ISSN 2717-4638

Processed Wood Factory to Address Energy Needs in Nepal

Sashank Khaniya[1], Bishnu Prasad Gautam [2*]
[1] Department of Forestry, Mississippi State University, Thompson Hall, 39759 Starkville, USA
[2] Swachchha Engineering Pvt. Ltd., Kathmandu, Nepal
*Corresponding Author: b.gautam@alumini.utoronto.ca

Abstract

With an increase in greenhouse gas emissions, growing challenges are faced in meeting the ever-increasing energy demands, both economically and environmentally. Many countries, including Nepal, rely heavily on imported fossil fuels to meet their energy demand. For example, Nepal spends more than 6% of its gross domestic product on petroleum imports, with liquefied petroleum gas comprising 20-25% of such imports. Although electricity is generated from renewable sources, its supply is not dependable to make electricity a primary source of cooking energy. Nepal is rich in forest resources, but they are vastly underutilized. While Nepal imports approximately 0.6 million tonnes of oil equivalent (Mtoe) of LPG gas annually, Nepal's wood resources have an estimated annual theoretical potential of 7.1 Mtoe of energy. This review paper presents the current status of energy production and consumption in Nepal, along with the status of forest resources, with a focus on utilizing the abundant wood resources. A novel approach is presented to tackle Nepal's energy deficit by supplementing through underutilized forest resources, encouraging the use of cleaner firewood, reducing imports of liquefied petroleum gas, and ultimately curbing carbon emissions. This review demonstrates that forest rich countries like Nepal can devise improved technology by utilizing forest-based sources while their population is transitioning from conventional sources to industrial products. A pilot project is proposed to produce seasoned firewood equivalent to 334 toe of energy annually, which may substitute 304 tonnes of liquefied petroleum gas imports, thus lowering the emissions by 882 tonnes of carbon dioxide equivalent.

Keywords: *Emission Reduction, Renewable Energy, Forest Biomass, Seasoning, Wood Technology*

Introduction

Transport Access to energy is a prerequisite for the economic and social development of a country. As the world is developing, growing demand of energy has intensified global concerns of energy shortage and greenhouse gas (GHG) emissions, largely from fossil fuels. Therefore, biomass, which is the oldest fuel in the history of humankind, has received growing research interest lately. Biomass is advocated to contribute to the reduction of GHG emissions through the replacement of fossil fuels (Hiloidhari et al., 2019; Thornley et al., 2015). Indeed, biomass accounts for 70% of renewable energy consumption in the world (WBA, 2019). Among different sources of biomass, forest residues and surplus forest growth are favorable due to carbon neutrality of wood (De Leeuw et al., 2014; Rogers, 2020; Sasaki, 2021; Sreevani, 2018; Tun et al., 2019; Yang et al., 2022). An estimate shows that emissions can be reduced by one-tenth with a unit increase in consumption of biomass (Sulaiman et al., 2020). Many wood-rich countries have used state-of-the-art technologies to utilize wood as a renewable source of fuel. For instance, 46% of district heating in Sweden was supplied from biomass, among which 70% was from wood chips and sawdust, and 16% from wood pellets and briquettes (Ericsson & Wener, 2016). Such global experiences indicate excellent opportunities for utilizing vastly underutilized forest resources in countries such as Nepal.

Nepal, with 44.74% of its land covered by forest (DFRS, 2015), holds potential for using forest firewood as an alternative source of energy. Firewood continues to be the largest source of cooking energy in Nepal (Das et al., 2022; Paudel et al., 2021). However, as with 2.3 billion people in the world, a majority of Nepal's population relies on the traditional use of firewood and does not have an accessible clean cooking source (IEA, 2023). In traditional use, firewood is a non-clean source of cooking energy, which produces household smoke and causes adverse health problems (Adhikari et al., 2020; Ranabhat et al., 2015; Raspanti et al., 2016). Household air pollution in Nepal was attributed to a death rate of 81 per 100,000 population in 2016 (WHO, 2018). Therefore, a clean source of cooking energy is a priority, which is also reflected in the Sustainable Development Goals (SDGs) roadmap of Nepal.

The seventh goal (SDG 7) aims to ensure universal access to affordable, reliable, sustainable, and modern energy services by 2030. To achieve this, Nepal aimed to increase the share of renewable energy from 11.9% in 2015 to 50% in 2030 (NPC, 2017). Ironically, this policy favors liquefied petroleum gas (LPG) (fossil-based fuel) over firewood due to concerns about its emissions in raw form. The import of LPG in Nepal increased by 5% in just one year, from the fiscal year 2018/19 to 2019/20, while an estimated 1 million cubic meters of wood and timber residues are decayed in Nepal's forests (MFSC, 2017). This situation warrants innovative approaches to utilize firewood resources by appreciating its carbon neutrality and renewability prospects. While new types of clean sources such as electric cooking are being promoted, the new technologies involved in them face the challenges of adoption (resistance to change). Conversion of traditional firewood into smoke-free firewood may have the least technological challenges for adoption, particularly among rural population. One way to achieve smoke-free firewood is to remove excessive moisture through drying it (i.e., wood seasoning).

Wood seasoning technology could be promoted to a) utilize the unused firewood sources, b) eradicate the problem of household smoke in many poor families in rural areas, c) enhance energy security based on domestic resources, d) substitute the import of non-renewable fossil-based energy sources, and e) curbing carbon emissions. Presenting the case of Nepal as an example, this paper reviews the literature on firewood seasoning technology to explore the potential of utilizing domestic forest waste as a sustainable and efficient cooking fuel. A processed wood factory is proposed as a pilot project.

