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FOREST–LIVELIHOOD EQUILIBRIUM IN THE EASTERN HIMALAYAS: CHALLENGES AND PATHWAYS TO SUSTAINABILITY

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Abstract: This study documents traditional indigenous knowledge of forest resource use in the Taktsom Chu watershed, a mid-elevation (932–3172 m) Himalayan region in East Sikkim, India. Objectives of the study were to examine forest biomass utilisation and consumption patterns in the watershed and identify strategies for optimising use to ensure long-term sustainability. Fieldwork and surveys were conducted across nine villages from June 2021 to September 2024, covering different altitudinal zones. A total of 300 informants were interviewed using semi-structured surveys and focus group interview, with prior consent obtained from all participants. Findings of the study shows that local communities use forest resources - food, fodder, fuelwood, and medicinal plants - for self-sustenance, following indigenous practices that maintain ecological balance. It was also reported by the participants that there is no significant loss of forest cover or biodiversity, attributed to eco-friendly policies and initiatives by the Government of Sikkim and India. However, proximity to urban areas, i.e., Gangtok, the capital of Sikkim, presents potential threats from population growth and urban expansion, but at the same time offers opportunities to stimulate local development in a sustainable way, for example through alternative supplementary livelihoods for local farmers such as small-scale slow tourism, as also confirmed by the predictive model for environmentally sustainable tourism development in the Taktsom Chu watershed. The results of the research provide valuable insights into the development of energy and fodder plantations and can serve as a baseline for future research and policy formulation, supporting forest conservation through sustainable exploitation.

Keywords: Firewood utilisation, traditional hill farming, sustainable hill farming, low-impact tourism, eco-agritourism, Sikkim Himalaya

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INTRODUCTION

In mountainous areas with dispersed settlements and limited economic opportunities, forest resources have traditionally been crucial in providing the local population with fuel, building materials and additional income. However, the traditional farming system based on coexisting with nature by maintaining pastures, mosaic fields, and extensive grazing is gradually declining due to socioeconomic changes and environmental pressures. Dependence on firewood extraction is increasing, often without long-term restoration and control, which is leading to the degradation of native forests, disturbance to the ecological balance, and loss of biodiversity. In light of this situation, growing discussions have emphasized the sustainable use of forest resources in alignment with the traditional principles of hill farming, with the broader objective of re-establishing harmony between human activities and the natural environment.

Alongside existing forms of nature tourism, the development of eco-agritourism is a promising alternative that could provide local farmers with an additional source of income. This approach offers economic diversification without increasing pressure on forest resources while promoting the preservation of cultural landscapes, local knowledge, and ecologically valuable forms of farming. By integrating organic farming and low-impact tourism, local communities can play a role in reducing fuelwood extraction and conserving local biodiversity through participating in eco-agritourism.

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At the same time, this can contribute to protecting the region's intangible cultural heritage and preserving traditional farming practices based on sustainable interactions between humans and nature.

This paper aims to investigate the current pattern of forest biomass utilisation in the traditional rural economy of the Himalayan Mountain system, using fuelwood consumption in the Taktsom Chua watershed (Sikkim, India) as an example, and to evaluate ways to optimise this utilisation to ensure its long-term sustainability. In this context, we will develop a predictive model of the potential impacts of sustainable rural tourism adapted to local conditions. This model will demonstrate how dependence on fuelwood can be reduced while protecting forest habitats and promoting the socio-economic development of communities in local mountain regions. This multidisciplinary approach links environmental management with regional planning, enabling recommendations to be made for the sustainable use of natural resources in ecologically sensitive areas.

The study was conducted using following research questions:

1. What are the current patterns and sustainability of forest biomass utilisation, particularly fuelwood consumption, in the Taktsom Chu watershed?
2. How sustainable are the existing forest resource use practices in terms of forest cover conservation and biodiversity protection supporting community livelihoods?
3. What strategies and policy measures can ensure long-term forest conservation and socio-economic development in ecologically sensitive Himalayan mountain regions?
4. To what extent can support for tourism development - specifically a 5% increase in visitor numbers - contribute to the rise in total fuelwood consumption in the TCW region?

Forest sustainability under pressure: the potential role of eco-agritourism in supporting mountain livelihoods

Natural resources form an important material basis for a country's economic growth and directly impact national economic security (Van Hoof et al., 2019; Song et al., 2020; Wang et al., 2023). Of these resources, forests are of particular importance due to their social, ecological and economic value (Andronache et al., 2019; Herman, 2019; Peptenatu et al., 2023). For communities living in proximity to forests, the role of forest resources in supporting livelihoods is gaining growing recognition (Yemiru et al., 2010). In mountain ecosystems, livelihood systems are shaped by the integrated use of forestry, agriculture, horticulture, agroforestry, and animal husbandry, which are mutually interdependent and collectively sustain the regional economy (Sundriyal et al., 1994). Rural households in these regions rely extensively on proximate natural resources and outputs from primary sectors—including agriculture, forestry, and livestock—for their subsistence and income generation (Patnaik, 1986; Sundriyal et al., 1994; Saxena, 2005; Sharma et al., 2009; Datta & Behera, 2024).

The depletion of natural resources is a critical global issue, driven by unsustainable usage patterns that impact economic growth and environmental deterioration. The intensity of this issue has increased in recent years, especially since 1990 (Blaga et al., 2019; Sarath, 2024; Yanyan et al., 2024). This is primarily because of industrialisation, population growth, pollution, forest fires and illegal logging, as well as over-exploitation, all of which can lead to biodiversity loss and ecosystem collapse (Gompil et al., 2022; Wang & Azam, 2024). There are also differences depending on altitude. Mountain farming systems, for example, are closely linked to altitude due to differences in resource availability and use (Mukherjee, 2012). However, globally, the total area of forest has decreased by 420 million hectares in the past three decades due to ineffective policies (FAO, 2020). A lack of effective management plans often leads to logging practices that hinder natural regeneration and make forests more susceptible to soil erosion, wildfires and weed infestations (Putz, 1994). To address this issue, it is essential to implement sustainable forest management practices and policies that discourage deforestation, emphasising the need for international support and effective governance to ensure the preservation of forest resources for future generations (Runyan & Stehm, 2020; Bytyqi et al., 2024). These practices are grounded in the principles of ecological sustainability, economic viability and social equity. Improving the vegetation pattern through sustainable forest resource management (including other management units, such as agroforestry and forestry systems) is crucial for addressing climate change, fostering adaptation, and safeguarding biodiversity and ecosystem services (Torres et al., 2016; Rawat et al., 2023).

In recent years, however, there has been a growing shift on sustainability concerns in forest management processes across many parts of the world, with the aim of maintaining or expanding forest coverage wherever possible (Gompil et al., 2020). Sustainably managed forests deliver a wide range of ecosystem services, including carbon storage, biodiversity preservation, and the safeguarding of water resources (Imai et al., 2009; Dhyani & Dhyani, 2016; Guo, 2022). Sustainable forest management is commonly conceptualized through three interrelated perspectives (Bartniczak & Raszkowski, 2018): the first relates to the wood industry, the second encompasses environmental considerations including ecosystem functions, and the third addresses the social dimension of the forestry sector (Reynolds et al., 2007). Forests and their resources, such as firewood, are a primary source of cooking fuel for many poor people, particularly in developing countries such as India, Southeast Asia, and Africa (Arnold et al., 2006). This is sometimes referred to as the 'energy of the poor' (Hiemstra-van der Horst & Hovorka, 2008). However, these resources are susceptible to deterioration and degradation as a result of unsustainable use. The subsistence farming economy of millions of farmers in tropical Asia is inherently dependent on forests, which are a major source of firewood, fodder and timber (Chettri, 2000). Consequently, tropical Asia is losing forest area at an annual rate of roughly 2% (Hughes et al., 2022).

In the context of rural mountain communities that are socio-ecologically vulnerable due to mounting stress on natural resource systems (Matlovicova et al., 2022; Brunn et al., 2018; Acharya et al., 2022), eco-agritourism emerges as a complementary, low-impact strategy that adheres to the principles of sustainable forest management (SFM). Drawing on the ideas of endogenous development and the sustainable livelihoods framework (Chambers & Conway, 1991; Noje et al.

2025), eco-agritourism combines small-scale organic farming with environmentally responsible tourism (Lochman & Vagner, 2022; Boros & Korcsmáros, 2024). This generates alternative income without compromising the capacity for forest regeneration or traditional land use. In theory, it aligns with the diversified farm economy model (Acharya et al., 2021), whereby households engage in various activities, including value-added services, rather than relying solely on agriculture or forestry. In mountain regions such as the Eastern Himalayas, this model supports the principles of resource subsidiarity by making use of local knowledge, labour, and materials to maximise circularity and resilience in rural economies (Altieri, 1995; Pretty, 2007; Laginová et al., 2024). There are several different models of eco-agritourism, reflecting the specific natural and socio-economic conditions of the territory. In the context of the Himalayan Mountain system in Sikkim, for example, the following model appears applicable: (A) *Community-Based Eco-Agritourism (CBEAT)* – We have discussed this model in more detail in the Demkova et al. (2022) study. It focuses on cooperative ownership and benefit-sharing among local households, enabling them to collectively manage infrastructure, guest accommodation, organic gardens, and guided activities. CBEAT has been shown to enhance community agency and investment in conservation (Stone & Wall, 2004; Sumarmi et al., 2021; Demkova et al., 2022). (B) *Farm stay and participatory agritourism* – under this model, smallholder farms offer visitors an immersive experience of sustainable farming, traditional food preparation, and biodiversity-based knowledge systems (Križan et al., 2022). These activities reinforce cultural continuity while generating income from everyday practices (Phillip et al., 2010). (C) *The Integrated Landscape Approach* – Inspired by agroecological zoning and mosaic landscape theory, this approach combines multifunctional land use, including agroforestry, pasture rotation, and habitat conservation, with tourism infrastructure (Sayer et al., 2013).

The fundamental principles that determine the viability and sustainability of eco-agritourism are as follows: (1) *Ecological carrying capacity* — the number of tourists must align with the regenerative capacity of the local agroecosystem, taking into account fuelwood and fodder dynamics (Taktsom Chu watershed); (2) *Participatory governance and benefit-sharing* — the equitable involvement of women, indigenous elders and young people in decision-making processes is essential for legitimacy and adaptive governance (Matlovicova et al. 2022); (3) *Knowledge valorisation* — Eco-agritourism promotes indigenous ecological knowledge, such as the use of medicinal herbs, fodder management, and traditional food systems (Laginová et al., 2024; Križan et al., 2022); (4) *Infrastructure-light development* — rather than large-scale lodging facilities, the focus is on homestays, camping and low-impact trails, thereby reducing land use change and environmental degradation (Kostilnikova et al., 2022; Bytyqi et al., 2024). Empirical evidence from other mountain regions such as Nepal, Uttarakhand (India) and Andean Peru (Rai & Sundriyal, 1997; Bhattarai et al., 2011), properly managed eco-agritourism can lead to a reduction in out-migration by providing on-site employment (Stupariu et al., 2022; Kostilnikova et al., 2022). It can also decrease dependence on forest biomass through supplementary income and increase investment in local education, ecological restoration projects, and the revitalisation of neglected traditional crops and sustainable landraces (Rai & Sundriyal, 1997; Bhattarai et al., 2011). In the case of Taktsom Chu, the region has great potential for developing pilot eco-agritourism models, given its high level of reliance on organic production, its existing knowledge systems and its relatively well-preserved agro-forestry landscape. These models could focus on promoting fodder species management, traditional dairy practices, the cultivation of medicinal herbs, and the seasonal gathering of wild edibles. All these activities form part of current livelihoods and would require minimal structural transformation.

