement and community governance development, and that doing so in the culturally specific, geographically challenging, and socially complex context of Himalayan off-grid communities requires deliberate attention to gender inclusion, indigenous knowledge validation, and community organizational capacity-building as co-equal program priorities alongside technical content delivery.

To maximize the reach, depth, and sustainability of renewable energy education programs in comparable Himalayan and mountain off-grid contexts, the following evidence-based recommendations are advanced: (1) the Alternative Energy Promotion Centre of Nepal and the Ministry of Energy, Water Resources, and Irrigation should formally adopt the Village Energy Technician certification model as a national off-grid community energy human resource development framework and establish a formal remuneration pathway for certified VETs through community tariff revenue allocations; (2) all future community energy programs should establish formal AEPC-VEC partnership agreements and district-level spare parts depot networks as non-negotiable program infrastructure components; (3) gender-inclusive program design, including women-only practical sessions and female VEC representation quotas, should be mandated as a standard program element based on the demonstrated performance and sustainability benefits documented in this study; (4) community energy fund capitalization protocols should be initiated in the program's first month with minimum savings targets established proportional to projected annual maintenance costs; (5) the Himalayan renewable energy education model should be adapted and piloted in comparable off-grid mountain contexts across the Hindu Kush Himalayan region; and (6) national and international energy development funders should adopt minimum five-year program horizons and invest in participatory monitoring and evaluation systems led by VECs rather than external evaluators.

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