Status of Energy in Nepal

Energy Consumption in Nepal

At the policy level, energy resources in Nepal are usually categorized into three types: traditional, commercial, and alternative (Ghimire & Kim, 2018). Table 1 shows the energy consumption scenario of Nepal for the last five years. Nepal's total energy consumption was 12.7 million toe (tonnes of oil equivalent) in the fiscal year 2022/23 (Ministry of Finance, 2024). It should be noted that toe is a commonly used unit of energy of fossil fuels and 1 toe is approximately equal to 41,870 MJ.

Traditional sources (biomass fuel such as firewood, agricultural residues, and animal dung) are the most common energy sources, comprising more than two-thirds of the total energy demand. Around 63% of people in Nepal use firewood for cooking (CBS, 2019). Firewood collection remains a major activity of rural households in Nepal, as firewood is usually collected with zero monetary cost from the forest and home gardens. A study conducted in the Langtang valley showed that 283,000 kg of firewood is consumed annually by the hotels there, with an average annual consumption of 6,229 kg per hotel. As shown in Table 1, traditional sources remain the largest share of energy even though their share appears slowly declining (from 68.5% in 2018/19 to 64% in 2022/23).

Table 1: Percentage of energy consumption in various fiscal years in Nepal (Ministry of Finance, 2024).

Source of Energy	**Energy consumption in various fiscal year (%)**				
	2018/19	**2019/20**	**2020/21**	**2021/22**	**2022/23**
A) Traditional	68.5	67	66	66	64
A.1 Firewood	62.2	61	60	59	57
A.2 Agriculture Residue	3.1	3	3	5	5
A.3 Cow dung cake	3.2	3	3	2	2
B) Commercial	29.4	31	32	32	33
B.1 Coal	6.9	7	10	7	6
B.2 Petroleum Products	18.8	20	18	19	19
B.3 Electricity	3.7	4	4	6	7
C) Renewable	2.1	2	2	2	3
Total (in thousands toe)	**14,015**	**14,465**	**14,928**	**15,130**	**12,716**

Commercial sources of energy in Nepal include electricity, coal, and petroleum products (Table 1). Electricity is dominated by hydro sources. In recent years, the capacity of hydroelectricity has been increasing in Nepal as shown in Fig. 1. Additionally, solar electricity has also increased to 175 MW as of 2024 (Fig. 1). The installed capacity of electricity in Nepal was 3,475 MW as of 2024 (IRENA, 2025). Despite increased capacity, Nepal still needs to import some electricity from India as domestic production fluctuates seasonally with water availability. During the fiscal year 2023/24, 13.6% of total available electricity in Nepal was imported from India (NEA, 2024).

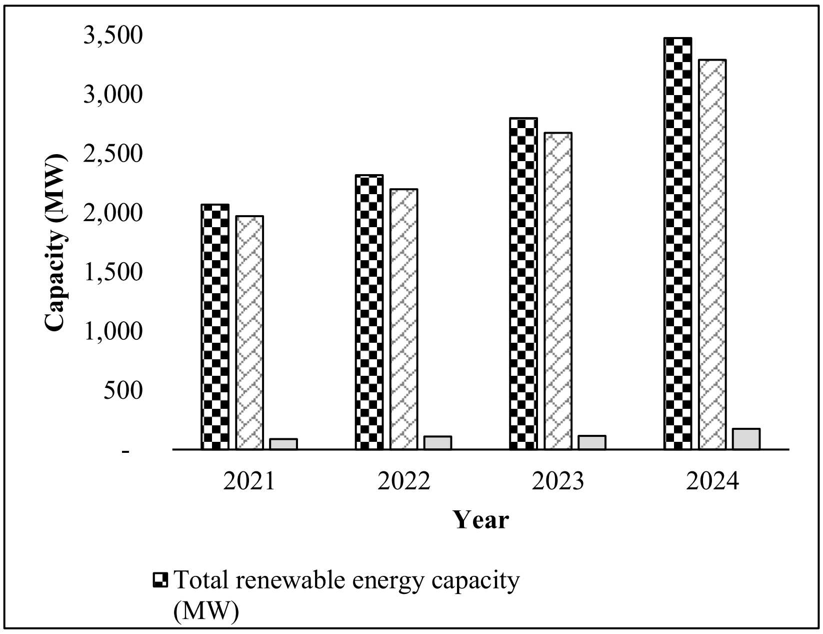

Fig. 1: Total capacity of electricity plants in Nepal 2021-2024 (data derived from IRENA, 2025)

The use of coal and petroleum has either decreased slightly or remained constant in recent years (Table 1). Currently, Nepal has no extraction of petroleum reserves except for one ongoing exploration in Dailekh. Refined petroleum products are imported from India. Petroleum imports amounted to NPR 307,078 (USD 2,221) million in the fiscal year 2022/23 (Nepal Rastra Bank, 2024). This import of petroleum products alone accounted for approximately 17% of the GDP of Nepal for the corresponding year. The import of coal from India amounted to NPR 11,287 (USD 81.65) million in 2022/23 (Nepal Rastra Bank, 2024).

A comparison of the renewable energy (electrical) capacity of Nepal with the world, Asia, China, and India is shown in Fig. 2, indicating Nepal is progressing well in the promotion of renewable energy (electrical). Additionally, the growth rate of Nepal's renewable energy capacity increased drastically by 53% in 2021 (IRENA, 2025), which is attributed to increase in production from new hydropower projects in Nepal. Nevertheless, the per capita consumption of electricity in Nepal is only 400 kWh per annum (NEA, 2024). This markedly low per capita electricity consumption, despite a promising growth rate, indicates that the energy consumption of Nepal may not be met anytime soon by electrical energy alone. Therefore, non-electrical renewable energy sources should also be promoted in parallel with electrical energy sources.

