SUSTAINABLE ENERGY DEVELOPMENT THROUGH COMMUNITY FORESTRY IN NEPAL: INSIGHTS FROM SIRANCHOWK RURAL MUNICIPALITY, GORKHA

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Abstract. The transition toward sustainable energy in rural Nepal remains a pressing challenge due to heavy reliance on traditional biomass and limited access to modern alternatives. This study explores the nexus between community forestry and household energy consumption in Siranchowk Rural Municipality, Gorkha. It focuses on the potential of community-managed forests to contribute to energy security. Employing a mixed-methods approach, the study integrates household surveys (n = 200), GIS-based forest cover analysis (1988–2024), and qualitative insights from key informant interviews and focus group discussions. Findings reveal that over 70% of households depend primarily on firewood, with limited but increasing adoption of biogas and solar technologies. Regression analysis highlights household income ($\beta = 0.62$, $p < 0.01$), CFUG membership ($\beta = 0.47$, $p < 0.05$), and access to subsidies ($\beta = 0.39$, $p < 0.05$) as significant predictors of renewable energy uptake. Spatial NDVI analysis indicates vegetation regeneration in areas with strong CFUG governance, demonstrating the ecological benefits of community forestry. However, economic constraints, policy fragmentation, and gendered labor burdens hinder broader transitions. The study recommends strengthening legal and institutional frameworks for community-based energy governance, expanding targeted subsidies, and aligning forestry and energy policies. By empirically linking decentralized forest governance with energy sustainability, this research contributes to a better understanding of how local institutions can drive equitable and environmentally responsible energy transitions in forest-dependent regions. These findings have broader implications for climate resilience and rural development strategies in Nepal and other developing economies.
Keywords: *NDVI-based forest monitoring, household energy consumption, land cover change, participatory forest management, GIS and remote sensing*

Introduction

Background of sustainable energy and community forestry

Sustainable energy development is crucial for achieving global environmental and socio-economic goals, particularly in rural areas that rely heavily on traditional biomass as their primary energy source (Afsharzade et al., 2016; Ali et al., 2024). This is attributed to the adoption of community forestry in sustainable energy policy to guarantee energy security and enhance environmental preservation (Jong et al., 2018). Community forestry is a central part of ecological stability, livelihood-supporting and fuelwood supply to rural families in Nepal (Gao et al., 2023). Although Nepal possesses vast amounts of forest

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resources, reliance on firewood and traditional biomass as a source of energy remains a challenge, causing environmental and health-related problems, which requires an energy shift towards a sustainable one (Suman, 2021).

Importance of energy security in rural Nepal

Energy security is a big challenge in Nepal given that not many people are actually enjoying a clean and modern source of energy especially in the rural settlements (Surendra et al., 2011). Firewood is still the most used source of energy, showing minimal production of other sources like the biogas, solar, and hydroelectric power (Islam et al., 2008). This tendency of over-reliance on firewood in the community forests is leading to deforestation, soil erosion, and growth in greenhouse gasses (Baumert et al., 2016). Simultaneously, the long-term survival of community forests is at risk due to unsustainable harvesting activities that are important in conserving biodiversity and resiliency to climate change (Duguma et al., 2018). In this regard, a sustainable exploitation of such forests by means of generating energy is key to not only environmental, but also socio-economic issues in the rural regions of Nepal (Kothari et al., 2021).

Research problem and significance of the study

Community forestry in Nepal has been identified to have had a number of positive benefits yet its potential in sustaining energy has not been exploited fully. The major issue here is that there are conflicting energy needs in homes to guarantee conservational goals which implies that the community forests should be run in a manner that is able to meet the human requirements and the ecological soundness (McGuire et al., 2017). It has been demonstrated that high rates of uncontrolled firewood harvesting cause degradation to the forest resources (Cooke et al., 2008). The present work aims to fill this gap by analyzing the application of community forestry as a source of household energy in Siranchowk Rural Municipality, Gorkha, and whether sustainable practices are implemented or not (Gannan et al., 2023). These dynamics should help in understanding the policy that needs to be integrated with the issues of energy security and the issues that concern the conservation of forests and that of rural development.

Objectives of the study

The present paper presents an exploration of how community forestry and sustainable energy may go hand-in-hand in Siranchowk Rural Municipality, Nepal through the lens of household energy consumption behavior and their implication towards forest sustainability. It seeks to determine the effect of firewood extraction on the forest resources, the extent to which Community Forest User Groups (CFUGs) are relevant in managing energy in rural Nepal and the obstacles to using alternative and renewable sources of energy in Nepal. In order to deal with them, the research aims to provide answers to several important research questions, such as the main sources of energy household energy sources used in the region, and the environmental impact of firewood extraction, and the effectiveness of CFUGs in resource use and conservation. Furthermore, the socio-economic and environmental issues related to household energy usage and the policy-based interventions that hold the potential to help amplify the viable use of community forests towards energy security are examined in the study. Finally, the study attempts to suggest specific policy suggestions to incorporate community forestry in a sustainable energy plan, which will manage not only environmental conservation, but also energy security in rural locations.