This could reduce the intensity of fuelwood extraction, thereby improve the Sustainable Fuelwood Index (SFI) and reinforcing the long-term resilience of the ecosystem and the cultural integrity of indigenous farming communities.

Overdevelopment of tourism in an area due to inappropriate management, loss of agricultural land due to tourist infrastructure development, and negative socio-cultural impacts such as regional inequalities, socio-pathological phenomena, commercialisation, standardisation and loss of authenticity due to globalised tourism offerings can be considered risk factors for development. However, appropriate tourism development can bring a range of benefits, such as economic growth, an improved standard of living for the population, educational development and the protection of biodiversity and cultural heritage (including the preservation of traditions).

These are important attributes that make the territory attractive to potential tourists. Other benefits include improved water and soil quality and sustainable production through targeted eco-agritourism offerings.

Drivers and patterns of forest resource utilisation, with an emphasis on traditional farming communities in the Indian Himalayan Region

In the Indian Himalayan Region, most farming systems have remained at a subsistence level (Fonzen & Oberholzer, 1984; Nair, 1985; Shah, 1982; Singh et al., 1989; Sharma, 1991; Toky & Ramakrishnam, 1981; Sati, 2005; Sundriyal et al., 2014; Rawat et al., 2025; Mishra et al., 2025). Through long-standing experimentation, farming communities have designed these systems to sustainably supply timber, fuelwood food and fodder (Sundriyal et al., 1994; Rai & Mishra, 2022) Furthermore, farming systems in the IHR include uncultivated and forest land, which act as 'support areas' as villagers generally obtain firewood, fuel wood, fodder, timber and water for domestic use from these areas. Forest use in the IHR is imbalanced - large areas remain untapped, whereas those adjoining villages are overexploited (Sati, 2023). Insufficient information on resource use patterns and utilization trends leads to significant gaps in management planning and intervention strategies.

In recent decades, the landscape of the IHR has come under increasing threat from unsustainable harvesting, large-scale hydropower development, pollutants and refuse creation, excessive sand extraction, unplanned tourism, invasive exotic species, and climate-related impacts (Dhyani & Dhyani, 2016). A trend of unsustainable resource harvesting and excessive use of forest and vegetation has resulted in degradation of the IHR (Awasthi et al., 2003; Khanduri et al., 2002). The increased dependency of local people on fuelwood, fodder, local raw materials and NTFPs in neighbouring forests has resulted in decreased productivity in Himalayan region (Saxena et al., 2005). The low agricultural yields in the Himalaya are largely due to the restricted use of modern techniques, difficult terrain, harsh climatic conditions, and the additional stress of climate change (Sharma et al., 2011; Mishra et al., 2021; Rawat et al., 2025). In addition, rapid population growth and expanding anthropogenic pressures - including construction, road development, hydropower projects, industrialization, urbanization, grazing, and hunting - are driving significant land use changes in the fragile Himalayan Forest ecosystems (Goswami et al., 2023). These factors collectively threaten forest biodiversity and ecosystem services, as well as the indigenous farming (Singh et al., 1984; Rawat et al., 2025). In mountain ecosystems, a mushrooming population, unplanned migration and uneven population distribution have forced people to exploit limited natural resources (Mahat, 2004). In addition, the Himalayan ecosystem has been adversely affected by forest degradation resulting from practices like litter collection for soil fertility management and excessive extraction of forest resources.

In light of the evolving socio-economic and environmental contexts of rural Himalayan communities, it is crucial to generate predictive understanding of trends in fuelwood and fodder consumption. This is because an increasing population puts pressure on natural resources, leading to erratic extraction and deforestation, as well as reduced soil fertility and productivity (Thapa & Weber, 1990; Sundriyal & Sharma, 1996; Rai & Sharma, 1998; Rana et al., 2012; Sharma & Samant, 2021). Sustainable natural resource management also involves exploring the intricate linkages between biophysical, technological, socio-economic, and environmental factors (Bhardwaj, 2020). During the 20th century, the concept of sustainable forest management evolved to encompass not only wood production, alongside multiple uses and ecosystem services of forests (Schmithüsen, 2013). However, continuous economic expansion conflicts with the principles of sustainable resource utilization (Hickel & Kallis, 2019). Researchers have proven that resource degradation can be mitigated through integrated watershed management, an approach that has become popular in different regions of the world over the past few decades, including the Himalayas (Dixon & Easter, 1991; Sharma, 1992; Bewket, 2003; Sharma, 2005; Gregersen et al., 2007; Rana & Gupta, 2009; Beheim, 2012). Management strategies can be formed based on the behaviour of available natural resources and their use in a watershed. Furthermore, agroforestry practices offer a reliable supply of fuelwood and fodder, thereby minimizing the time and effort required to collect resources from outside the farm (Nagar et al., 2021).

The Eastern Himalayas are characterised by diverse farming practices that have been developed and nurtured over many generations. Traditional farming practices in the Sikkim Himalaya are largely subsistence-oriented, having evolved through generations of farmers' experiential learning and innovation to provide food, fibre, fodder, fuelwood, medicinal resources, and timber. These agro-systems demonstrate remarkable self-sufficiency and biological diversity, while simultaneously supporting ecosystem functions at low cost and enhancing the livelihood security and economic viability of local communities (Brookfield & Padoch, 2007; Altieri, 2004; Negi & Maikhuri, 2017; Gurung, 2018).

In the Sikkim Himalayas, natural and agroforestry systems meet 76% of resource needs owing to their simplicity and accessibility (Sundriyal & Sharma, 1996; Chettri et al., 2002). It is therefore essential to efficiently and integrally develop these natural resources to ensure sustained yields and avoid imbalanced conditions (Chettri & Sharma, 2006). Over centuries of experimentation and innovation, indigenous farmers of the Sikkim Himalayas have developed diverse land-use systems that sustain a wide range of domesticated and wild species.

The Sikkim Himalayas are one of India's agro-biodiversity hotspots, where agriculture is the main source of income for over 75% of the population (Kumar, 2012). The region is also rich in cultural diversity, and its inhabitants possess a great deal of knowledge about the resources with which they live. There is a strong connection between people and nature in this region (Theengh, 2023). In the Sikkim Himalayas, agricultural, land and forest use practices have been shaped by indigenous knowledge and conserved (Sharma et al., 2018).

In the context of IHR, farming communities have lived close to nature and been custodians of critically important natural resources (Ramakrishnan, 2007; Sati, 2023). Studies on the traditional ecological knowledge of natural resource use patterns for self-sufficiency have been conducted on the Pangwals community in the Western Himalayas (Rana et al., 2022). In addition, evidence highlights traditional hill farming practices as key mechanisms for enhancing resilience and promoting conservation within the IHR (Sharma et al., 2023). Research highlights that indigenous agricultural systems provide innovative means of conserving local crop diversity, maintaining environmental sustainability, and supporting food and health security, social well-being and cultural values in rural communities (Sharma et al., 2023).

Following an overall review of the published research on forest resource consumption, we can conclude that most of it has focused on the Western Himalayas (e.g. Tomar et al., 1992; Chandra et al., 2008; Rawat et al., 2009; Sharma et al., 2009; Gupta et al., 2009; Bagwari & Todaria, 2011; Sharma et al., 2011; Khuman et al., 2011; Shaheen, 2011; Mukherjee et al., 2012; Dhyani & Maikhuri, 2012; Dhanai, 2014; Akhter & Malaviya, 2014; Dhanai, 2015; Kumar & Kumar, 2015; Kanwal, 2016; Mitra, 2017; Singh et al., 2017; Singh et al., 2018; Parmar & Negi, 2019; Qureshi et al., 2019; Kumar et al., 2020; Jiju et al., 2021; Singh et al., 2021; Agarwal & Chandra, 2021; Puspwan et al., 2021; Sharma et al., 2023). Only a few studies have examined the Eastern Himalayas (Sundriyal & Sharma, 1996; Chettri et al., 2002; Chettri & Sharma, 2008; Dollo et al., 2009; Chettri et al., 2015; Chettri et al., 2021; Dasgupta et al., 2022). Despite the global rise in studies on sustainable forest use, such research is still scarce in the IHR (Bhatt & Sachan, 2004; Dasgupta et al., 2022). However, there are very few studies relating to the sustainable forest resource use by the farming communities in the IHR which are mostly from the Western Himalaya (Rawat, 2023; Sati, 2023). The above facts motivated the authors to address the lack of knowledge regarding the sustainable use of forest resources by farming communities in the less-investigated region of the Eastern Himalayas, using Sikkim as an example.

Description of the study area

The Taktsom Chu watershed is in the East District of Sikkim, in the Eastern Himalayas. The study area comprises a total population of 5,669 individuals, which consists of 1,343 households across all surveyed village settlements. A general socio-economic profile was compiled through a comprehensive door-to-door survey (Tables 2, 3, 4).

The livelihood structure of the area is predominantly agricultural, engaging nearly 75% of the population, while 15% are employed in government services and about 10% are involved in business-related activities. The average household size was found to be approximately six members per family. The Taktsom Chu watershed, the focus of this study, is in the mountainous zone of Sikkim (Figure 2), a mid-elevation Himalayan watershed ranging from 932 to 3,172 metres. Situated in the southeastern part of the state, it is in the East district (Figure 1, 2). Extending from 27°15’ to 27°20’ N and 88°37’30” to 88°42’30” E, the watershed covers an area of 35.42 km², accounting for approximately 0.49% of Sikkim's total geographical area. The watershed is the catchment area of the 13 km² Taktsom Chu river. It finally drains into the Ranikhola river at Jalipool, 2 km from Ranipool. The Taktsom Chu is a tributary of the Ranikhola and lies within the Teesta basin. The Ranikhola merges with the Teesta River at Singtam, about 30 km from Gangtok. The watershed is covered by three revenue blocks: Naitam, Assam, and Lingzey. The Naitam part of the watershed is very steep, while the Assam and Lingzey parts are moderately steep. The watershed is elongated in shape. In terms of altitudinal zonation of the study area, the highest area (10.01 km²) falls within the 1500–2000 m altitude zone, followed by the zone above 2500 m (9.01%), with the lowest area (7.40 km²) falling within the 2000–2500 m zone (Table 1). The study area has a temperate climate, with average annual temperatures of about 18 °C and summer maximum rarely surpassing 28 °C.