Need of technological intervention on the use of firewood

The residential sector alone accounts for 63.2% of energy consumption in Nepal (Das et al., 2022). The largest chunk of this energy demand is attributed to cooking fuel needs. In particular, biomass dominated the supply of energy (Malla, 2013). However, with urbanization and improved economy of people, traditional biomass-derived fuels are being increasingly replaced primarily by LPG. Nearly 29.4 % of people migrate from rural to urban areas in Nepal every 10 years (CBS, 2014) and nearly 60% population of Nepal now live in urban areas. The use of modern cooking fuel, particularly LPG, has become one of the symbols of urban living. When such trends increase, the consumption of firewood decreases, and a large mass of firewood is wasted on the forest floor. Appropriate technology shall be developed for the sustainable use of otherwise wasted firewood resources.

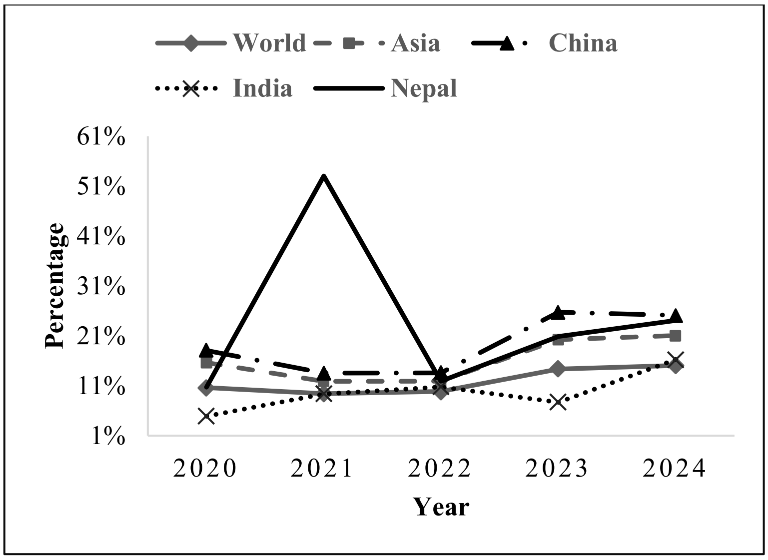

Fig. 2: Growth rate of renewable energy capacity in Nepal compared with neighborhood and global scenarios (data derived from IRENA, 2025)

Nepal aims to become a middle-income country by 2030 (NPC, 2017), a vision that hinges on industrial growth, which in turn will drive a rise in energy demand. The industrial sector mostly uses coal and electricity. Lack of domestic reserves for coal and the environmental threats posed by coal question the usability of coal in the future. Since the net import of energy doubled from 2015 to 2020 (Fig. 3), a growing pressure is felt to reduce the import of energy by increasing energy production within the nation. Nepal should realize its diverse resources of energy (not limited to hydro) and make sustainable use of them. It is postulated that the country needs to identify ways to utilize firewood, thereby contributing to the rural economy, creating employment, and mitigating the impacts of GHG emissions.

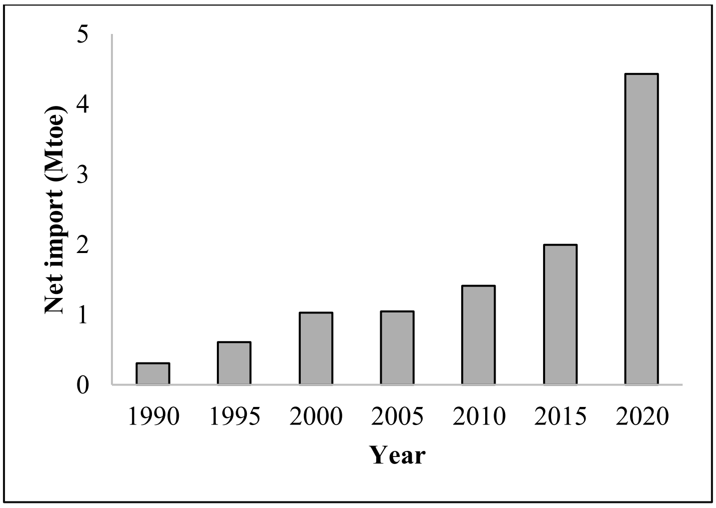

Fig. 3: Net import of energy in Nepal (in Mtoe) (data derived from IEA, 2025).

Status of Forests in Nepal

The present state of the Nepali forest is the outcome of three stages of development of forest policy: privatization (1768-1951), nationalization (1951-1978), and finally decentralization through people's participation (1978 onwards) (Pokharel et al., 2005). Almost 76% of the country's population is formally associated with forests (Amatya, 2013). Forest cover in Nepal increased from 37% of the total land in the country to 44.74% in the last two decades (DFRS, 2015). According to the Department of Forest Research and Survey of Nepal, the total stem volume of Nepal is 982 million m3 (165 m3/ha), among which High Himalaya and High Mountain physiographic regions combinedly have the largest stem volume per hectare (225 m3/ha) (DFRS, 2015). On the other hand, the lowest stem volume per hectare is present in the Middle Mountains (124 m3/ha). Terai and Churia regions have 162 m3/ha and 147 m3/ha stem volumes, respectively. In terms of mass, Nepal's forests contain 1,160 million tonnes (195 t/ha) of above-ground biomass (air-dried equivalent), and it is estimated that 1,055 million tonnes (177 t/ha) of carbon stock is present in Nepal's forests (DFRS, 2015).

Nepal's forests have at least 443 tree species of 239 genera and 99 families, among which the major species are: Sal (*Shorea robusta*), Banjhi (*Quercus* spp.), Khote Salla (*Pinus roxburghii*), Lali Gurans (*Rhododendron* spp.), Saaj (*Terminalia alata*), Thingure Salla (*Abies* spp.), Gobre Salla (*Pinus wallichiana*), Uttis (*Alnus* spp.), Thinge Salla (*Tsuga dumosa*), Chilaune (*Schima wallichii*), Katus (*Castanopsis* spp.), Bhojpatra (*Betula utilis*), Jhule Salla (*Picea smithiana*), Angeri (*Lyonia ovalifolia*), Botdhaiyaaro (*Lagerstroemia parviflora*), and Kaan Chiro (*Acer* spp.) (DFRS, 2015). Fig. 4 shows the stem volume of these species and their share in the total stem volume of Nepal. Sal has the highest stem volume of 19.3%. This and the three species, namely, Banjhi*,* Khote Salla*, and* Lali Gurans, occupy a combined stem volume of 46.5%, and thus, dominate the stem volume in the forests of Nepal.

