

# *Firewood Dependency and the Shift to Biogas in Rural Nepal: Evidence from Koshi Province*

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## **Abstract**

Firewood remains the predominant household energy source in rural Nepal, particularly in Koshi Province, where it poses significant economic, health, and environmental burdens. This study, based on empirical data from 240 households, quantifies firewood consumption patterns and associated impacts while assessing the viability of transitioning to biogas systems. The results indicate that households consume an average of 14977.44 kg of firewood annually, contributing to the felling of 20–30 trees per year and emitting 18.5 tons of CO<sub>2</sub> per household. Women and children spend approximately 386.88 hours per year on firewood collection, and indoor air pollution affects 60% of households, contributing to respiratory illnesses and other health concerns (WHO, 2022). The study finds biogas systems can reduce firewood use by up to 90% and significantly improve health outcomes and economic conditions. However, barriers such as upfront costs, limited infrastructure, and low awareness hinder adoption. This paper offers detailed policy recommendations to address these barriers and support sustainable energy transition aligned with Nepal's SDG commitments.

**Keywords:** Firewood dependency, Biogas systems, Energy poverty, Indoor air pollution, Deforestation, Sustainable energy transition, Koshi Province, SDGs

## **Introduction**

In rural Nepal, traditional biomass—particularly firewood—remains the cornerstone of household energy. In Koshi Province, this dependency underscores broader challenges of energy poverty, which restricts access to affordable, reliable, and sustainable energy (CBS, 2021). Firewood use has widespread consequences: it imposes a financial burden, exacerbates health risks through indoor air pollution, and accelerates deforestation and carbon emissions (FAO, 2020).

Despite national commitments to promoting renewable energy and improving rural livelihoods, the transition away from traditional biomass has been slow and uneven across regions. In many remote areas of Koshi Province, firewood remains the default option due to its availability, entrenched usage patterns, and the lack of viable alternatives. This persistent reliance contributes not only to environmental degradation but also to social inequality, as women and children—typically responsible for fuel collection—bear a disproportionate burden of time and health costs. The adverse effects of firewood dependency intersect with critical development concerns, including public health, gender equity, and climate resilience.

Emerging evidence suggests that biogas, a clean and locally available renewable energy source, holds significant potential to mitigate these challenges. Biogas systems convert animal and organic waste into combustible gas and nutrient-rich slurry, offering a sustainable solution aligned with rural livelihoods. Yet, adoption remains limited due to upfront costs, technical constraints, and insufficient awareness or institutional support.

This study aims to comprehensively analyze firewood consumption in Koshi Province, quantify its economic, health, and environmental impacts, and evaluate the feasibility of transitioning to biogas systems. Through a mixed-methods

approach, the research seeks to identify region-specific barriers and enabling conditions for biogas adoption. The findings provide actionable insights for policymakers and development stakeholders seeking to foster clean energy adoption and support Nepal's achievement of SDGs 3 (Good Health and Well-Being), 7 (Affordable and Clean Energy), and 13 (Climate Action) (UN, 2015).

By situating the analysis within the broader context of Nepal's decentralized energy policy, environmental commitments, and rural development priorities, this study contributes to the growing discourse on sustainable energy transitions in South Asia. It underscores the need for targeted interventions that not only address energy access but also promote environmental stewardship and inclusive development in underserved regions.

## Literature Review

Firewood remains the primary cooking fuel for approximately 2.4 billion people worldwide, particularly in developing regions where access to modern energy infrastructure is limited (World Bank, 2021). In Nepal, firewood constitutes about 68% of total energy consumption, with its use especially concentrated in rural and mountainous regions such as Koshi Province, where cleaner energy alternatives remain scarce or unaffordable (CBS, 2021). This overwhelming dependence on traditional biomass reflects a nexus of poverty, underdevelopment, and weak institutional support for renewable energy dissemination.

Empirical studies highlight the severe economic implications of continued reliance on firewood. Households in low-income brackets commonly allocate between 10% and 20% of their annual income to firewood acquisition, either through direct purchases or the opportunity cost of time spent collecting fuel (World Bank, 2021). The burden falls disproportionately on women and children, who spend several hours daily gathering firewood, often from increasingly distant or degraded forest areas (UNICEF, 2020). This time poverty limits their access to education, health care, and income-generating opportunities, perpetuating intergenerational cycles of deprivation.