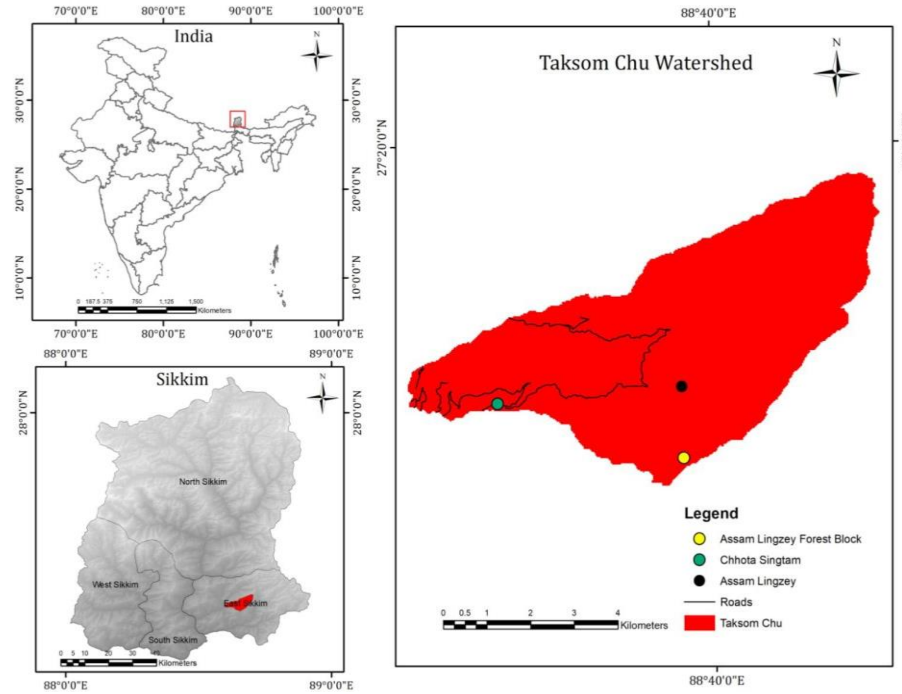

Figure 1. Location of the Taktsom Chu watershed in the Eastern Himalayas, Sikkim, India


Figure 2. A panoramic view of the Taktsom Chu watershed (Kholagaon Village: 15.01.2009) (Source: Santosh Sharma)

Table 1. Altitudinal zonation of the Taktsom Chu watershed (Source: Primary data, 2023)

Altitudinal zone	Area (sq.km.)	Percentage (%)
500 -1500m	9	25.44
1500 -2000m	10.01	28.26
2000-2500m	7.4	20.9
Above 2500m	9.01	25.44
Total	35.42	100

Table 2. Socio-economic Characteristics of Surveyed Households by Ecological Zone, 2024

SL. No.	**Parameters (n = 300)**		**Ecological Zone**		
			Low(%) N=100	**Mid(%) N=100**	**High(%) N=100**
1	Respondents of Households Surveyed	Male	43	62	56
		Female	57	38	44
2	Age of the Respondents	Between 30 and 45 years	65	56	62
		Between 46 and 60 years	35	44	38
3	Family Structure	Nuclear	55	60	46
		Joint	45	40	54
4	Education of Household Head	Illiterate	15	12	10
		Up to senior secondary Level	45	50	45
		Graduation and above	40	38	45
5	Average Size of Household (Person/Household)		4.0	3.6	4.5
6	Operational Size of Holding(ha)	Marginal (<0.5)	70	68	74
		Medium (0.5–1)	20	18	17
		Large (>1)	10	14	9
7	Livelihood Sources	Agriculture	54	47	58
		Agriculture and Non-agriculture	25	23	30
		Services	21	30	12

Table 3. General profile of the study area villages in the Taktsom Chu Watershed

SL. No.	**Parameters**		**Ecological Zone**		
			Low(%) N=100	**Mid(%) N=100**	**High(%) N=100**
1	Respondents of Households Surveyed	Male	43	62	56
		Female	57	38	44
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		Between 46 and 60 years	35	44	38
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		Joint	45	40	54
4	Education of Household Head	Illiterate	15	12	10
		Up to senior secondary Level	45	50	45
		Graduation and above	40	38	45
5	Average Size of Household (Person/Household)		4.0	3.6	4.5
6	Operational Size of Holding(ha)	Marginal (<0.5)	70	68	74
		Medium (0.5–1)	20	18	17
		Large (>1)	10	14	9
7	Livelihood Sources	Agriculture	54	47	58
		Agriculture and Non-agriculture	25	23	30
		Services	21	30	12

Table 4. Characteristics of the surveyed villages in the study area

Villages of the study area	**Ecological Zones**	**Lat, Long**	**Altitude (m)**	**DM (km)**	**TH (no.)**	**PoP (no.)**	**L (no.)**
Pastanga	High	27^{0}17’13”N 88^{0}39’10”E	1440	200 m	112	485	280
Gairigaon		27^{0}16’51”N 88^{0}38’39”E	1455	150 m	125	580	332
Naitam		27^{0}18’12”N 88^{0}38’50”E	2067	100 m	350	1245	1000
Pabyuik		27^{0}17’55”N 88^{0}37’50”E	1684	100 m	136	544	420
Daragaon	Mid	27^{0}16’50”N 88^{0}38’16”E	1431	100 m	129	520	396
Lingzey		27^{0}16’55”N 88^{0}36’44”E	1245	100 m	163	767	520
Palung		27^{0}17’44”N 88^{0}38’04”E	1530	400 m	96	419	272
Soureni	Low	27^{0}16’41”N 88^{0}36’08”E	1017	100 m	144	729	444
Nimthang		27^{0}17’32”N 88^{0}37’00”E	1030	100 m	88	88	240
DM-Distance from motorable road, **TH-** Total Households, **PoP-**Population, **L-**Livestock							

METHODOLOGY

The primary research focused on data collection by field survey in the local communities inhabiting the Taktsom Chu watershed area. These were structured and semi-structured interviews that focused on the socio-economic aspects of the study area. These included demographics, the structure of economic activities carried out (occupation), land use patterns and structured information on livestock rearing. Approximately 30% of households in each village were interviewed. This was followed by group discussions, household interviews, guided field walks and field observations.

Sources of energy and methods of extraction, as well as details of fuel and fodder collection, availability, utilisation and consumption, and the types and quantities of fuel used, were collected, along with livestock details and other miscellaneous information (social caste, economic level, gender and age). At the same time, observations were carried out in each sampled household to quantify the collection of fuelwoods, fodder, leaf litter, sticks and branches, along with medicinal and wild edible plants, by accompanying households during their routine forays. In addition, discussions were held with gram pradhans (village council heads). Lists of families were obtained from the Gram Panchayat/Gram Sabha or family registers to obtain secondary information about the village. The collected data was validated/verified through a field-based survey, primary and secondary data, and data collected through the Participatory Rural Appraisal (PRA) method by approaching villagers representing different age groups and genders. Personal observations and discussions with villagers in the watershed were also conducted. The actual amount of fuelwood consumed in different watershed blocks was estimated based on regular observations in villages. Fuelwood consumption was assessed over a 24-hour period using the weight survey method (Bhatt et al., 1994). Per capita daily fuelwood consumption (F) was computed by dividing the total household fuelwood use by the number of family members, following the method outlined by Gupta et al. (1997):

$$F = \frac{TFc}{TFm} \tag{1}$$

where: TFc = total fuel consumption (in kg) by the sample household; TFm = total number of family members.

The quantity of fodder consumed by each animal (Fd) was measured by weighing the quantity consumed over a 24-hour period (Vishvakarma et al., 1998; Rawat et al., 2009; Kanwal et al., 2016):

$$Fd = TFc - Fdl \tag{2}$$

where: TFc = total fodder collected (in kg); Fdl = fodder left.

To evaluate the major fuelwood species used by villagers and their preferences, the *index of use (I%)* of each species was calculated according to the method described by Lance et al. (1994), using equation (3):

$$I\% = \frac{n}{N} \times 100 \tag{3}$$

where: n - represents the number of people citing the use of the tree species;

N - represents the total number of people surveyed;

If I% = 100 - 60% - the species is widely used; If I% = 60 - 30% - the species is moderately used;

If I% < 30% - the species is not used or minimally used.

The Sustainable Fuelwood Index (SFI) was also used to create the prediction model (4).

$$SFI = \frac{R}{C} \tag{4}$$

where: R - annual volume of fuelwood reproduced (kg/year);C - annual volume of fuelwood consumed (kg/year).

If the value of: SFI > 1, then it is a sustainable harvest (production exceeds consumption);

SFI = 1, then the harvest is at its maximum sustainable level (there is a balance between regeneration and consumption);

SFI < 1 indicates an unsustainable harvest (consumption exceeds regeneration).

RESULTS AND DISCUSSIONS

Traditional farming systems, livestock holdings, and household livelihoods in the Taktsom Chu Watershed (Eastern Himalaya)

Similar to other parts of the IHR animal husbandry remains a central practice in the studied villages, closely integrated with agriculture and supplemented by tourism-related employment. Agriculture and livestock together form the backbone of household economies, while a smaller section of the population is engaged in the service sector.

Livestock holdings, averaging 3–5 animals per household (typically cows, bullocks, pigs, and goats), not only serve as a source of income but also represent household wealth in this agriculture-based economy. Beyond financial returns, livestock provide critical livelihood support through milk, butter, curd, meat, wool, and dung, thereby contributing both direct resources and value-added products essential for marginal households. Agriculture, predominantly rainfed and practiced on terraced slopes, is the primary occupation, with per capita landholding estimated at 0.59 ha. The cropping system exhibits considerable diversity, with farmers cultivating 15–20 varieties of crops encompassing cereals, pulses, vegetables, millets, condiments, spices, and medicinal plants though only a few (e.g., maize) are grown extensively. Traditionally, farming systems have been sustained through farmyard manure (FYM) derived from cattle dung, with little or no reliance on chemical inputs. However, land-use and cropping patterns have undergone significant changes over the past two decades. While paddy fields once occupied a substantial share of cultivated land, their area has drastically declined, giving way to an expansion of vegetable cultivation. This transition reflects not only a response to market demand and income opportunities but also an adaptation to changing socio-economic and environmental contexts in the valley.