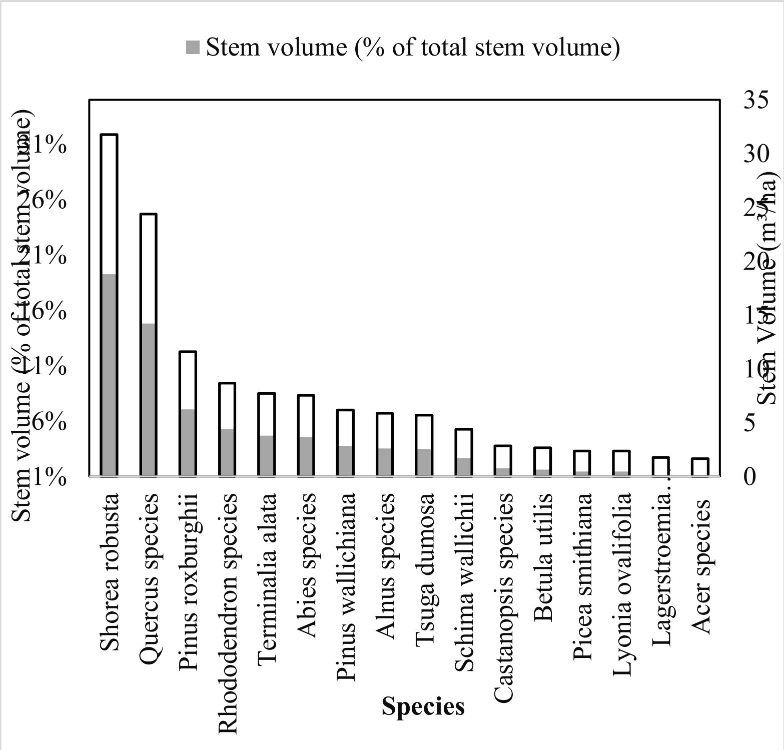

Fig. 4: Stem volume of major tree species in Nepal (data derived from DFRS, 2015).

Production and prospects of timber and firewood in Nepal

Wood is produced and supplied to the market as timber and firewood in Nepal. Table 2 shows the timber and firewood production status in Nepal from 2012/13 to 2022/23. During the eleven years, timber production increased by 20 times from 44,821 m^3 to 900,474 m^3 and firewood production increased by 64 times (as per the official records). The annual growth rate in the production of timber and firewood during the timeframe is not uniform. This can be attributed to different changes in policies and management practices for tree harvesting in Nepal. In particular, a Scientific Forest Management Program was launched as a pilot program in Tilaurakot collaborative forest of Kapilbastu district in 2012 (Poudel, 2018; B. H. Poudyal et al., 2020), but it is no longer being implemented. During its implementation, the program allowed maximum tree harvest compared to prevailing tree harvesting rules and regulations in Nepal (Bhusal et al., 2020). The program expanded to other forest areas of Nepal with the introduction of scientific forest management guidelines in 2014 (MFSC, 2014). The production of timber and firewood increased at an annual average growth rate of

15.7% and 97%, respectively, for the last five years (Table 2). The reduced production of timber and firewood in 2019/20 is attributed to the Covid-19 pandemic.

Table 2: Annual production of timber and firewood (Ministry of Finance, 2024)

Fiscal year	Timber (m^3)	Firewood (Chatta*)	% Change in timber	% Change in firewood	Energy equivalent of firewood** (toe)
2012/13	44,821	661	-	-	1,191
2013/14	279,758	8,550	524.2	1192.9	15,395
2014/15	279,196	8,606	-0.2	0.7	15,496
2015/16	229,377	3,668	-17.8	-57.4	6,605
2016/17	254,148	8,059	10.8	119.7	14,509
2017/18	497,037	10,528	95.6	30.6	18,956
2018/19	549,346	47,968	10.5	355.6	86,367
2019/20	404,930	13,280	-26.3	-72.3	23,911
2020/21	550,026	17,132	35.8	29	30,846
2021/22	614,475	14,626	11.7	-14.6	26,353
2022/23	900,474	41,998	46.5	187.1	75,673

* Chatta is a unit for firewood measurement in Nepal and is equivalent to 14.16 m^3 of stacked volume.
**The weight of 1 Chatta is taken as 10.4 tonnes (Subedi et al., 2014) and the calorific value (CV) of greenwood is taken as 7.2 MJ/kg (Krajnc, 2015) for calculations. CV is the amount of energy liberated by burning a unit mass of fuel.

Compared to the stem volume of 982 million m^3, the maximum annual production so far (2022/23) is merely 0.09%. To meet the SDGs by 2030, Nepal should optimally utilize forest resources by striking a balance between economic development and environmental conservation (Gautam, 2021). The 15th plan of the National Planning Commission for 2019/20 to 2023/24 (NPC, 2020) has identified the "Forestry for Prosperity Program" as an important initiative aimed at sustainably producing 0.85 million m3 of wood annually and creating 500,000 annual employments. The plan also declares a policy of establishing one medium to large scale timber-based industry in each of the seven provinces of Nepal.

To materialize the national plan, the country should not only focus on traditional use of wood but also identify new technologies and innovations to add value and diversity to wood products. In this light, processed firewood industry appears to be a promising development in Nepal. The development of firewood industries with standard operation modalities and specified production capacity could be a meaningful strategy for ensuring the sustainable use of firewood resources.