Health outcomes associated with firewood use are also well-documented. Firewood combustion in traditional stoves emits harmful pollutants, including fine particulate matter (PM<sub>2.5</sub>), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (PAHs), which penetrate deep into the respiratory system (WHO, 2022). In Nepal, indoor air pollution accounts for over 23,000 premature deaths annually, with women and young children being the most affected due to prolonged exposure (WHO, 2022). These health risks translate into high public health costs and productivity losses, highlighting the urgent need for clean energy alternatives.

Environmental consequences of firewood harvesting are equally severe. Nepal loses an estimated 1.3% of its forest cover annually due to unsustainable biomass extraction (FAO, 2020). This contributes to a cascade of environmental issues, including soil erosion, reduced water retention capacity, loss of biodiversity, and increased vulnerability to natural disasters. From a climate perspective, every kilogram of firewood burned emits approximately 1.9 kg of CO<sub>2</sub> (IPCC, 2021), positioning household energy use as a non-negligible contributor to national greenhouse gas emissions.

In this context, biogas technology has emerged as a viable and sustainable alternative. Biogas systems utilize animal dung and organic waste to produce methane, which can be used for cooking and lighting. In Nepal, various studies have demonstrated that biogas adoption can reduce household firewood consumption by 80–90% (AEPC, 2023), thereby significantly lowering exposure to indoor smoke and improving respiratory health by 60–70% (WHO, 2022). Additionally, the slurry by-product serves as a potent organic fertilizer, enhancing soil fertility, reducing dependence on chemical inputs, and contributing to sustainable agricultural practices (AEPC, 2023).

Despite these benefits, the uptake of biogas remains limited, particularly in marginalized and remote communities. Several barriers persist, including high initial capital costs, lack of financial incentives, inadequate technical know-how, limited access to repair and maintenance services, and socio-cultural reservations regarding the use of animal waste in cooking (AEPC, 2023). These challenges underscore the need for an integrated policy framework that combines subsidies, awareness campaigns, capacity building, and local participation in planning and implementation.

The literature suggests that the successful transition from firewood to biogas depends on a confluence of enabling conditions: affordability, accessibility, institutional support, and social acceptability. Moreover, the alignment of clean energy initiatives with national development goals and international commitments—such as the Sustainable Development Goals (SDGs)—is critical for achieving transformative outcomes. Specifically, interventions that promote biogas adoption can directly support SDG 3 (Good Health and Well-Being), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action), while indirectly contributing to gender equality, poverty reduction, and environmental sustainability.

## Methodology

This study adopted a mixed-methods research design, integrating descriptive quantitative analysis with exploratory qualitative inquiry to provide a comprehensive understanding of household firewood dependency and the potential for biogas transition in Koshi Province, Nepal.

### *Quantitative Component*

A structured household survey was administered to systematically assess key variables, including firewood consumption patterns, associated economic costs, time burden, emissions, and self-reported health impacts. The survey instrument was developed based on relevant literature and pre-tested in a pilot phase to ensure clarity and contextual appropriateness.

The sampling frame comprised households from diverse ecological and socioeconomic zones within Koshi Province. Stratified random sampling was employed to ensure representativeness across three primary strata:

- **Income level:** low (< NPR 300,000/year), middle (NPR 300,000–500,000/year)
- **Household size:** small (<5 members), medium (5–8 members), and large (>8 members), with an average household size of 5.67
- **Geographic location:** forest-proximal areas and market-accessible regions

A total of 240 households were selected. The sample size was derived from Cochran's sample size formula (Cochran, 1977) and adjusted for logistical feasibility while preserving statistical reliability and representativeness.

The questionnaire collected data on the following domains:

- Household demographics
- Monthly and annual firewood consumption (in kilograms)
- Time spent collecting firewood (hours per week)
- Purpose and modality of firewood use
- Self-reported health symptoms (respiratory and ocular conditions)
- Awareness of biogas technology and perceived adoption barriers

### *Qualitative Component*

To complement the quantitative analysis, semi-structured interviews were conducted with selected household heads and key community informants (e.g., local leaders, women's group representatives). These interviews explored perceptions of firewood use, cultural attitudes toward biogas adoption, and barriers to renewable energy uptake. Interviews were conducted in the local language and transcribed for analysis.