A clear shift is evident in crop diversity, as vegetables such as carrot (*Daucus carota*), radish (*Raphanus sativus*), broccoli (*Brassica oleracea* var. *italica*) and cauliflower (*Brassica oleracea* var. *botrytis*), which were previously absent, are now cultivated. Conversely, the cultivation of finger millet (*Eleusine coracana*) and dalle kodo (*Paspalum scrobiculatum*), previously important staples, has markedly declined in recent years. The cultivation of traditional crops such as large cardamom has been largely abandoned. At present, households meet their requirements for fuelwood, fodder, crops, and non-timber forest products (NTFPs) through a combination of forest resources and farmland. Traditional farming systems are slowly changing as mountain regions become more physically, administratively, and economically integrated into wider socio-economic networks. This shift has resulted in the marginalization of traditional resource-use practices.

The indigenous communities of the watershed remain highly dependent on forests for their livelihood and sustenance, reflecting their close cultural and ecological association with forest ecosystems. A broad spectrum of plant species is employed by households to meet needs ranging from fuelwood, fodder, and timber to soil fertility inputs, medicinal uses, and dietary supplements through spices and wild edibles. Such diversity in use highlights the multifunctional role of forests in sustaining rural livelihoods. The dependency of households on forests in the study area ranges from meeting domestic energy demands through fuelwood to securing fodder, construction timber, agricultural implements, and supplementary resources in the form of NTFPs. The intensity of extraction, however, varied across villages and was influenced largely by resource availability, accessibility, and the distances households were willing to travel (Table 5). Resource use also displayed clear temporal patterns: while fuelwood and fodder were extracted year-round, leaf litter collection was seasonal.

Semi-wooden construction characterizes most housing structures in the area, where preferred timber species include *Alnus nepalensis, Prunus cerasoides, Quercus leucotrichophora*, and *Abies pindrow*. Notably, timber extraction is relatively infrequent, typically occurring once every 15–20 years per household, reflecting both the durability of wood products and the recognition of timber as a long-cycle resource. These findings indicate that while dependence on forests remains high, the type, timing, and intensity of extraction are shaped by ecological availability and socio-economic considerations, illustrating the adaptive strategies of mountain communities in managing forest resources

Table 5. Village-Level Practices of Traditional Resource Use in the Study Region (2023) (Source: own primary research, 2023)

Resource Type	Extraction Process	Species	Frequency	Consumption calendar	Average
Fuel wood	Felling Lopping Collecting	*Alnus nepalensis, Betula alnoides, Toonaciliata Macaranga pustulata, Ostodes paniculatus* *Schima Wallichi, Terminalia myriocarpa, Virburnum sp., Albizzia sp., Engelhardtia sp., Jambosa formosa, Berchemia floribunda, Pyrulariaedulis Alnus nepalensis*	Once in 2–3 days	Entire year	35.00 kg / 2–3 day
Fodder	Lopping, Chopping Mowing	*Quercussp., Ficus sp.* *Imperatasp.,Capillipediumsp*	Twice a day	February–May and August–September	86.8 ± 10.5–157.5 ± 17.5 kg / day
Timber	Sawing	*Castanopsis sp.; Choerospondiasaxillaris Symingtonia populnea ; Betula cylindrostachyes Michelia sp.; Albizzia sp.*	1/15-20 yrs	Nov- March	5.9 m^3/tree
NTFP and wild edibles	Lopping, chopping, uprooting	Ningro (*Dryopteris* sp.); Sisnoo (*Urticaparviflora/H.dioica*), Simrai (*Nastritumofficinale*); Naakima (*Tupistranutans*) Thotney (*Acogonum molle*); Gurbey (*Araesima* sp.), Tama(*Dendrocalamushamiltonii, Cephalosaechumcapitatum*), Mushroom (*Agaricus* sp.), Aisaloo(*Rubusellipticus*)	2–3 Times a week	March–June	1.5 kg / household / week
Medicinal herbs	Lopping, chopping, uprooting Umbel picking	*Swertia chirata*(Chiraita); *Astilbe rivularis*(Buriokahti); *Berginia ciliata*(Pakhanbed); *Viscum articulatum*(Harchur); *Fapophyrum sp.*(Phapar); *Artemisia vulgaris*(Titeypati); *Equesetumsp*(Kurkurejhar); *Eupatoriumsp*(Kalijhar/Bankmara); *Heracleum wallichi(Chimphing)*	1-2 times a month	March–July	1kg/household/ week
Leaf litter	Collecting	Leaves of *Alnus* sp. and *Schima* sp.	Twice a day	November–April	45 kg / household / day

Fuelwood dependency and socio-ecological dynamics in the Taktsom Chu Watershed

Firewood collection is an important component of the daily chores in the rural communities/households and was found to be extracted by the local populace from community forestry, social forestry, farm forestry and sometimes from adjacent reserved forests. The fuel wood was collected either directly by felling the tree itself or only lopping the branches or by collecting the fallen branches. About 10 males are engaged in felling one tree and 3 trees/household are logged in a year.

Besides, felling lopping and chopping methods are also used by the villagers. In the watershed, people collect fuel wood during winter months only (November-March) as these months are considered to be the best for fuel wood extraction because of dry months (with no rainfall).In contrast, it is rarely extracted in summer and rainy seasons (April-October).

The collection of fuel wood was done from 10 am-4.30 pm. On an average for a distance of less than half kms a villagers collects 1 *Bhari* (= about 30 kg loose weight of fuel wood approx.) in a *Doko (*Large multipurpose bamboo/ringal basket*)* in one turn and about 15-20 times in one day. After collection, the local populace stores it in heaps (‘peel’) close to their home and keep using from it almost daily for the whole year. The frequency of wood fuel collection varied from 2-3 times daily, especially during morning or day times. Women and Children were found to be more involved in the fuel wood collection activity. Fuel wood is used for cooking food and fodder, boiling water, preparing alcohol/beverages, heating space and curing cardamom (once in a year) and performing rituals and festivals etc.

In the study area, it was observed that the felling of only those trees were attempted which have been not in use and trees with straight bole for e.g. *Castanopsis tribuloides*, *Toona Ciliata, Terminalia myriocarpa* and *Michelia* sp. Since these trees have less branches, they were used extensively for generating wooden planks for furniture and for household construction.

Further, the dried branches including, twigs, wood shavings, saw dust and branches after cutting of wooden planks of these tree species were used as fuel wood and leaves as fodder for livestock. On the other hand, trees such as *Schima wallichii, Engelhardtia sp., Maesa chisea. Virburnum sp., Macaranga sp.*were not used for extracting the timber for generating wooden planks. *Schima wallichii* was highly preferred tree, *Alnus nepalensis* and *Macaranga sp.* were moderately preferred while *Maesachisea* was least preferred tree species for fuel wood extraction. The availability status of *Schima wallichii*was high followed by *Alnus nepalensis* and *Macaranga sp.* with medium availability status whereas as *Maesachisea*was least available in the study area. During survey, it was observed that *Alnus nepalensis* takes about 5 yrs to reach adult stage and after five yrs, it can provide about 500 kg of wood fuel after been logged. Despite the population growth and accompanied urbanization, there is no shortage of fuel wood among the local population due to the fast regeneration capacity of the different fuel wood species. As a result there is no environmental degradation and no pressure on the forests.

The dependency rate of the local population on fuel wood is 80% in spite of 98-100% of households with Liquefied Petroleum Gas (LPG) connection. This is because majority (90%) of the families possess few livestock (cow) in their households. Livestock distribution per household consists of 1-2 cattle, pig and goat. Some families have also maintained few poultry birds. Consequently, lot of wood fuel is required by majority of families (90%) for preparation of animal feed.

Fuelwood constitutes the principal source of domestic energy in India’s rural areas, with mountain villages showing particularly high dependence (Bhatt & Sachan, 2004). Fuel wood is collected by men and women from nearby forested areas. In the Himalayas, depletion of forest resources has directly aggravated the pressures on rural livelihoods through shortage of wood fuel (Thapa & Weber, 1990). In the study area, illicit felling was also observed in forest areas near to human habitations.

Forest as a source of fuelwood consumption

In the study villages, fuelwood extraction is carried out by both male and female members from the surrounding forest landscapes. The elevated dependence on fuelwood stems from the presence of forest resources in the immediate surroundings, which households can access without financial expenditure. Fuel wood use ranged from 60-90% in different wards of the watershed. Traditional *chulha* was very commonly used for cooking with fuel wood as fuel.

On average, a family of 4 persons with 1-2 cattle (cow) consumed 7-8 kg/day of fuel wood using LPG for cooking food for all the family members. While a family of 5 persons with 1-2 cattle (cow) and with no LPG consumed 5-6 kg/day of fuel wood for cooking food for the family members and 8 kg/day of fuel wood for cooking food for cow totaling 13-15 kg/day of fuel wood consumption. It was estimated that a family of 4 persons with LPG consumed 2920 kg/yr of fuel wood for meeting fuel requirement of 2 cow whereas about 4745 kg/yr of fuel wood was consumed by a family of 4 persons without LPG for meeting fuel wood requirement of both family members and cow. In all the households of the 5 wards of the study area (Pastanga, Gairigaon, Daragaon, Lingzey and Soureni), the use of LPG ranged from 98-100% while the use of fuel wood ranged from 60-90%. The Government of India scheme of ‘*Pradhan Mantri Ujjawala Yojana’* (social welfare scheme) launched in 2016 offered low-income households free LPG connections to women of BPL families may have played a major role in thisin order to relive the pressure on forest resources (PMUY, 2019) (Table 6). Some of the residents of Lingzey (5%) and Soureni (10%) are tenants working in pharmaceuticals and so they also use LPG. About 90% of the population of study area depended on cows as a source of milk and money (Figure 3). The local population get only 2 litres of kerosene per month which they use occasionally for lighting purposes. About 76.82%. of households use both LPG and fuel wood for meeting their energy requirement. Furthermore, it was also found that with the increase in altitude (Pastanga and Gairigaon), the villagers used higher percentage of fuel wood in comparison to the villagers residing at lower altitudes (Lingzey and Soureni).

Table 6. Fuel wood use (in %) in different villages of the study area (Source: Field Survey, 2021-2024)

Villages	Fuel wood only	Fuel wood and LPG	LPG Only
Pastanga	22.73	69.1	8.14
Gairigaon	24.2	65.18	10
Naitam	22.11	64.1	14
Pabyuik	25.24	58.56	17
Daragaon	15	65.38	19.68
Lingzey	17.12	53.24	29.23
Palung	19	43.57	37.36
Soureni	15.41	45.2	39.4
Nimthang	12.25	32	55

Earlier studies (Pócs, 1976) have established that with increasing altitude, ambient temperature declines at a lapse rate of approximately 0.6–1.7 °C per 100 m, leading to higher fuelwood consumption. Consistent with this pattern, the present study shows that fuelwood continues to be the dominant household energy source, with 95.2% of households relying on it, even though alternative fuels such as kerosene and LPG are available. This persistent dependence suggests that factors such as accessibility, affordability, cultural preferences, and reliability of supply outweigh the adoption of commercial fuels. Similar trends of continued fuelwood reliance despite the introduction of modern energy sources have been reported in earlier studies (Dhanai et al., 2014), highlighting the resilience of traditional energy use patterns in mountain regions. During the course of study, it was observed that it is lot cheaper for the families to use LPG to meet their household energy requirement in comparison to fuel wood use. The main reason being cost of cutting and collecting fuel wood far exceeds cost of LPG on an annual basis. Therefore, the families use LPG for meeting their household energy requirement while they use fuel wood for meeting the requirement of their livestock, heating space, for preparing tea or quick food, performing rituals etc.