Seasoning Technology

Freshly felled wood has moisture content (MC) of 50-70% (Horvat & Dovic, 2018). Water exists in two forms in wood (free water in cell cavities and bound water in cell walls) (Chauhan, 2022; Mishra, 2017; Reeb, 1997). On drying the wood, water is evaporated easily until MC is reduced to the fiber saturation point of the wood. The fiber saturation point refers to the MC at which all free water from the cell cavity is removed but the cell wall is saturated by bound water. It corresponds to the MC in the range of 25-30% for most species (Chauhan, 2022; Reeb, 1997). Further drying of wood (exposure to heat) causes the evaporation of bound water in the cell walls. Seasoning, also known as drying, is the removal of MC (free water and part of bound water) from wood through evaporation. Timber seasoning is mainly done to prevent decay, increase durability and strength, reduce the weight of wood, and improve various performance requirements of wood (Chauhan, 2022; Mishra, 2017; Reeb, 1997). Specific to the firewood, firewood should be seasoned to achieve two more essential objectives:

- To increase the thermal efficiency and CV (a 10% reduction in MC through seasoning approximately increases the CV by 2.16 MJ/kg of seasoned wood (Krajnc, 2015)).
- To reduce GHG emissions.

Seasoning can be either air seasoning (natural drying) or kiln seasoning (artificial drying) (Chauhan, 2022). Under air seasoning, heat is supplied by the natural air, whereas various sources of heat can be used for kiln seasoning. Air seasoning is done in an open space through the stacking of wood so that air circulates through it. This method is particularly suitable in countries with hot and dry climates, but it is less efficient for large-scale industrial applications. Air seasoning can reduce the MC of the wood to 18 to 20%, but to reduce the MC of the wood even further, kiln seasoning is needed (Kofman & Kent, 2009).

Kiln seasoning occurs inside an insulated chamber of a relatively large volume through careful control of temperature, humidity, and airspeed. A typical kiln is shown in Fig. 5. The size of the kiln is designed considering the amount of wood to be seasoned in one batch. It is well-insulated and has controlled air velocity, temperature, and humidity that can be adjusted according to the characteristics of timber species. Psychrometers (dry bulb and wet bulb thermometers) are also present at both ends of the kiln. Furthermore, a kiln is provided with an air outlet and fans to force air circulation through the chamber. The temperature to be maintained in the kiln varies as per the wood species.

Depending upon the final target of MC and species used, the temperature from 40-50 ℃ to over 100 ℃ can be used, and the time of the drying process can be 15-20 days for low temperatures to 20-30 hr for high temperatures (Chauhan, 2022; Mishra, 2017). High-temperature kilns, which can dry the wood within a day, can be operated at 93 ℃ to 115 ℃, and the air velocity can be higher than 4 m/s (Kofman & Kent, 2009). Conventional kilns generally use temperatures of 38 ℃ to 54 ℃ for initial drying, whereas for final drying (i.e., when the MC of the lumber declines below 15%) the temperature ranges from 66 ℃ to 93 ℃ (Denig et al., 2000). In the kiln, humidity is maintained sometimes by steam spray or a cold-water misting system. A kiln for softwood heating operates at a temperature between 32 ℃ and 115 ℃ whereas the kiln temperature for hardwood is maintained between 38 ℃ and 82 ℃ (Boone & Wengert, 1998; Cheremisinoff & Rosenfeld, 2010).

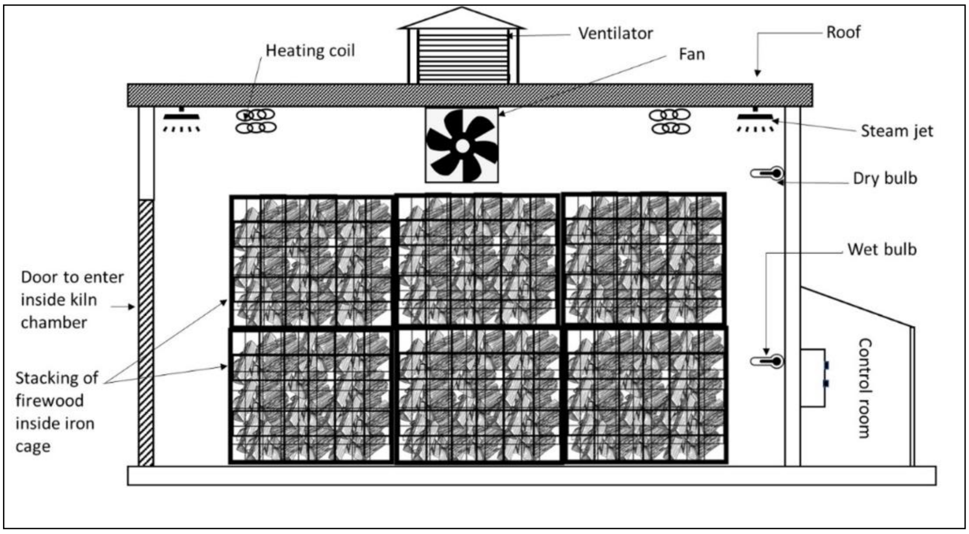

Fig. 5: A schematic diagram of a kiln showing its components (illustration by the authors).

The time required for air seasoning is significantly longer compared to kiln seasoning. A comparison of the kiln and air-drying behaviors of *Tectona grandis* and *Gmelina arborea* revealed that kiln drying takes significantly less time and brings wood with low MC as compared to air drying (Salas & Moya, 2014). For the tests spanning the same range of MC, kiln seasoning was 15 times faster than air seasoning when compared to *Gmelina arborea* lumbers (Desalegn et al., 2020). This study demonstrated that any industrial production of processed firewood will require kiln seasoning technology.