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Literature review

Concept of community forestry and its role in sustainable energy

Community forestry is also of massive importance in terms of developing sustainable energy sources where community forestry boosts the decentralized management of forest resources and sustains the livelihood of populations and maintains environmental health. Community forestry came around, as a reaction to forest degradation, land degradation, and unsustainable use of resources, enabling the local communities to be involved in the management of forests and make use of their resources in a sustainable way (Duguma et al., 2018). The community forestry model has played a significant role in sustaining the use of forests in Nepal in addition to guaranteeing the energy security through the usage of biomass energy especially firewood, biogas, and other sources of renewable energy (Gao et al., 2023).

Use of forest biomass is an integral role of community forestry and household energy, which mostly happens in rural places where there are scarce other energy sources. Forest-based bioenergy has been proved to be a viable energy source with less dependence on fossil fuel emissions, and enhancement of rural energy security (Baumert et al., 2016). As an example, Cambero and Sowlati (2014) manifest the relevance of sustainable supply chains in the forest biomass industry, suggesting that forest-based energy is not only an environmental concern, but it is also viable in terms of monetary resources in remote communities.

Moreover, Blanco et al. (2015) indicate that community forestry can promote the sustainability of energy since it incorporates the production of biomass energy to local economies. In their paper about rural district heating, the topic studied displays how forests can be used to decrease the use of traditional forms of energy by using firewood and other forest waste materials as green energy sources with the aim of alleviating climate change. Such funding mechanism of carbon financing, in case of Nepal as argued by Staddon (2009), offers rewards to the communities to move towards sustainable energy traditions into better alternatives like improved cookstoves and biogas.

Previous studies on energy consumption in forest-dependent communities

Several studies have examined the pattern of energy consumption in communities that rely on the use of forest resources, focusing on the use of biomass energy and its socio-economic consequences. According to Cooke, Kohlin, and Hyde (2008), evidence of the current existence of fuel wood as the most common source of energy amongst the rural households in most developing countries is presented in that, patterns of fuel wood consumption among households are dependent on the availability, income, and also on the interventions of policy amongst others. Mazimpaka (2014), likewise, addresses the problem of the rural energy security of Rwanda through discussing the consequences of the use of wood fuel and the necessity to develop sustainable management of resources to find balance between energy requirements and maintaining forest cover.

Surendra et al. (2011) examine the situation with renewable energy and its contribution to decreasing the fuelwood dependency in Nepal. Their results reveal that Nepal has succeeded in the promotion of biogas and solar energy, but rural households still use firewood because of financial and transportation factors. This is also corroborated by the author, Suman (2021) who makes a point that the renewable energy technologies although beneficial have not entirely displaced traditional biomass when it comes to costs and a lack of enthusiasm by those policies involved in such fields.

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The other important article by Baumert et al. (2016) evaluates the chain of charcoal and the effects that this chain has on energy access in sub-Saharan Africa. The research indicates that informal charcoal markets are of great significance to household energy security, yet sustainable problems exist because of inefficient production and unsustainable harvest activities. In a similar way, Boschiero et al. (2015) examine the use of agricultural residues to generate bioelectricity, stating that different biomasses can be used as an energy source around households, eliminating the forest load. Beyond forest-based biomass, studies on energy crops such as energy cane also highlight potential for sustainable energy generation. For example, Boschiero et al. (2019) showed that energy cane genotypes in Brazil can deliver high biomass yields and nutrient recycling benefits, which underscores the broader role of alternative biomass sources in rural energy security.

Furthermore, the article by Duguma et al. (2018) deals with community forestry models in sub-Saharan Africa by focusing on how local governance can provide sustainable access to energy. In their study, they give weight to the concept of participatory forest management as a method of reconciling energy needs against high levels of conservation, a significant idea that may also be very relevant to the Nepalese community forestry model.

Policy frameworks on renewable energy and forestry in Nepal

According to Nepal, different policy frameworks have been evolved to combine community forestry and sustainable energy development as they identify the intake of the forest resources in rural energy security. The Forest Act of 1993 and Community Forestry Program (CFP) has played a central role in decentralizing the rights to manage forest to the local communities so that the people can extract firewood and other forest products in a sustainable manner to use in their household energy consumption (Staddon, 2009). These policies are meant to help the communities take control of their forests in fostering conservation and sustainability of energy.

Also in the energy sector, the Renewable Energy Subsidy Policy of Alternative Energy Promotion Centre (AEPC) has been extremely helpful in advancing biogas, solar and improved cookstoves (Surendra et al., 2011). The above policy framework has an intention of eliminating reliance on firewood by offering economic and technical assistance in the adoption of alternative sources of energy. As mentioned by Suman (2021), numerous factors tend to interfere with the success of such initiatives (i.e., insufficient funding, awareness, and logistical issues in inaccessible regions).