Fuelwood consumption patterns in the Himalaya show considerable regional variation, ranging from 4.55 to 23.88 kg/person/day (Khuman et al., 2011; Dhanai et al., 2014; Dhanai et al., 2015). In this study, fuelwood use per person was greatest in the Assam block (3.12 kg/day), moderate in Naitam (3.01 kg/day), and lowest in Lingzey (1.91 kg/day), resulting in a watershed average of 2.87 kg/day. These levels are higher than those observed among rural and tribal communities of the western Himalaya (1.49 kg/day; Bhatt et al., 1994) and southern India (1.92–2.20 kg/day; Reddy, 1981; Hedge, 1984). but lower than the 3.5 kg/day observed by Sundriyal et al. (1994) in the Sikkim Himalaya and the 3.15 kg/day average recorded for the western Himalaya (Bhatt et al., 2020). When compared internationally, the observed average fuelwood consumption of 2.87 kg/day across the watershed exceeds earlier findings from southern India (1.92–2.20 kg/day; Hedge, 1984), South and Southeast Asia (1.70–2.50 kg/day; Donovan, 1981), and the Nepal Himalaya (1.23 kg/day; Mahat et al., 1987). Nonetheless, it falls within the consumption range recorded for Pakistan's Himalayan belt (2.19–3.76 kg/day; Shaheen et al., 2011). At the village level, daily household fuelwood use was highest in the Assam block (238.03 kg/day), followed by Lingzey (179.07 kg/day) and Naitam (142.97 kg/day). These findings highlight both the persistence of high fuelwood dependency in the Taktsom Chu watershed and the spatial heterogeneity in consumption across blocks. The comparatively elevated per capita use relative to several South Asian contexts underscores the continued centrality of fuelwood in household energy security in this Himalayan landscape, despite the gradual introduction of alternative fuels.

Total fuelwood consumption in the Assam, Lingzey and Naitam blocks of the watershed were 4284.5 kg/day, 1253.5kg/day and 2430.5 kg/day respectively. Cooking energy requirements were met predominantly through fuelwood in Naitam block (72.45%), while relatively lower reliance was observed in Assam (43.73%) and Lingzey (36%).

From the observation and discussions with the local people and NGOs it was learnt that the resource utilization depends upon three factors, namely, altitude, distance from the resource and distance from road head. The major fuel wood species are *Alnus nepalensis, Schima wallichi, Macaranga pustulata* etc. In the watershed, two distinct patterns of fuelwood collection were identified: daily collection and seasonal collection. Consumption levels were strongly influenced by altitude, seasonal variation, and household size, consistent with earlier observations by Bhatt et al. (1994).

A distinctive feature of the study villages, compared with other Himalayan regions, was the absence of alternative fuel use, particularly animal dung cakes and crop residues. Two key factors explain this pattern firstly, given that Sikkim is an officially declared organic state where the use of pesticides, chemical sprays and fertilizers is banned, animal dung serves as the main source of manure. Second, fuelwood is abundantly available from private lands and community forests at no direct cost, and its ease of use makes it a preferred household energy source. Compost manure in the area is typically prepared from a mixture of soil and dung, which underscores the dual importance of livestock in both farming systems and organic nutrient cycling. These findings suggest that while fuelwood continues to dominate domestic energy use, its preference is reinforced not only by ecological availability but also by institutional factors (organic state policy) and cultural practices around soil fertility management. This distinguishes the study area from other parts of the Indian Himalayan Region where dung cakes and crop residues often constitute supplementary fuels.

Crop residues from agricultural fields—including paddy, wheat, millet, and pea—were primarily utilized as supplementary fodder or as bedding material for livestock. Nearly every household stored hay or other crop by-products, which after drying, were preserved for year-round use. These residues are particularly valuable during the lean winter months when green fodder availability is minimal. By contrast, in the rainy season, naturally regenerating fodder near settlements reduces both the distance travelled and the time invested in collection across all altitudinal zones, thereby easing household labour burdens. Despite the availability of crop residues and other potential biomass, fuelwood remains the overwhelmingly preferred source of household energy. This preference is driven by multiple interlinked factors: (1) the easy and abundant availability of fuelwood from nearby forests, (2) its status as a virtually free commodity, (3) the limited access to alternative energy options, and (4) cultural and behavioural resistance to shifting away from traditional energy sources. Notably, kerosene oil was rarely used for cooking and served primarily for lighting. These patterns reflect a strong reliance on forest-based energy despite gradual modernization of rural economies. The sustained dominance of fuelwood use underscores both structural constraints—such as limited energy alternatives—and socio-cultural preferences that reinforce traditional practices. At the same time, the use of crop residues for fodder and livestock management highlights their dual role in supporting both animal husbandry and household subsistence, illustrating how rural communities balance competing demands on biomass resources.

As far as Himalayan range is concerned, per capita annual consumption of wood ranges between 4000-1500 kg fresh weights which is very higher than other parts of India (Campbell & Bhattarai, 1984; Metz, 1990; Straede & Treue, 2006). The Himalayan Mountain system accounts for nearly 18% of India's geographical area and supports over 50% of the country's forest cover (Malik et al., 2014). It is well known that trees and shrubs form bases for fuel wood and fodder in villages of the Himalayas. Particularly, fuel wood is the primary source of cooking and heating energy for the Himalayan communities which increase with increase in altitude (Bhatt et al., 2016). This is primarily due to the limited accessibility and affordability of commercial fuels such as liquefied petroleum gas (LPG) for rural households (Sharma et al., 2009). Notwithstanding, shortages of fuel wood and fodder as a result of population pressure have also been reported in the Himalayan region (Sharma et al., 2009; Singh & Sundriyal, 2009).The profound disturbances to land surface such as land use changes, livestock grazing and fodder extraction, fuel wood collection, timber harvesting, mining, reservoir and road constructions have been accentuated during the past four decades in the Himalayan region due to population pressure and socio-economic policies (Tiwari, 2000; Rao & Pant, 2001; Awasthi et al., 2002; Wakeel et al., 2005). In the Himalayan mountain regions, fodder and fuelwood constitute the two most critical resources supporting rural livelihoods (Ramakrishnan et al., 2000). The usage of fuel wood as a primary one for both domestic and commercial use has severely led to deforestation and soil erosion in whole of Himalaya thus threatening its biodiversity (Parmer & Negi, 2019). Traditional knowledge is now declining over the period because of several factors like modernization, migration, etc (Rana et al., 2022). Growing global concerns over ecological crises have intensified interest in traditional ecological knowledge, recognizing its potential as an effective approach to natural resource management (Nepal, 2023; Withanage & Gunathilaka, 2022; Withanage et al., 2024).

Fuelwood species composition and utilisation

It has been observed during the survey that about 19 prominent tree species excluding shrubs are mostly used as fuel wood with the availability distance varying from 100m-500 mts from each household in the study area (Table 7). Local preferences for particular tree species, combined with their availability in the area, play a key role in shaping patterns of total fuelwood consumption. A very small fraction of firewood comes from the agriculture fields. Within the watershed, the primary household uses of wood energy include cooking, preparation of livestock feed, and water heating, with space heating constituting a secondary use. The sources of energy were twigs, logs, crop residue and kerosene. No dung cakes are used. They are used directly as a manure in the crop field. There is not much seasonal variation in the consumption of logs. Variation was more marked in the case of twigs which are used in increasing proportion during winter season. The average time spent daily on cooking ranged between 3 to 6 hours. The traditional mud *chulha* is used in the watershed.

The wood of species *Alnus nepalensis, Schima wallichi, Macaranga sp, Terminalia myriocarpa*and *Ostodes paniculatus,* were predominantly utilized for household energy needs due to their easy availability.

Table 7. Availability Statusand Dependence Index (*DI%) of common fuel wood species in the study

Family	Species(Local Name)	Availability Status	Dependence Index (*DI%)
Betulaceae	*Alnus nepalensis* (Uttis)	High	0.80
Theaceae	*Schima wallichii* (Chilaune)	Medium-High	0.60
Juglandaceae	*Engelhardtia spicata* (Mahuwa)	Low	0.30
Betulaceae	*Betula cylindrostachyes* (Saur)	Low	0.28
Fabaceae	*Albizzia sp.* (Siris)	Low	0.25
Euphorbiaceae	*Ostodes paniculatus* (Byapari)	Medium-High	0.45
Myrtaceae	*Jambosa Formosa(*Ambakay)	Low-Medium	0.35
Meliaceae	*Toonaciliate(*Tooni)	Low-Medium	0.38
Combretaceae	*Terminalia myriocarpa* (Panisaj)	Low-Medium	0.40
Rhamnaceae	*Berchemia floribunda* (Bangay)	Low	0.25
Caprifoliaceae	*Virburnum sp.(*Asaray)	Low-Medium	0.36
Lauraceae	*Machilusedulis(*Pomsee)	Low	0.28
Santalaceae	*Pyrulariaedulis (*Amphi)	Low	0.32
Nyssaceae	*Nyssa sessiliflora (*Aulchilaune)	Low-Medium	0.40
Meliaceae	*Amoorawallichii* (Lahsune)	Low	0.28
Myrsinaceae	*Maesachisia (*Bilaune)	Low	0.20
Theaceae	*Euryaacuminata* (Zigane)	Low	0.20
Lythraceae	*Duabanga sonneratoides* (Lampatay)	Medium-High	0.55
Lauraceae	*Cinnamomumcecidodaphne* (Malagiri)	Low	0.20
Cupressaceae	*Cryptomeriajaponica* (Dhupi)	Low(Timber only)	0.12
Elaeocarpaceae	*Elaeocarpuslanceafolius* (Bhadrase)	Low	0.15
*Dependence Index is calculated on a scale of 0-1			

Fodder consumption scenario

Another important resource used in the study area is the fodder. Fodder collection constitutes the foundational activity driving the agrarian economy of village communities throughout the Indian Himalayan Region (Patnaik, 1986; Dhyani et al., 2011; Makino, 2009; 2014a). It is important here to mention that all the green biomass (foliage) is not consumed by animals. They are highly selective with regard to plant species eaten and even plant parts (Negi et al., 1993). Collection of fodder in the study area is mainly attempted from the private land holding, margin of the agricultural land, cultivable wasteland, reserve forest, and from forest adjacent to the households (private forest) every day in all seasons. Fodder was extracted by chopping tree branches and grasses were collected by harvesting with the use of sickles. In addition, crop residues are also used to meet daily requirement of fodder by livestock population. Per household per day amount of fodder use was quantified and showed that the household with single cow (20%), having 2 cows (60%), household with more than 2 cows (15%) and household with no cows (5%). The fodder extraction occurs during all months. Generally, on an average it takes about 3 to 3.5 hours by 1 male and 1 female to collecting fodder for 2 cows from the nearby fodder collecting sites close to the households.