Unlike air drying, kiln drying is not affected by environmental conditions such as temperature, relative humidity, rainfall, sunshine, and wind of the location where wood is seasoned (Denig et al., 2000). Even though kiln seasoning has a higher cost of capital investment and operation compared to air seasoning, kiln seasoning is more feasible commercially (Denig et al., 2000; Reeb, 1997).

Various sources of heating (electricity, biomass, fossil fuels) can be used for operating a kiln. However, the aim of proposing processed firewood in this study is to propose an environmentally friendly alternative to fossil fuels. Therefore, fossil fuel should be ruled out as a source of heat for seasoning firewood. Considering the increasing production of electricity in Nepal from renewable sources, electricity is recommended for the kiln to be used for seasoning firewood. Part of the processed firewood from the kiln could also be used as an alternative source of heating energy. A detailed analysis will be the subject of further research.

A processed wood factory as a new avenue for diversifying energy mix in Nepal

Conventionally, firewood has been the predominant source of cooking fuel in Nepal and firewood is seasoned by using air seasoning. Use of a kiln for seasoning firewood is a new idea in Nepal. Recently, a prefeasibility study was conducted by the Province Planning Commission of Lumbini province, Nepal, with the aim of establishing a processed wood factory in the province (Gautam & Khaniya, 2020). The study proposed to establish a processed wood factory based on kiln seasoning technology in Dang district. Wood resources of the province were assessed and Dang and Kapilvastu were identified as two districts with forest resources to be supplied to the industry. A kiln was proposed with a capacity to process 163 Chatta (2,308 m^3) green wood with an annual production capacity of 736 tonnes of processed firewood. An establishment of such a kiln would require a capital investment of NPR 37,805,446 (USD 270,738) and will have a payback period of 7 years (Gautam & Khaniya, 2020).

As an environmentally friendly and sustainable development measure, the kiln is proposed to be integrated with a solar plant that will generate 150 kW of electricity. Grid electricity will be connected to the factory, and it will supply energy during nighttime operation and the downtime of the solar plant. Processed firewood technology is proposed with multiple objectives including utilizing forest resources, promoting firewood in the urban market, providing alternative fuel sources, substituting LPG imports, and creating employment opportunities. The investment for the factory could be arranged through a public-private partnership with a government subsidy for installing the solar plant. The private component of the investment is sought from community forest groups or private organizations. The involvement of community forest user groups as investors allows income diversification for the community and most importantly ensures sustainable utilization of forest resources with no risk of over-exploitation.

The processed wood factory can be established as a pilot project for producing processed wood in Nepal and gaining market acceptance. The proposed production of 736 tonnes of processed firewood (with assumed CV of 19 MJ/kg) is equivalent to 334 toe of energy and can theoretically replace 304 tonnes of LPG (with assumed CV of 46 MJ/kg and 1 ton of LPG considered equivalent to 1.1 toe energy). As the SDG roadmap of Nepal plans to increase the number of households using a clean source of cooking fuel from 46.5% in 2019 to 100% in 2030 (Bharadwaj et al., 2021), processed firewood could partially contribute to achieving this target. Likewise, processed firewood could evolve as a new type of fuel for serving industrial demands.

Discussion and Way Forward

This review shows Nepal has a substantial challenge in fulfilling its energy demand. At the same time, Nepal’s ample forest resources can sustainably supply firewood for energy use. Advancing this potential, however, requires use of firewood beyond traditional use. The adoption of kiln seasoning technology offers a pragmatic solution to create pathways for the commercial development of seasoned firewood as a viable energy source.

Firewood is still the primary source of energy in rural areas of Nepal where communities rely on it for cooking and heating (Kandel et al., 2016; R. Poudyal et al., 2019). Nepal has an average annual fuelwood consumption of 3,060 kg per household (Kandel et al., 2016). Considering 3,398,316 households in Nepal consuming fuelwood for cooking (CBS, 2019), the annual fuelwood consumption is estimated to be around 10 million tonnes. If processed firewood is used, these 10 million tonnes could be reduced to just 5 million tonnes (authors' estimation), as the CV of firewood is significantly increased through kiln seasoning. The conventional use of firewood results in indoor air pollution and other gaseous emissions (Adhikari et al., 2020; Singh et al., 2023). On the other hand, several factors such as higher costs, unreliable distribution, and inaccessibility due to poor infrastructure impede the use of electricity and LPG (Bharadwaj et al., 2021; Paudel et al., 2021) For instance, the cost of LPG can be as high as ten times the cost of using firewood with equivalent energy production and is difficult to carry to rural areas that lack road infrastructures (Bharadwaj et al., 2021). Even though urbanization is leading to a decline in the traditional use of firewood, firewood is predicted to account for as high as 45% of the total energy demand until 2051 AD, under the current scenario in Nepal (Bharadwaj et al., 2021; Malla, 2022). Hence, it is vital to find innovative ways that can help to use firewood economically, efficiently, and at the same time to reduce indoor air pollution and carbon emissions.

There is an opportunity to process the plentiful firewood in the Nepal's forest into commercially viable fuel for urban communities. Estimates suggest that 15.7 million tons dry matter (which is equivalent to 7.1 Mtoe) can be sustainably supplied annually from forests in Nepal (WECS, 2022). On the other hand, Fig. 6 shows the import of LPG in Nepal growing significantly in the recent past. When considered alongside Nepal's current LPG import scenario, the adoption of seasoned firewood offers a pragmatic alternative. This argument is further reinforced when viewed in the context of Nepal's geopolitical vulnerabilities. The blockade in Nepal by India for two months in 2015 resulted in a huge shortage of petroleum, and salt (Paudel et al., 2021; R. Poudyal et al., 2019). Considering such vulnerabilities, Nepal should explore viable ways to diversify its energy mix by making use of resources easily available within the country. Therefore, promoting the sustainable use of firewood for energy production can be a win-win strategy for meeting Nepal's energy needs through diversification in the energy mix while also strengthening rural livelihoods by sustainably utilizing forest resources. Additionally, establishment of a firewood processing industry could also offer financial opportunities for rural communities engaged in firewood collection. A study by Bharadwaj et al. (2021) shows the use of firewood in Nepal has several social benefits, including low operation and installation costs, operational flexibility, cultural suitability, and ease of maintenance, thus, making it more practical than other cooking sources such as LPG, biogas, kerosene, and electricity. A comprehensive analysis of the opportunities and challenges associated with establishing a processed firewood industry based on kiln seasoning will be the scope of future research.