The fact that community forestry is also included in the National Adaptation Program of Action (NAPA) in Nepal and is recognized as a priority in the Sustainable Development Goals (SDGs) also demonstrates the determination towards a connection between forestry and energy security. According to Gao et al. (2023), the process of the greening of the landscape in Nepal related to the community forestry project has given implications for rebuilding and building climate resilience and sustainable energy development. Nevertheless, they emphasize the importance of having better institutional coordination and policy coherence to maximize those benefits.

Despite these policies, gaps remain in ensuring widespread access to renewable energy solutions. Duguma et al. (2018) highlights the need for cross-sectoral collaboration between forestry and energy agencies to develop integrated strategies that address both conservation and rural energy needs. Similarly, Baumert et al. (2016) call for improved monitoring and enforcement mechanisms to prevent overextraction and promote sustainable firewood harvesting practices.

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Gaps in existing research

As many as numerous studies have been carried out on community forestry and renewable energy, there are still some gaps to be filled requiring further research. First, there is a paucity of studies besides the direct linkage between community forestry and household energy consumption, especially when it comes to the Nepalese case scenario. Most of the literature available on forests deals with either the topic of forestry management or renewable energy, without many studies touching on the two issues.

Second, there is no empirical evidence available concerning how community forestry policies affect household energy security. As indicated in the study by Staddon (2009) where the author discusses carbon financing and the policy mechanisms involved, not much talk of quantitative measures towards how such policies impact energy choices and the sustainability of the rural households.

Third, there should be additional studies of the socio-economic processes of energy transition in forest-based populations. According to Surendra et al. (2011), economic obstacles are a challenge that often denies rural households the opportunity to utilize cleaner energy generation technologies although little is known about financial tools that could be used to curb this phenomenon. According to Suman (2021) and Gao et al. (2023), research identifies the gaps in policy however, the research does not embody the solutions at the community level to increase the sustainability of energy.

Fourth, little is known about gender aspects of household energy use and decision-making. According to Cooke et al. (2008), women are vital in the energy management and fuelwood collection service, but little is spoken about gender specific energy interventions in terms of community forestry research.

Lastly, long-term evaluation of effects of community forestry projects on energy sustainability is also required. Although Duguma et al. (2018) offer some vision on the governance mechanisms, future research is needed to evaluate the long-term effectiveness of the community forestry interventions in transforming households to rely on sustainable sources of energy.

Materials and methods

The study will employ a mixed-methods study design to comprehensively explore the role of community forestry, covering an area of approximately 42.12 ha, in the sustainable energy development of Siranchowk Rural Municipality in Gorkha District, Nepal. Such an approach to methodology brings together quantitative and qualitative studies and their further consideration in order to obtain a comprehensive picture of the interconnection between forest resource governance and energy behavior on the household level (Duguma et al., 2018; Gao et al., 2023). The quantitative element consisted of controlled household surveys prepared to capture specific data entries amounting to essentially the energy consumption pattern, the frequency of firewood use and preferred energy source as well as the socio-economic characteristic elements of income levels and education. To supplement this, Geographic Information System (GIS) technology and Normalized Difference Vegetation Index (NDVI) analysis were utilized to assess the impact on the changes in forest cover and vegetative health in the Tarpakha Community Forest between 1988, 2009 and 2024. These spatial maps made it easier for one to understand the relationship between ecological situation and close proximity of households to forest boundaries and energy sourcing behaviors (Baumert et al., 2016; Staddon, 2009).

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A selected Community Forest to carry out this study was the Tarpakha Community Forest in the Ward No. 8 of Siranchowk Rural Municipality of Gorkha District, Gandaki Province, Nepal. Tarpakha Community Forest was intendedly chosen because it possesses an active Community Forest User Group (CFUG), a past experience on participatory forest management and visible differences in household energy use. *Figure 1* indicates the place where the study area was located.