### *Data Analysis*

Quantitative data were processed using descriptive statistics (means, frequencies, cross-tabulations) to capture patterns in firewood use and related variables. A cost-benefit analysis framework was applied to compare the economic and health costs of firewood dependency with the potential benefits of biogas substitution.

Carbon emissions from firewood use were estimated using default emission factors provided by the IPCC (2021), which approximate 1.9 kg of CO<sub>2</sub> per kg of firewood combusted. Health effects were approximated through frequency analysis of self-reported symptoms.

Qualitative data were subjected to thematic analysis to identify recurring patterns and emergent themes related to awareness levels, technological resistance, institutional constraints, and cultural perceptions. Coding was conducted manually and validated through inter-coder agreement procedures.

### *Ethical Considerations*

Informed consent was obtained from all participants prior to data collection. The purpose and voluntary nature of participation were clearly explained. Participants were assured of confidentiality, and all data were anonymized to

protect individual identities. Ethical protocols also allowed respondents the right to withdraw from the study at any stage without consequence.

## Results and Discussion

### *Firewood Consumption Patterns*

Survey results indicate that average household firewood consumption in Koshi Province is 1,248.12 kg per month, which translates to 220.12 kg per capita per month. This level of dependency is considerably high and demonstrates firewood's pervasive role in rural household energy systems. The primary uses of firewood were reported as follows:

- **Cattle feed preparation:** 605.79 kg/month (48.5%)
- **Cooking:** 442.25 kg/month (35.4%)
- **Water heating:** 200.08 kg/month (16.0%)

These findings highlight that energy use extends beyond basic cooking needs, reflecting the integrated role of biomass in rural agrarian livelihoods. This multi-functional use complicates efforts to shift toward cleaner energy sources, as substitution must account for multiple energy needs.

### *Time and Economic Burden*

Households spent an average of 386.88 hours annually collecting firewood, amounting to more than 1 hour per day per household. The direct financial cost of firewood—whether purchased or valued by replacement—is estimated at NPR 16,393.91 per household per year. Additionally, the opportunity cost of labor, calculated at NPR 50 per hour (based on prevailing unskilled wage rates), resulted in an estimated NPR 9,672 annually per household.

This dual burden—both time and money—is disproportionately borne by low-income households, consistent with World Bank (2021) findings that poor rural families allocate a higher share of income and labor toward meeting basic energy needs. The time commitment also reinforces gender-based inequities, as women and children are primarily responsible for firewood collection, limiting their access to education, employment, and personal development.

### *Health Impacts*

Approximately 60% of households reported indoor air pollution as a major concern, citing chronic coughing, eye irritation, and respiratory distress as common symptoms. These health outcomes were concentrated among women and children, who spend more time indoors and near cooking fires. Corroborating evidence from UNICEF (2020) and WHO (2022) suggests that:

- Exposure to biomass smoke during pregnancy is linked to a 30% increase in risks of stillbirths and low birth weight.
- Children in firewood-dependent homes are twice as likely to develop pneumonia compared to those in households using cleaner fuels.

Such outcomes underscore the public health urgency of addressing biomass reliance, particularly in rural settings where healthcare access is limited.

### *Environmental Impact*

Each household's annual firewood usage corresponds to the removal of estimated 20–30 mature trees, resulting in 18.5 metric tons of CO<sub>2</sub> emissions per household per year (IPCC, 2021). Extrapolating to the study population, the surveyed households were collectively responsible for the extraction of nearly 6,000 trees and the emission of 4,432.32 tons of CO<sub>2</sub> annually. Beyond emissions, deforestation contributes to soil erosion, biodiversity loss, and declining agricultural productivity, which are already pressing concerns in Koshi Province.

### *Comparative Discussion and Policy Implications*

Firewood consumption in Koshi Province exceeds national averages, reflecting region-specific dynamics such as forest proximity, limited access to cleaner energy alternatives, and prevailing economic hardships (CBS, 2021). These structural conditions perpetuate the cycle of energy poverty, environmental degradation, and social inequality. The gendered workload associated with firewood collection reinforces traditional labor divisions and limits educational opportunities for children, particularly girls.