Lopping, chopping and mowing are the various methods of collection. Fodder is extracted from 7 am - 10 amevery day. Per day average extraction is 42.5 kg/cow (summer 45 kg and winter 40 kg/cow). Fodder use in households with single cow is 40 kg/day in winter while 45 kg/day in summer whereas households with 2 cow consumes is 80 kg/day in winter and 90 kg/day in summer months. Generally, one animal head (cattle) is given one head load in a day. Less distance (250m -1km) is covered during summer season in comparison to winter season (half -2 km) for one head load (30kg) for fodder collection from forest since the fodder becomes available close to household during rainy season which facilitates fodder growth considerably. The availability of food during summer season (May to September) is high, while during the winter season (October to January), the availability of food is moderate. During the spring season (February to April), the availability of fodder is lowest in the watershed. Tables 8 and 9 show the fodder consumption in each village in the watershed, alongside the availability, and Table 10 shows the utility values of the different plant species in the watershed.

Table 8. Village wise fodder consumption in the watershed along with availability (Source: Primary data based on household survey, 2022-23)

Villages	Sources*	Resource Status	Availability distance from village (km)
Pastanga	GF	High	1.5
Gairigaon	CF, PF	Medium–High	1
Naitam	GF	High	1-2
Pabyuik	CF	Medium–High	1-1.5
Daragaon	JFM	Medium	1
Lingzey	JFM CF	Low	1-2
Palung	CF	Medium	1-2
Soureni	CF	Medium	1-1.5
Nimthang	-	Low	2
* PF=Private Forests, GF = Goucharan Forests, CF= Community Forests, JFM = Joint Forest Management			

Table 9. Fodder species collected from on the basis of preferences of inhabitants

Most preferred species (widely used)	Preferred species (moderately used)	Less preferred species (minimally used)
Arundo donax[2]; *Saurauianapaulensis*[1] *Rhaphidophora decursiva*[2] *Thysanolaena maxima*[1]; *Ficus hirta*[1]; *Ficus clavata*[1]; *Ficusnemoralis* *Ficus cunia*[1]; *Ficus roxburghii*[1]; *Imperata cylindrica*[2]	*Brassiopsis mitis*[2] *Cinnamomum cecidodaphne*[2] *Sechiumedule*[1] *Oryzasativa*[2] *Querqus lamellosa*[2] *Capillipediumsp*[3].	*Toonaciliata*[3] *Elaeocarpus sikkimensis*[3] *Prunuscerasoides*[3] *Betula cylindrostachys*[3] *Euryaacuminata*[3]
** 1= Abundant: 2= Common, 3=Scarce*		

Table 10. Utility values of different plant species in the watershed (* TM=Timber, FD=Fodder, FW=Fuel wood)

Family	Scientific Name (Common/Local Name)	Utility values
Actinidiaceae	*Saurauia napaulensis (*Gogoon)	FD
Anacardiaceae	*Choerospondiasaxillaris (*Lapsi)	TM
Araceae	*Rhaphidophoradecursiva* (Kanchirna)	FD
Araliaceae	*Brassiopsismitis* (Chuletra/Phutta)	FD
Hamamelidaceae	*Symingtonia populnea* (Piplee)	TM
Moraceae	*Morus sp.* (Kimbu)	TM
	Ficushirta (Khasray)	FD
	Ficusclavata (Khaneau)	FD
	Ficusnemoralis (Dudhiloo)	FD
	Ficusroxburghii (Dudhiloo)	FD
Betulaceae	*Alnus nepalensis* (Uttis)	TM, FW
	Betula cylindrostachyes (Saur)	TM
	Betula alnoides (Saur))	TM, FW
Magnoliaceae	*Michelia excelsa* (Rani Champ)	TM
	Michelia lanuiginosa (Champ)	TM
Meliaceae	*Toonaciliata* (Tooni)	FD, TM, FW
	*Amoorarohituka (*Lahsune)	FW
Combretaceae	*Terminalia myriocarpa (*Panisaj)	TM, FW
Cornaceae	*Nyssa sessiliflora* (Lekhchilaune)	TM
Caprifoliaceae	*Virburnum sp .*(Asaray)	FW
Cupressaceae	*Cryptomeriajaponica (*Dhuppi)	TM
Elaeocarpaceae	*Machilusedulis* (Pomsee)	TM, FW (Bark only)
	*Elaeocarpussikkimensis (*Bhadrasay)	TM, FD
Euphorbiaceae	*Macaranga pustulata (*Malata)	FW, TM
	Ostodes paniculatus (Byapari)	FW
Fagaceae	*Quercus lanceaefolia* (PatleKatus)	TM
	Castanopsis indica (DhalneyKatus)	TM
	*Castanopsis tribuloides (*Katus)	TM
	Albizzia sp. (Siris)	FW, TM
Juglandaceae	*Engelhardtia sp.* (Mauwa)	TM, FW
Lauraceae	*Cinnamomumcecidodaphne* (Malagiri)	FD
Myrtaceae	*Jambosa formosa* (Ambakay)	FW
Poaceae	*Thysanolaenamaxima (*Amliso)	FD
Rhamnaceae	*Berchemia floribunda* (Bangay)	TM, FW
Rosaceae	*Prunus sp. (*Paiyun)	TM
Santalaceae	*Pyrulariaedulis* (Amphi)	FW
Theaceae	*Schima wallichii* (Chilauney)	FW

Animal husbandry constitutes an important source of household income in the study area, with nearly every family maintaining 2–3 cows regardless of economic profitability. Fodder is collected twice a day showing dependency rate 9 (on a scale of 1-10) meaning 90% of households of watershed are dependent on fodder for their livestock. Per household per year demand of fodder amounts to 14.6 ton during winter season and 16.4 ton during summer season with families possessing single cow. In the study area almost all the families possess cow (90%), followed by goat (5%) and pig (5%). Since almost all the families possess cows (90%), stall feeding of livestock is the common practice which is usually two times a day (Morning and evening). During stall feeding livestocks (milking animals; Figure 3) are provided with concentrated mixture of roughage /oil cakes ('peena'). In general, one cow is fed by about half kg of 'peena' per day which is purchased at Rs. 18/kg from the local market in Ranipool (50 mins-1.40 mins motorable distance from different villages of the watershed).

Arundodonax, Saurauianapaulensis, Ficussp. were the highly preferred fodder trees species in addition to climber *Sechiumedule*while *Thysaenolenamaxima* were moderately preferred species at all elevation zones of the watershed. Husk of *Oryzasativa*was moderately preferred in Soureni and Lingzey areas. *Prunuscerasoides, Betula cylindrostachys*and *Euryaacuminata* were the least preferred fodder species in the watershed. Depending upon the availability in the different villages, the common plant species used in the watershed for fodder are *Ficus roxburghii, Ficusclavata, Ficuscunia, Ficusnemoralis, Thysolaena maxima, Saurauia napaulensis, Imperatacylindrica and Querquslamellosa*. Watershed inhabitants are dependent mainly on these resources for their day to day requirements of feeding livestock. The local perennial grass species'amliso' (*Thysolaena maxima*) not only provides fodder to animals in winter but also protect the degraded lands in the watershed. Besides, the villages also uses its spikes for making brooms. The demand for fodder remains consistent year-round; however, the scarcity of green fodder during winter persists as a major challenge (Dhyani & Maikhuri, 2012).

Besides, the villagers of the TCW were also observed to be collecting different wild edibles such as Ningro (*Dryopteris* sp.), Sisnoo (*Urticaparviflora / H.dioica*), Simrai (*Nastritumofficinale*) and Naakima (*Tupistranutans*) from their private forest and agricultural lands during different seasons of the year for consumption and for selling in the local market at Ranipool. In addition, they were found to consume some other wild edibles such as Thotney (*Acogonum molle*), Gurbey (*Araesima* sp.), Tama (*Dendrocalamushamiltonii, Cephalosaechumcapitatum*), Mushroom (*Agaricus* sp.), and Aisaloo (*Rubusellipticus*).

Between tradition and transition: sustainable resource management in a changing Himalayan landscape

Sikkim hills are comparatively younger and have not yet been exposed to such onslaughts of land misuse (Balaraman & Gupta, 1988). During the field survey it was found that since the early 1980's, local people of the TCW used to grow paddy on a wide scale throughout the watershed at all elevation zones. During the decade from 1980's and 1990s since the agricultural field was used for paddy cultivation, there was shortage of fodder plants.

However, after the Public Distribution System (PDS) system introduced by Govt. of India in June 1997, people stopped cultivation of rice especially at high elevation areas of the watershed (Goucharan, Pabyuik, Chiplekharka etc.). This government scheme led to not removing the weeds and not maintaining the field for rice cultivation throughout the year. As a result, the fodder plants started growing in sufficient quantity in different villages of the watershed and so there has been no shortage of fodder for livestock after 2000. However, shortages of fodder were observed closed to households in the lower elevation villages such as during winter or during throughout the year (Table 6). Several studies, including those by Chettri et al. (2002), Sharma et al. (2009), Shaheen et al. (2011), Singh & Rawat (2012), Bhatt et al. (2016), have consistently highlighted firewood extraction as a dominant factor contributing to forest degradation in the Himalayan region. Nevertheless, in the current study due to the high natural regeneration rates, the forest is not degraded due to firewood extraction. Comparable findings have been documented along the Yuksam - Dzongri trekking corridor, where woody biomass extraction was observed to be lower than the annual productivity of the forest stands (Chettri et al., 2002).

Agriculture and wage labor constituted the primary occupations in the study area, while dairy farming contributed substantially to total household income. Across all villages, over 75% of fodder and fuelwood were sourced from private landholdings, with the remainder obtained from privately managed forests. The low pressure from human and livestock populations, combined with sustainable forest management practices, has contributed to the preservation of good forest cover and the prevention of ecological degradation in the study area. The Government of India's Pradhan Mantri Ujjwala Yojana (PMUY), launched in 2016 to provide 50 million LPG connections to women from BPL households (PMUY, 2019), has further reduced dependence on wild-extracted fuelwood to a considerable extent. Nevertheless, a substantial proportion of households in the study area continue to rely on fuelwood due to economic constraints. Importantly, firewood collection by local communities does not pose a significant threat to forest resources or tree species, as most extraction occurs from private lands. It is therefore anticipated that the harvesting of fuelwood and fodder by villagers will have a minimal ecological impact in the near future, especially when compared to forest clearing for agriculture, horticulture, infrastructure development, and other anthropogenic activities, which are likely to drive more pronounced environmental degradation in the region.