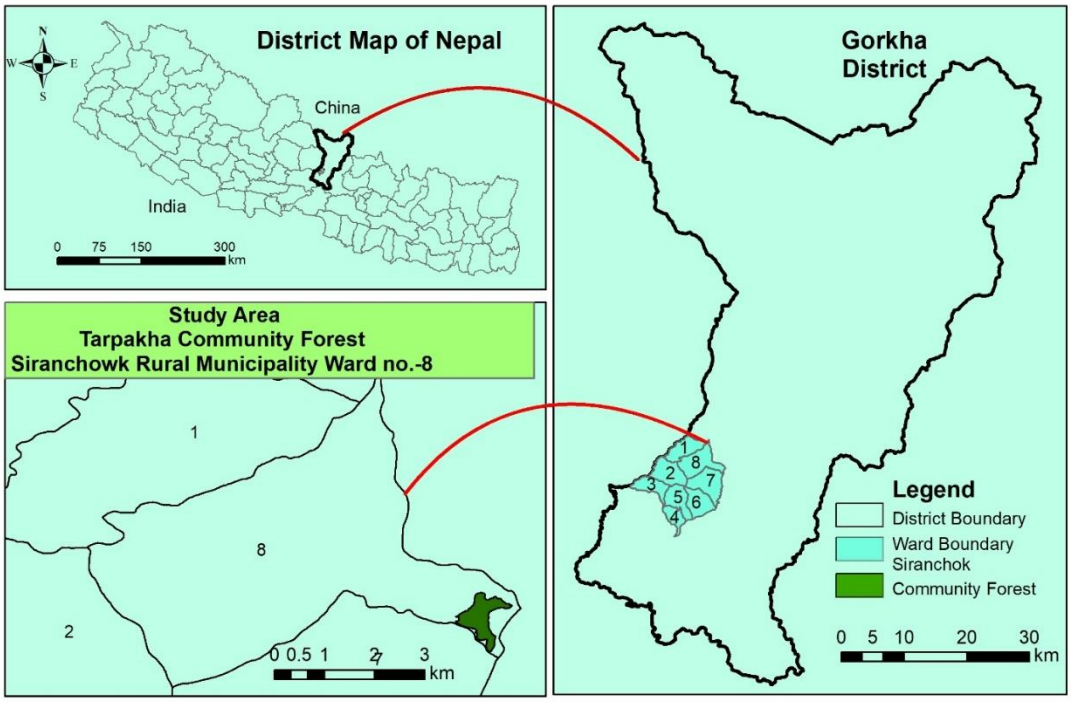

Figure 1. *Location map of Tarpakha Community Forest in Siranchowk Rural Municipality, Gorkha*

According to the National Population and Housing Census 2021, Ward No. 8 of Siranchowk Rural Municipality has a total population of 2819 individuals living in approximately 560 households (CBS, 2022). For this research, a total of 200 households were selected using stratified random sampling. This sample size represents approximately 35.7% of the total households in the ward. The sample size was calculated using the Yamane formula (1967) with a 95% confidence level and an estimated margin of error of approximately 6%. Stratification was done based on key socio-demographic variables such as gender, income level, and forest user group affiliation to ensure proportional representation. The household survey was conducted between March and May 2023.

A household survey was conducted using structured questionnaires to collect data from 200 respondents in Siranchowk Rural Municipality. The survey questionnaire was structured into five thematic sections: (1) demographic and socio-economic characteristics, including age, gender, education, landholding, and income levels; (2) household energy use patterns, focusing on the type and quantity of fuel used for cooking, lighting, and heating; (3) forest resource dependency, examining firewood collection frequency, access patterns, and perceptions of resource availability; (4) community forest user group (CFUG) participation, including decision-making involvement, awareness of conservation activities, and perceptions of CFUG governance; and (5) barriers and

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enabling factors for renewable energy adoption. The questionnaire included both closed and open-ended questions, and Likert-scale items were used to measure perceptions. The survey tool was pre-tested in a neighboring ward for clarity, reliability, and contextual appropriateness, after which minor revisions were made.

In this study, forest dependency was classified based on three key criteria: (1) frequency of household visits to the forest for resource collection; (2) volume and diversity of forest resources extracted annually (including firewood, fodder, and leaf litter); and (3) level of household participation in the local Community Forest User Group (CFUG), including decision-making and benefit-sharing mechanisms. These indicators were gathered through the household survey and validated with qualitative inputs from FGDs. A household was considered forest-dependent if it regularly collected multiple forest resources and actively participated in CFUG activities. This classification framework ensured that firewood usage, while highly prevalent, was treated as an outcome of forest dependency rather than its defining criterion, thus avoiding circular logic in the interpretation of energy use patterns.

The other methodology used besides household survey was Geospatial methods to estimate forest health and land cover. The analysis of the Normalized Difference Vegetation Index (NDVI) was realized on the basis of Landsat 8 Operational Land Imager (OLI) satellite images were obtained in March 2023 on the USGS Earth Explorer resource. The standard formula was used in order to compute the NDVI:

$$\text{NDVI} = \frac{\text{NIR Band} - \text{Red Band}}{\text{NIR Band} + \text{Red } Band}$$

where NIR (Near-Infrared) and RED refer to Bands 5 and 4 of the Landsat 8 datasets, respectively. The spatial resolution of the data used was 30 m. The images were preprocessed using ArcGIS 10.8 and ERDAS Imagine 2015, including geometric correction, radiometric enhancement, and cloud masking. NDVI values were reclassified into five vegetation categories ranging from non-vegetated to very high vegetation cover. These classifications were validated through field observations and participatory mapping with CFUG members. Due to the relatively small spatial extent of Tarpakha Community Forest, intra-forest spatial NDVI variability may not appear prominent when using 30-m resolution Landsat imagery. However, pixel-based NDVI values were extracted for each time period (1988, 2009, and 2024), and their statistical comparison provides meaningful insight into the spatiotemporal ecological dynamics of the forest. Despite visual limitations, this approach remains widely accepted for detecting broad vegetation trends in community forest settings where high-resolution imagery is unavailable.