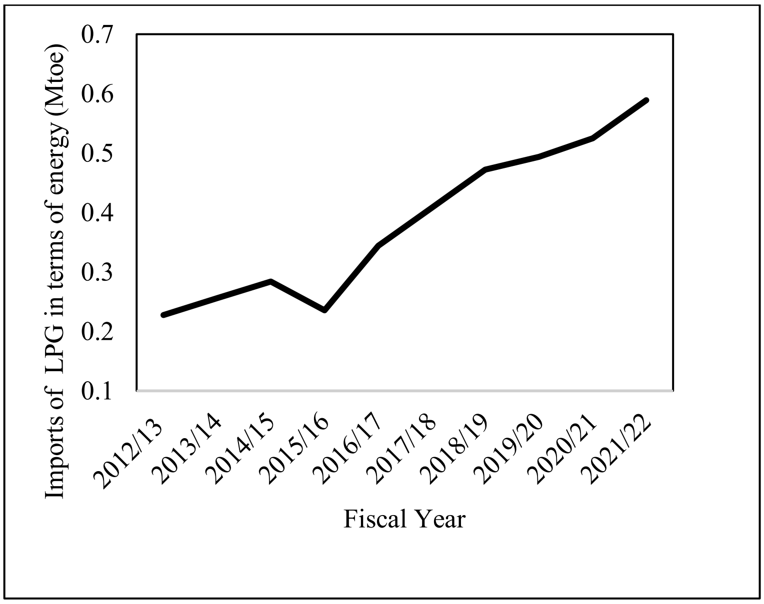

Fig. 6: Trends of LPG imports in Nepal from 2012/13 – 2021/22 (NOC, 2025). Conversion applied CV of 46 MJ/kg.

A major challenge for large scale adoption of the proposed technology is its economic viability, which shows dynamic response to factors such as market dynamics, production scale, and geographic location. Studies in high-income countries, such as the United States, have shown that wood-drying enterprises can achieve annual profits of up to 29.6% (Jorgensen, 2011). The transferability of such findings to countries like Nepal may be constrained by differences in socio-economic conditions, market volatility, and infrastructure availability. Additionally, the dearth of literature on the economic aspects of firewood processing in similar socio-economic settings further underscores the need for targeted research to evaluate its feasibility and long-term financial sustainability.

The use of seasoning technology targeting commercial firewood production is a new avenue yet to be explored. If successful at large scale expansion, the major challenge will be over-exploitation of forest resources which will increase the threat to biodiversity (Szulecka, 2019). However, Forest Sector Policies and Forest Act (1993) will safeguard sustainable harvest of fuelwood from forests (Yasami et al., 2016). Likewise, forest certification schemes such as Forest Stewardship Council (FSC), and the Programme for the Endorsement of Forest Certification (PEFC) can be used to ensure that firewood will be sustainably sourced from the forest (Szulecka, 2019).

Another challenge to the adoption of processed firewood technology is the lack of enabling policies in Nepal. Previous public policy interventions in Nepal have focused on providing alternative cooking stoves and reducing traditional sources of energy (e.g. fuelwood). Mostly due to lack of understanding of the socioeconomic realities, improved cooking stoves distributed in rural areas of Nepal have not been successful in significantly reducing firewood demand (Nepal et al., 2010). While electric energy potential is high in Nepal, remote villages are still deprived of the national grid. Moreover, natural disasters such as storms and floods lead to power outages (R. Poudyal et al., 2019). Unplanned power outages are also common in Nepal resulting in economic loss of 24.69 million USD per year (R. Poudyal et al., 2019). Furthermore, seasonal changes in water volume in rivers which is further exacerbated by climate change affects hydro-electricity production. Therefore, it is essential to reform energy strategies in Nepal from solely focusing on electricity to promoting energy mix comprising diverse sources.

Although this study focuses on Nepal, the novel outlook presented in this paper and the methodological approach for integrating kiln seasoning technology with sustainable utilization of forest wood to meet energy needs have potential for broader applicability. The issues with firewood burning, such as inefficient energy consumption and indoor air pollution, are not unique to Nepal. Globally, 2.3 billion population is still deprived of access to clean energy, with majority in Asia and Africa (IEA, 2023). Countries belonging to these continents and rich in forest resources can adapt the kiln seasoning technology to diversify their energy mix. Moreover, adaptability of the proposed kiln seasoning technology is also supported by advancements in solar kiln drying research, which indicates global interest towards the adaption of such technology (Lamrani et al., 2023; Kumar et al., 2023).

The analysis in this study was constrained by availability, scope, and quality of secondary data as it was based on the review of literature. Despite the apparent feasibility of a kiln processing technology for firewood processing, further research through large scale field trials would aid its validation and practical implementation. This would allow to empirically assess large scale economic feasibility, energy efficiency of the processed firewood, and environmental impacts of the proposed industry under real world conditions. Future research should address these gaps through experimental trials, region-specific study, and comparative studies across multiple geographic locations. Through rigorous study and research, technologies can be developed and applied to generate innovative solutions to traditional problems.