The transition to biogas presents a viable alternative. Based on cost comparisons, households could achieve annual savings of approximately NPR 13,393.91 by replacing firewood with biogas. Health benefits are equally substantial, with evidence suggesting a 60% to 70% reduction in respiratory ailments following biogas adoption (WHO, 2022). Moreover, biogas slurry enhances soil fertility and reduces dependence on chemical fertilizers, providing co-benefits for agricultural productivity.

However, the uptake of biogas remains low; only 30% of respondents were aware of biogas systems (AEPC, 2023). Key barriers identified through interviews include:

- High upfront installation costs ranging from NPR 35,000 to NPR 50,000
- Inadequate technical support and post-installation servicing
- Cultural resistance and low trust in unfamiliar or externally promoted technologies

These findings align with prior studies emphasizing that financial incentives alone are insufficient. Broader institutional support—including targeted subsidies, awareness campaigns, and community-based training—is essential to facilitate adoption, particularly among marginalized groups.

In sum, the results underscore the multifaceted burden of firewood dependency in Koshi Province and present a compelling case for scaling up biogas as a clean, culturally sensitive, and economically viable solution. Doing so would contribute directly to Nepal's efforts to achieve Sustainable Development Goals 3, 7, and 13, while also promoting environmental resilience and gender equity in rural communities.

## Conclusion

The study reveals that household dependence on firewood in Koshi Province imposes substantial and interlinked environmental, economic, and health-related burdens. Households incur high opportunity and financial costs, experience significant exposure to indoor air pollution—particularly affecting women and children—and contribute to considerable deforestation and carbon emissions. These findings reaffirm the systemic nature of energy poverty in rural Nepal, where firewood remains both a necessity and a constraint.

Biogas systems emerge as a promising alternative, offering multi-dimensional benefits including reduced firewood use, improved respiratory health, lower emissions, and enhanced agricultural productivity through organic fertilizer use. Despite these advantages, adoption remains low due to economic barriers, limited technical infrastructure, and socio-cultural resistance.

The study's mixed-methods approach—combining quantitative and qualitative data—provides a nuanced understanding of both the quantifiable costs and the contextual barriers shaping energy use in rural Nepal. Addressing these challenges through integrated policy responses can catalyze a just and sustainable energy transition, aligned with Nepal's commitments to Sustainable Development Goals (SDGs) 3, 7, and 13.

## Policy Implications

Based on the empirical findings, several policy interventions are recommended to facilitate the transition from firewood to biogas in rural households:

### *Financial Strategies*

- **Expand subsidies:** Increase government subsidies to cover up to 75% of biogas installation costs for low-income households, thereby reducing the upfront financial burden (AEPC, 2023).
- **Develop targeted microfinance schemes:** Introduce low-interest loan products and repayment plans tailored to the financial cycles of rural households, particularly those engaged in subsistence agriculture.

### *Infrastructure Development*

- **Build technical capacity:** Establish local technician training and deployment programs to support installation, maintenance, and repair of biogas units.
- **Promote collective solutions:** Invest in village-scale or community-managed biogas systems to reduce per-unit costs and foster shared ownership and maintenance responsibility.

*Awareness and Behavioral Change*

- **Strengthen community engagement:** Conduct localized outreach campaigns using trusted community leaders to enhance trust and uptake.
- **Promote success stories:** Disseminate evidence-based narratives and case studies that demonstrate the reliability, health benefits, and long-term savings of biogas systems.

*Environmental Restoration*

- **Integrate with reforestation:** Align biogas promotion with reforestation and agroecological programs to amplify climate and biodiversity benefits.
- **Encourage slurry utilization:** Incentivize the use of biogas slurry as an organic fertilizer to improve soil fertility and reduce dependency on synthetic agricultural inputs.

**Broader Implications**

This study adds to the growing body of research on sustainable energy transitions in developing contexts by offering empirically grounded insights from Koshi Province. It highlights the importance of designing context-sensitive policies that address economic, technical, and cultural barriers simultaneously. The policy framework proposed here is not only applicable to Nepal but also provides a scalable model for community-led energy transformation across similar rural settings in South Asia.

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