For the analysis of survey data, IBM SPSS Statistics 26 was used. Descriptive statistics such as frequencies, means, and standard deviations were calculated to summarize household characteristics and energy use patterns. Inferential statistical tools, including cross-tabulation and chi-square tests, were employed to assess relationships between socio-economic variables and energy choices or forest dependence.

Qualitative data were collected through four key informant interviews (KIIs) with community leaders, forest officials, and local energy providers, and two focus group discussions (FGDs) involving forest user group members. The qualitative data were transcribed and analyzed using thematic content analysis, where key ideas were coded and grouped into themes related to forest governance, renewable energy adoption, and perceived environmental changes. Triangulation between survey results, NDVI analysis, and qualitative insights enhanced the robustness and contextual richness of the findings.

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Results and discussion

Socioeconomic characteristics of respondents

The survey conducted in Tarpakha Community Forest, Siranchowk Rural Municipality, included 200 households representing approximately 35.7% of the total households in Ward No. 8. Among the respondents, 56% were male and 44% were female, ensuring a reasonably balanced gender representation. The age distribution revealed that the majority (68%) of the respondents fell within the age group of 30–60 years, followed by youth (18–29 years) at 18%, and elderly respondents (above 60 years) constituting 14%. Educational attainment varied significantly, with 22% of respondents reporting no formal education, 45% having completed primary or secondary education, and only 33% attaining higher secondary or above. This reflects the limited access to higher education in rural Nepal, consistent with findings from the Central Bureau of Statistics (CBS, 2022) and the Human Development Report (UNDP, 2020). In terms of income, most households (72%) reported annual earnings below NPR 200,000 (approx. USD 1500), which aligns with the national poverty trends in hill communities of Nepal (World Bank, 2021). The survey also categorized households by landholding status, revealing that 28% were landless or marginal farmers with less than 0.1 ha, while only 12% owned more than 0.5 ha. These socio-economic characteristics underscore the community's high dependency on forest resources for livelihoods, energy, and subsistence needs a pattern echoed in previous studies on forest-based rural economies in South Asia (Chhetri et al., 2012; Gautam, 2009) (*Fig. 2*).

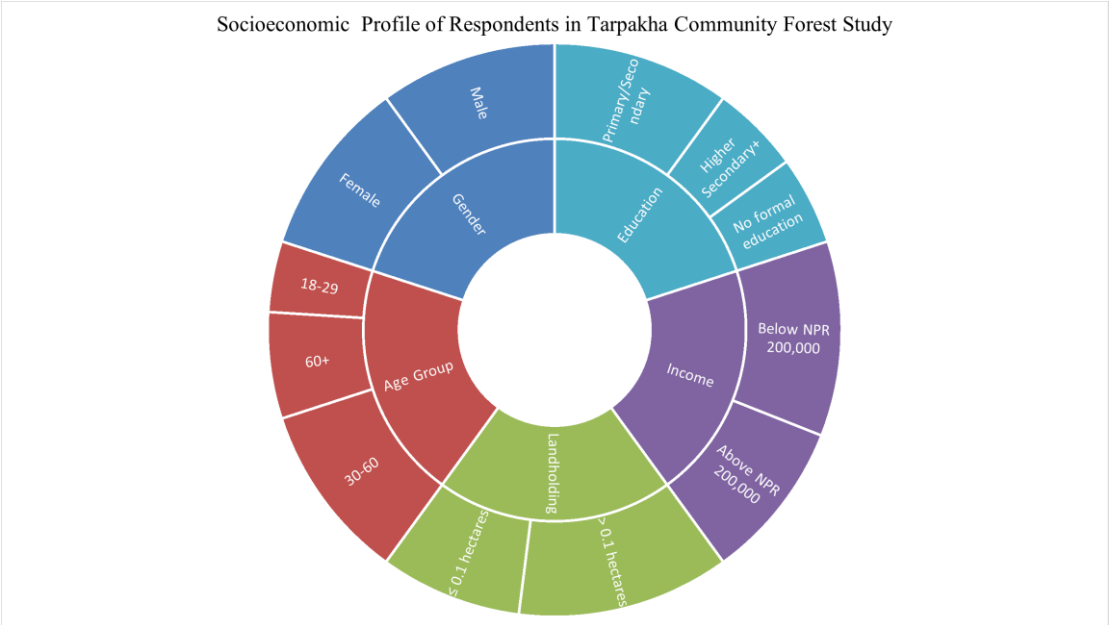

Figure 2. *Sunburst chart depicting gender, age group, education, income, and landholding distribution of respondents in Tarpakha Community Forest study (n = 200)*

Energy consumption patterns in the study area

The analysis of household survey data reveals that traditional biomass remains the dominant source of energy in Siranchowk Rural Municipality. Specifically, over 70% of

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the respondents primarily rely on firewood, while only 15% use biogas, 8% depend on solar energy, and a mere 7% utilize LPG for their daily household energy needs. This indicates a strong dependence on the Tarpakha Community Forest for fuelwood, which is consistent with findings from Cooke et al. (2008) and Surendra et al. (2011), who observed similar reliance patterns in other forest-dependent communities. Households residing closer to the forest were found to extract more fuelwood, supported by GIS spatial mapping and NDVI analysis that highlighted zones of higher biomass depletion. This proximity-energy consumption relationship illustrates how geography continues to shape household energy behaviors in rural Nepal (*Fig. 3*).