Ecology and Environment of a place is largely influenced by the balance between demand and supply of fodder and fuel wood, which in turn, is a function of biotic pressure (human and livestock population). Fuelwood and fodder consumption in the study area was observed to be strongly influenced by the prevailing cold climate and seasonal variations. By way of existing legislation, the villagers need to obtain permission from the forest department for cutting down trees even from their own private holding. However, it is not possible to prohibit collection of fuel wood from the fallen and/dry log as well as collection of fodder. Timber generated from different tree species of private land holding or buffer zone of the forests was used locally for construction purposes (Table 6). Such practices in the watershed were sporadic. *Betula cylindrostachyes, Michelia excelsa, Nyssa sessiliflora*and *Castanopsis indica* were used in the various settlements of watershed for timber generation. In the watershed, trees raised on terrace-raisers, banks of water streams and trees grown in plantations are also the main sources of fuel wood. Repeated loop of fodder species leading to the pollard and stubby branched trucks with insufficient leaf area to sustain its existence was also observed in the study area. Such practices lead to death of fodder tree which can be used for fuel wood (Chettri et al., 2006).

Nevertheless, the frequency of such practices is not common. Average fuel and fodder consumption in the different villages of the watershed carried out revealed that most of the fuel wood and fodder trees are regenerative in nature. Due to collection of firewood (Figure 3), forests near to the watershed villages were not subjected to rapid degradation and over exploitation because of the following reasons. (i) Absence of extensive agriculture (ii) Absence of eroded and denuded hills (iii) High percentage of total area under forest (iv) Density of forest cover very high (v) No evidence of heavily lopped trees (vi) Disappearance of vegetative cover, ground flora and shrub growth from most forests due to excessive grazing and regular annual fires. (vii) No signs of open grazing (viii) Micro-climatic extremes (drought and desert – like conditions between monsoons) (ix) Reduced productivity of natural ecosystems.

Although distribution of LPG in remote rural areas under the Pradhan Mantri Ujjwala Yojona is functional for most of the Indian Himalayan region, the villagers depend on the fuelwood from the common pool resources for cooking and space heating (Velho et al., 2018; Negi & Maikhuri, 2017).

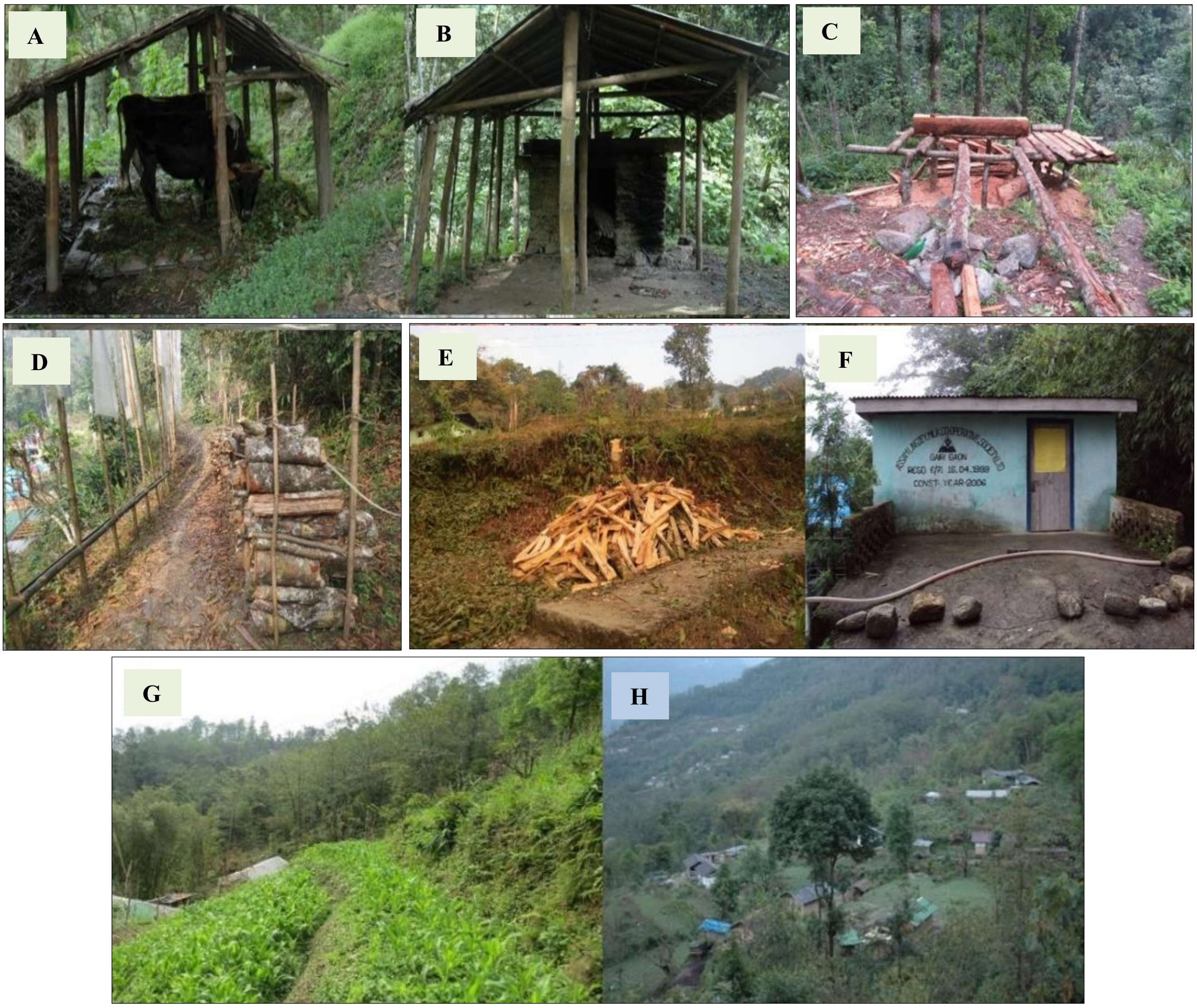

Figure 3. (A) Cowshed feeding fodder grass representing the animal husbandry activity Gairigaon village, Assam Lingzey (Dated: 17. 10. 2024); (B) Cardamom Curing Kiln: **Represents the post-harvest processing stage** in cardamom cultivation (Pastanga village, Assam Lingzey (Dated: 17. 10. 2024); (C) Generation of wooden planks represents the **primary stage of wood processing** (Naitam village, Assam Lingzey(Dated: 24.04. 2025); (D) Stocking of Fuel wood (Peel) represents **drying and later use as fuel** for cooking, heating, or curing (e.g., in cardamom kilns) (Naitam village, Naitam (Dated: 11.02. 2025); (E) Firewood extraction represents the **primary energy source and livelihood activity** in rural communities (Naitam village, Naitam (Dated: 12.02. 2025); (F) Milk collection Centre represents a **community-level facility for** storage of milk before it is transported to processing units (Gairigaon village, Assam Lingzey (Dated: 06.08. 2024); (G) Agro forestry ecosystem represents an **integrated land-use system** between **trees, crops, and sometimes livestock** (Pabyuik village, Naitam; Dated: 28.04. 2024); (H) Self-sustaining village of study area in terms of livelihood (Naitam village, Naitam (Dated: 15.04. 2024) (Source: All the photographs by Santosh Sharma)

The present study indicates that traditional agricultural practices and forest resource use in the study area remain largely sustainable, as fuelwood extraction by indigenous and rural communities does not contribute to forest cover loss or threaten the diversity and density of tree species. This has been possible because of the implementation of many eco-friendly green policies and sustainable environmental initiatives by Govt. of Sikkim and Govt. of India such as *Harit Kranti*Year (1995-96), banned cattle grazing (1998), *Smritivan* (1999), Sikkim Forests Cattle Trespass Rules (2000), Organic State Policy declaration (2003), State Green Mission (2006), Ten Minutes to Earth (2009), *Paryavaran Mahotsav (*2013), *Mith/Mitini Tree* (2017), *Pradhan Mantri Ujjwala Yojana* (2017), *MeroRukhMero Santati* (2023) etc. has contributed to the state's efforts in expanding green cover across both public and private lands. In light of the above, the insights gained on resource use patterns in the study area can inform the development of suitable technologies for establishing energy and fodder plantations. Furthermore, the findings provide a valuable baseline for future research and policy-making aimed at promoting sustainable management and conservation of the region's forest resources.

A predictive model for environmentally sustainable tourism development in the Taktsom Chu watershed

Based on the primary data obtained, we have constructed a tourism development forecast model for the area up to 2040. This model takes into account a medium population growth scenario, with an annual growth rate of 1.5%. This model corresponds to the medium demographic scenario commonly used for long-term forecasting in rural areas under development, reflecting a moderate increase in natural growth and migration levels (Table 11).

Table 11. Predictive model of the impact of tourism on the development of a small number of participants and fuelwood consumption up to 2040

Year	Population	Tourists / Year	Schneider Index (SI)	Fuelwood consumption (kg)	LPG consumption (kg)	Sustainable Fuelwood Index (SFI)
2025	5669.0	500.0	8.82	4515459.0	119166.0	0.35
2026	5754.0	525.0	9.12	4398418.0	132161.0	0.36
2027	5840.0	551.0	9.43	4276853.0	145519.0	0.37
2028	5928.0	579.0	9.77	4150655.0	159249.0	0.39
2029	6017.0	608.0	10.10	4019711.0	173358.0	0.4
2030	6107.0	638.0	10,45	3883907.0	187855.0	0.41
2031	6199.0	670.0	10.81	3743129.0	202748.0	0.43
2032	6292.0	704.0	11.19	3597256.0	218046.0	0.44
2033	6386.0	739.0	11.57	3446169.0	233758.0	0.46
2034	6482.0	776.0	11.97	3289743.0	249892.0	0.49
2035	6579.0	814.0	12.37	3127853.0	266458.0	0.51
2036	6678.0	855.0	12.80	2960371.0	283465.0	0.54
2037	6778.0	898.0	13.25	2787164.0	300922.0	0.57
2038	6880.0	943.0	13.71	2608100.0	318840.0	0.61
2039	6983.0	990.0	14.18	2423041.0	337228.0	0.66
2040	7088.0	1039.0	14.66	2231849.0	356097.0	0.72

Due to the underdeveloped tourism infrastructure in the area, tourism is currently at a low level (see Demková et al., 2022 for a more detailed explanation). In our prediction model, we estimate growth at 5% per year (Table 11 and Figure 4). According to our assumptions, this growth will require active support and additional infrastructure development.