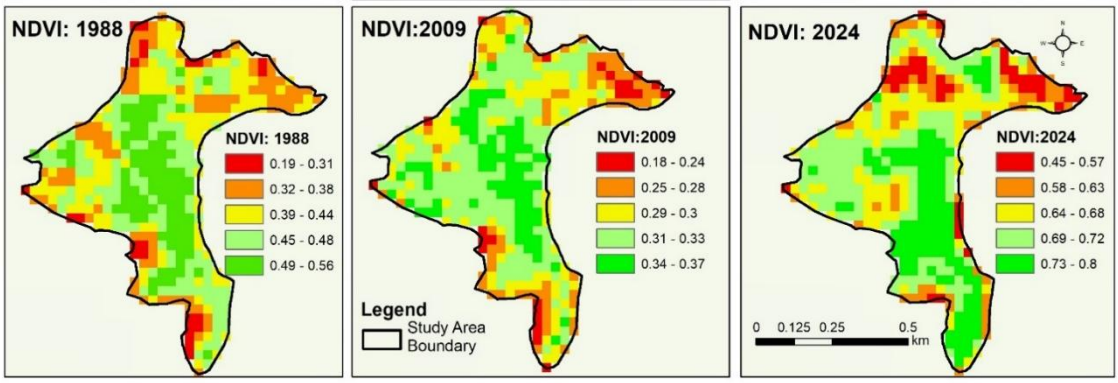

Figure 3. *NDVI-based spatiotemporal analysis of vegetation cover within the Tarpakha Community Forest for the years 1988, 2009, and 2024*

The maps illustrate vegetation density using classified NDVI ranges, where higher NDVI values (green shades) indicate denser and healthier vegetation, while lower values (red and yellow shades) represent sparse or degraded vegetation cover. Over the 36-year period, a notable increase in NDVI values is observed.

NDVI values in the year 1988 were normally distributed and shown to range between 0.19 and 0.56 with a mean and standard deviation of 0.43 and 0.06, respectively, implying moderate cover of vegetation but with some variation in the entire forest. The average NDVI decreased to 0.30 in 2009, with a lower range of values (0.18 to 0.37) and one standard deviation (0.03), which could be explained by the deterioration of vegetation and the decrease of spatial heterogeneity (probably, because of the increase in the anthropogenic pressure, or forest exploitation).

On the contrary, the NDVI map of 2024 looks very promising, as the vegetation health is increased to 0.45-0.80 with the average value of 0.67 years and the standard deviation of 0.06. Such geographic distribution provides a thick re-occurrence of forest cover, greatly probably associated with increased community forestry activity and sustainable resources. The positive change in NDVI along the study period evidences the ecological contribution in the community-based forest governance in increasing vegetation density and resilience.

Figure 4 presents a pictorial showcase of comparative statistics of NDVI of Tarpakha Community Forest in 1988, 2009, and 2024. A bar graph indicates time variations in the averages, minimum, and maximum standard deviations of the NDVI, as well as the arrival of the standard deviation. There is a marked fall in the year 2009, followed by an impressive rise in the year 2024, implying that there is good regeneration of forests by

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community forestry. The trend of the maximum and mean NDVI between the years 2009 and 2024 indicated an enhancement of the vegetative health and density.

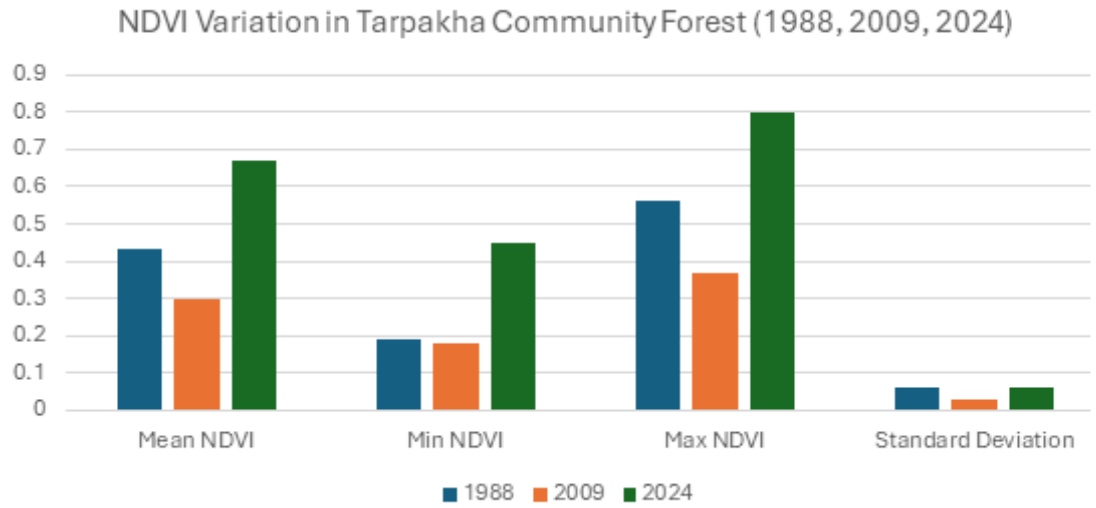

Figure 4. *Temporal comparison of NDVI statistics for Tarpakha Community Forest (1988–2024)*

Role of community forestry in sustainable energy development

Community Forest User Groups (CFUGs) in Siranchowk is involved in the management of biomass access, preservation, and conservation ideas. According to KIIs, rotational harvesting measures and programs of afforestation are used to avoid over-exploitation. The propriety of such efforts at the community level plays a crucial role in forest sustainability and, by implication, energy security. Following the study of Duguma et al. (2018), the result indicates that good governance using CFUGs has helped induce the regeneration of the vegetation cover, as evidenced by the NDVI comparison between 1988 and 2024 in Tarpakha. In addition, CFUGs have aided in the introduction of biogas plants and improved cookstoves, hence leading to a progressive transformation to the cleaner forms of energy.

Challenges in community-based energy utilization

Despite these beneficial interventions, members of the communities encounter several barriers to their energy transitions. Economic limitations were also the single greatest barrier to adoption as evidenced in FGDs, particularly because poor households must pay a high upfront cost of obtaining solar panels or biogas systems. Ecologically advantageous restrictions on the use of firewood extraction during seasons generate extra difficulty in maintaining second-long energy. Besides, gender differences in energy work have deeper routes with women and children still being burdened with firewood collection. Another factor identified by key informants as a great obstacle towards reaching effective development of renewable energy promotion was policy fragmentation between the forestry and the energy sector.

Alternative energy sources and adoption trends

While adoption of alternatives remains low, a trend toward increased use of biogas and solar was observed, especially among higher-income and better-informed households. Regression analysis showed that household income ($\beta = 0.62$, $p < 0.01$), CFUG

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membership ($\beta = 0.47$, $p < 0.05$), and access to subsidies ($\beta = 0.39$, $p < 0.05$) were significant predictors of alternative energy adoption. These results align with Cambero and Sowlati (2014), who emphasize the role of economic and institutional support in promoting renewable energy technologies.

Although the NDVI maps (*Fig. 3*) may appear visually uniform due to the coarse spatial resolution and compact forest area, statistical analyses (*Fig. 4; Table 1*) reveal distinct variations over time. The mean NDVI decreased from 0.43 in 1988 to 0.30 in 2009, then increased sharply to 0.67 in 2024, supported by changes in minimum, maximum, and standard deviation values. These changes correspond with local forest management efforts and reforestation practices initiated under the community forestry program.

Table 1. *Regression analysis summary of factors influencing alternative energy adoption*

Independent variable	Coefficient (Î²)	p-value	Interpretation
Household income	0.62	<0.01	Higher income increases the likelihood of adopting renewable energy
CFUG membership	0.47	<0.05	CFUG members are more likely to adopt alternatives
Access to subsidies	0.39	<0.05	Subsidy access positively influences adoption

Impact of community forestry on rural energy security

Community forestry has contributed positively to rural energy security by ensuring a regulated supply of biomass and supporting afforestation programs. Households affiliated with CFUGs were more likely to report stable access to firewood and alternative energy incentives. However, continued reliance on biomass poses long-term sustainability risks, particularly under growing demographic pressures. There is a pressing need for improved coordination between forestry and energy institutions, expanded access to financial tools, and targeted interventions that consider socio-economic disparities. As supported by Baumert et al. (2016) and Suman (2021), effective integration of community forestry into national energy policy can enhance resilience and sustainability in Nepal's rural energy systems.