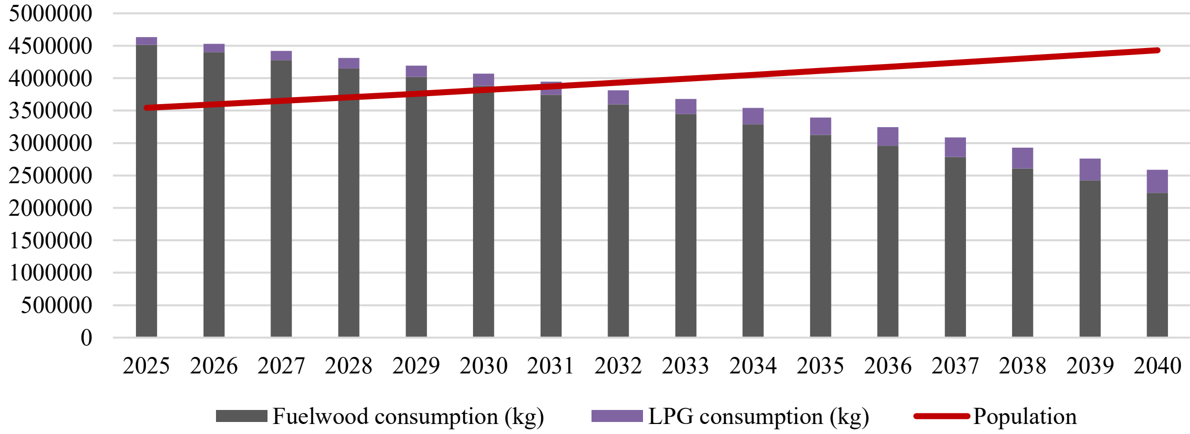

Figure 4. The predicted consumption of fuelwood and LPG up to 2040

When estimating firewood consumption up to 2040, we based our calculations on current average consumption per person per day (2.87 kg) and the proportion of the population using firewood (76% in 2025). This proportion will decrease linearly each year and, under the current government's support for the planned transformation of the area's household energy mix (described above), we estimate that it will decrease to 0.3 by 2040. We also predict that the proportion of the population using LPG will increase from 23% to 55% by 2040. Consumption related to tourism development has been considered, taking into account the area's potential and prerequisites for a three-day stay. At the same time, it was assumed that 50% of tourists would use firewood and the other 50% would use LPG. This is based on the assumption that environmentally friendly tourism products will be targeted at slow tourists looking for a high level of authenticity, who will therefore prefer traditional-style accommodation and wish to experience a traditional, local way of life (e.g., slow food, eco-agritourism, and other forms of nature tourism). In this case, only low volumes of tourist traffic are predicted, with the load on the tourist destination not exceeding the critical point SI=100, which is reached when the number of visitors exceeds the number of inhabitants. In the case of the Taktsom Chu valley, the currently developing tourism model achieves low visitor numbers (mostly day trips and easy treks), with minimal impact on firewood extraction (Table 11).

The above results show that, with current fuelwood consumption of approximately 4.5 million kg and LPG consumption of 119 thousand kg in the area, the SFI sustainability index is 0.35. However, with projected population growth of 1.5% plus tourist arrivals of 5%, the SFI sustainability index will increase to 0.72 by 2040 (Figure 5). This indicates an increase in the sustainability of the chosen approach of state support for transforming the area's household energy mix.

However, it is not expected to reach an ecological tipping point (SFI = 1) within the 15-year timeframe, although the trend suggests that this may occur shortly thereafter. This would require a significant reduction in local populations' dependence on fuelwood (e.g. by adding other energy sources to the mix). At the same time, the low volume of tourism appears to have only a marginal impact on total fuelwood consumption, and the same household-dominated trend is projected for the future.

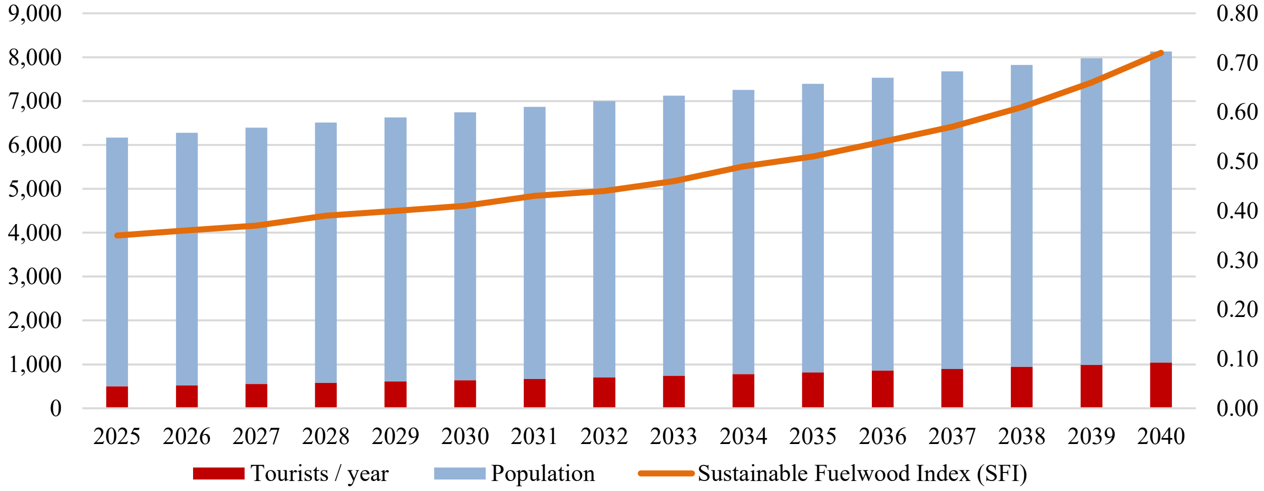

Figure 5. SFI prediction based on expected growth in tourism volumes up to 2040

In most regions of the world, forests are under intense pressure due to the demand of timber and fuel wood. Furthermore, most communities are not tapping the full potential of forests to improve their livelihoods and reduce poverty. Sustainable forest management is a key to wellbeing of local communities. Farming community of the study watershed were engaged in agriculture as well as in allied activities and their livelihood is dependent on the forest resource, three important sources of fodder production were internal factors, natural forests and external sources.

In internal sources, i.e., agro forestry includes trees along crop fields, residues of food crops, medicinal crops and cash crops, the grasses in interspaces of terraces, cultivated (managed) grasslands and agriculture weeds. So far, the watershed has not shown any signs of environmental degradation due to overuse of fodder and wood fuel species even when urbanization taking place at a rapid place due to its proximity to the urban capital town of Gangtok.

The development of alternative fuel supplies (for example from plantations and subsidized supplies of kerosene and LPG) coupled with the adoption of improved code of environmental conservation ethics by both the community and the responsible authorities. The documented patterns of fuelwood consumption and the preferred species in the Taktsom Chua Watershed provide a valuable baseline for future research and policy development aimed at conserving the region’s forest resources. Efforts should focus on establishing a localized framework to promote a sustainable forest-based economy. A key challenge in the Sikkim Himalayas lies in balancing sustainable livelihoods with ecosystem productivity, particularly in areas vulnerable to pressures from urbanization and infrastructure development.

Over the past three decades, insufficient forest management, weak regulatory enforcement, unregulated tourism, and population growth have placed increasing pressure on forest resources and biodiversity in the study area.

If current trends persist, the anticipated rise in population in villages surrounding the watershed is likely to intensify demand for forest resources. This escalation could further accelerate ecosystem degradation, with the potential loss of multiple species over time. Such projections underscore the urgent need for proactive management interventions and community-based conservation strategies to safeguard biodiversity and sustain ecosystem services.

Intensive awareness programmes on resource use and management, targeted at both villagers and local officials, could play a major role in protecting the forests and conserving the region’s unique biodiversity.

CONCLUSIONS

In most regions of the world, forests are under intense pressure due to demand for timber and fuelwood. Furthermore, many communities are failing to exploit the full potential of forests to improve their livelihoods and alleviate poverty. Sustainable forest management is key to the well-being of local communities. Sustainable forestry is seen as key to the well-being of local communities. In the TCW region of the Eastern Himalayas (Sikkim, India) that we studied, there are other alternative sources of income available to local communities, such as small-scale tourism, which requires little investment in missing infrastructure. This is a suitable additional source of income with the potential to reduce dependence on forest biomass. With thoughtful management, it can also stimulate local community development and revitalise neglected or degraded areas through logging. It can also stimulate the restoration of traditional crops and landraces that are attractive to potential visitors and generate resources for the rehabilitation of infrastructure used by both tourists and local communities.

Traditional farming systems, livestock holdings, and household livelihoods in the watershed are deeply interlinked. About 75% of the households in the Taktsom Chu watershed engage in agriculture as well as allied activities, and their livelihoods depend on forest resources. Three important sources of fodder production were internal factors, natural forests, and external sources. Fuelwood remains the primary source of energy, accounting for about 60–90% of use, with nearly 19 prominent tree species (excluding shrubs) being commonly harvested for this purpose. Seasonal variation strongly influences fodder availability: while the summer months (May–September) provide relatively abundant fodder, the spring season (February–April) marks the period of acute scarcity. Internal sources include agroforestry, which involves planting trees alongside crop fields, as well as the residues of food, medicine, and cash crops. Other sources include grass in the spaces between terraces, cultivated grasslands, and agricultural weeds. So far, the watershed has not shown any signs of environmental degradation due to the overuse of fodder and fuelwood species, even though urbanisation is taking place rapidly due to its proximity to the capital town of Gangtok. This is due to the development of alternative fuel supplies, for example from plantations and subsidised supplies of kerosene and LPG, coupled with the adoption of an improved code of environmental conservation ethics by the community and the relevant authorities. The collected data on fuelwood consumption patterns and species preferences in the Taktsom Chua Watershed can serve as a foundational baseline for future research and policy initiatives aimed at forest conservation in the region.

Efforts should focus on developing a localized framework to promote a sustainable forest-based economy. A key challenge in the Sikkim Himalayas is maintaining a balance between supporting sustainable livelihoods and preserving productive ecosystems, especially in areas susceptible to the pressures of urbanization and infrastructure development. As shown by our 2040 forecast model, fuelwood usage in TCW could fall by up to 50% if the local population grows moderately and the Indian government's programmes to alter household energy sources continue. In this scenario, the development of ecotourism appears to be an interesting way to change attitudes towards fuelwood consumption. If we assume a 5% increase in the TCW population due to tourist arrivals, the sustainability index would rise to 0.72 by 2040 (up from 0.35 in 2025). To reach the tipping point (SFI = 1) within a 15-year timeframe, however, other energy sources (e.g., solar, hydropower) would need to be incorporated into the energy mix. Conversely, inadequate forest management, unregulated tourism, and population growth have posed significant threats to forest resources and biodiversity over the past three decades. With projected population increases in surrounding villages, pressure on forest resources is likely to intensify, potentially leading to species loss. Targeted awareness programs for both local communities and officials on sustainable resource use and management could help safeguard the forests of this ecologically unique region.

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