Policy implications and recommendations

The research results of the present study imply a number of decisive policy implications and practical recommendations that would improve the sustainable energy development using community forestry in Nepal in rural areas. Empowering energy governance at the community level necessitates strengthening of legal frameworks, institutional coordination, and community Forest User Group (CFUG) capabilities, in terms of focusing on minding the gap of inclusive participation of marginalized groups and women (Duguma et al., 2018; Cooke et al., 2008). Driving the uptake of renewables, including biogas, solar and upgraded cookstoves, requires the extension of financial support, subsidies and specific awareness campaigns to overcome the issues of affordability and knowledge gaps (Cambero and Sowlati, 2014; Surendra et al., 2011). Socio-economic and environmental issues need to be addressed, such as together with the improvement of gender inequalities in energy labor and the involvement of energy

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programs in the context of overall rural development and afforestation (Gao et al., 2023; Suman, 2021). Lastly, community forestry should also be linked to the country-level energy and climate policies (e. g. the National Adaptation Programme of Action (NAPA) and Sustainable Development Goals (SDGs) in Nepal), to deliver synergies, public-private collaborations, and catalyze the deployment of climate finance on sustainable energy access (Baumert et al., 2016; Suman, 2021). Such policy measures when put in place can create an equitable, resilient and environmentally sustainable energy future in the rural areas (*Table 2*).

Table 2. *Policy implications and recommendations for sustainable energy development through community forestry*

Policy area	Key recommendations	Supporting references
Strengthening Community-Based Energy Governance	Enhance legal frameworks, institutional coordination, and capacity-building for CFUGs; promote inclusive participation	Duguma et al. (2018); Cooke et al. (2008)
Promoting Alternative and Renewable Energy Sources	Provide financial incentives, subsidies, and awareness campaigns for biogas, solar, and improved cookstoves adoption	Cambero and Sowlati (2014); Surendra et al. (2011)
Addressing Socio-Economic and Environmental Challenges	Mitigate economic and gender barriers; link energy efforts with rural development and afforestation strategies	Gao et al. (2023); Suman (2021)
Integrating Community Forestry with National Energy Policies	Align CFUGs with national policies like NAPA and SDGs; integrate forestry and energy policies through public-private partnerships and carbon financing	Baumert et al. (2016); Suman (2021)

Conclusion

Summary of key findings

This paper examined the sustainability of community forests and the development of sustainable energy in Siranchowk Rural Municipality Gorkha District, Nepal and its complex interconnectedness. The study revealed that more than 70 percent of households continue to use traditional firewood even though there are continuous campaigns to make them adopt alternatives such as biogas and solar energy. The current sources of the traditional firewood are the community-managed forests. The paper has revealed how Community Forest User Groups (CFUGs) are critical in the community control of forest use and enhancing sustainable activities such as afforestation and rotational harvesting. Regression analysis showed that access to subsidies, higher income per household, and CFUG membership were positively related to adoption of alternative energy technologies. GIS and NDVI analysis also demonstrated the changes in forest vegetation health over the period, which is indicative of successful conservation results associated with community governance. But the transition to clean energy still cannot be fully achieved due to socio-economic limitations, gender imbalance, and policy disunity.

Contribution to existing knowledge

The study adds to the body of knowledge, and this is the fact that it establishes empirically that forest governance structures can explain household energy behaviors

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in a rural setting that is diverse both geographically and socio-economically. Whereas the present study closes a critical gap in understanding the practical implications of community forestry functionalities with the focus on energy security and sustainability as compared to past studies focusing on ecological and socio-political advantages of the system (Duguma et al., 2018; Gao et al., 2023). Combining spatial, statistical, and qualitative analysis, this study allows establishing the substantive methodological framework that will help us advance our knowledge of how the decentralized forest management can change energy transition processes in rural Nepal. Moreover, the paper emphasizes the value of institutional setups, economic incentive, and grassroot involvement in enhancing speed of the implementation of renewable energy technologies.

Future research directions

Research in the future should focus on the assessment of community forestry interventions on the pathways of energy transition and the health of the forests, which should be done on a longitudinal basis. It is also worth exploring the role that gender interactions play on household choices to access energy especially with the firewood collection taking a toll on the women and girls. Additionally, there is a need for more granular policy evaluations to determine how national and local energy initiatives align with community forestry goals. Comparative studies across different ecological zones in Nepal could further elucidate the scalability of community forestry as a model for sustainable rural energy development. Lastly, exploring innovative financial mechanisms such as carbon credits, microfinance for energy appliances, and public-private partnerships could inform more integrated and scalable policy solutions.

One limitation of this study is the use of moderate-resolution satellite data (30-m Landsat), which may underrepresent micro-scale spatial heterogeneity within the small forest area. This may contribute to the limited visual variability observed in NDVI maps. Future research could incorporate higher-resolution satellite data (e.g., Sentinel-2) or Unmanned Aerial Vehicle (UAV)-based imagery to capture finer spatial details and validate the trends identified in this study. Similar remote sensing approaches have been effectively applied in Nepal for hazard and environmental monitoring in sensitive water resource environments such as dam reservoirs (Rimal and Tiwary, 2024). Additionally, integrating seasonal NDVI composites could offer better temporal granularity for ecological monitoring in community forests.

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Declarations. The authors declare that no generative AI tools were used in the creation of this manuscript, and the credibility of this work is preserved, with no competing interests or conflicts elsewhere. This study was conducted according to the good clinical practice in social and behavioral research from the National Institutes of Health (U.S.A.) and the human subject protection from the National Research Council of Thailand.

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