Conclusion

This paper provides an overview of energy consumption and demand in Nepal, highlighting the application of seasoning technology to use firewood as an alternative energy source. While the case of Nepal was the focus of this study, the findings have global relevance, especially in forest-rich countries where inefficient energy consumption and indoor air pollution are prevalent.

Kiln seasoning technology was evaluated as a viable method for processing firewood. Seasoning technology should be used to remove moisture from the wood to improve its combustion properties and preserve wood for an extended period. While the country imports approximately 0.6 Mtoe of LPG gas annually, Nepal's wood resources have an estimated annual theoretical potential of 7.1 Mtoe of energy. A pilot project was proposed in which a processed wood factory will be established with a production capacity of 736 tonnes per year of processed firewood. The production is equivalent to 334 toe of energy and may substitute 304 tonnes of LPG import, thus reducing the emission by 882 tonnes of CO_2 equivalent.

To adopt the firewood seasoning technology, countries must revisit their policies and develop a new strategy to diversify the energy mix so that biomass-based energy will equally receive attention as other energy sources. Likewise, environmental and social safeguards need to be researched to mitigate adverse effects on forest arising from promotion of firewood. Sustainable harvest practices, value chain of firewood, and equitable benefit distribution are the topics of future research that should be prioritized for the efficiency of the processed firewood industry. It is also essential to validate the economic feasibility, energy efficiency of the processed firewood, and environmental impacts of kiln seasoning technology under real world conditions and make comparative studies across diverse geographic regions to ensure its global scalability.

Conflict of Interest

We have no conflict of interest to disclose.

References

Adhikari, S., Mahapatra, P. S., Pokheral, C. P., & Puppala, S. P. (2020). Cookstove smoke impact on ambient air quality and probable consequences for human health in rural locations of southern Nepal. *International Journal of Environmental Research and Public Health, 17*(2), 550. https://doi.org/10.3390/ijerph17020550

Amatya, S. M. (2013). *Financing for sustainable forest management in Nepal*. INDUFOR.

Bharadwaj, B., Pullar, D., To, L. S., & Leary, J. (2021). Why firewood? Exploring the co-benefits, socio-ecological interactions and indigenous knowledge surrounding cooking practice in rural Nepal. *Energy Research & Social Science, 75,* 101932. https://doi.org/10.1016/j.erss.2021.101932

Bhusal, P., Karki, P., & Kimengsi, J. N. (2020). Timber distribution dynamics in scientifically managed community forests: Learning from nepal. *Forests*, *11*(10), 1–16. https://doi.org/10.3390/F11101032

Boone, R. S., & Wengert, E. M. (1998). Guide for using the oven-dry method for determining the moisture content of wood. *University of Wisconsin-Madison*, *89*(June), 1–4. https://forestandwildlifeecology.wisc.edu/wp-content/uploads/sites/111/2017/07/89.pdf

CBS. (2014). *Population monograph of Nepal*. https://nepal.unfpa.org/sites/default/files/pub-pdf/Population Monograph V02.pdf

CBS. (2019). *Nepal statistical year book 2019* (17th ed., Issue 47). CBS.

Chauhan, S. S. (2022). Basics of wood drying/seasoning. In *Science of Wood Degradation and its Protection* (pp. 534–557). Springer Nature. https://doi.org/10.1007/978-981-16-8797-6_21

Cheremisinoff, N. P., & Rosenfeld, P. E. (2010). Wood-preserving technology. In *Handbook of Pollution Prevention and Cleaner Production* (Vol. 2, Issue 5, pp. 27–41). https://doi.org/10.1016/b978-0-08-096446-1.10002-4

Das, I., Rogers, B., Nepal, M., & Jeuland, M. (2022). Fuel stacking implications for willingness to pay for cooking fuels in peri-urban Kathmandu Valley, Nepal. *Energy for Sustainable Development*, *70*, 482–496. https://doi.org/10.1016/j.esd.2022.08.017

De Leeuw, J., Njenga, M., Wagner, B., & Iiyama, M. (2014). *An assessment of the resilience provided by trees in the drylands of Eastern Africa* (Issue January). ICRAF.

Denig, J., Wengert, E. M., & Simpson, W. T. (2000). *Drying hardwood lumber*. United States Department of Agriculture, Forest Service, Forest Products Laboratory.

Desalegn, G., Kaba, G., Tesfaye, A., & Amanuel, S. (2020). Seasoning technologies of Gmelina arborea Roxb . lumber species grown at Bonga , SNNP , Ethiopia. *World News of Natural Sciences*, *29*(February), 269–281.

DFRS. (2015). *State of Nepal's forests* (Issue December). Department of Forest Research and Survey.

Ericsson, K., & Werner, S. (2016). The introduction and expansion of biomass use in Swedish district heating systems. *Biomass and Bioenergy*, *94*, 57–65. https://doi.org/10.1016/j.biombioe.2016.08.011

Gautam, B. P. (2021). A concept of optimum forest area for the sustainable development of Nepal. *Journal of Engineering Technology and Planning*, *2*, 1–14.

Gautam, B. P., & Khaniya, S. (2020). *Processed wood factory: Pre-feasibility report*. Province Planning Commission, Butwal, Nepal.

Ghimire, L. P., & Kim, Y. (2018). An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renewable Energy*, *129*, 446–456. https://doi.org/10.1016/j.renene.2018.06.011

Hiloidhari, M., Baruah, D. C., Kumari, M., Kumari, S., & Thakur, I. S. (2019). Prospect and potential of biomass power to mitigate climate change: A case study in India. *Journal of Cleaner Production*, *220*, 931–944. https://doi.org/10.1016/j.jclepro.2019.02.194

Horvat, I., & Dović, D. (2018). Combustion of agricultural biomass-issues and solutions. *Transactions of FAMENA*, *42*(SI-1), 75-86.

IEA. (2023). A vision for clean cooking access for all. In *International Energy Agency*. International Energy Agency. www.iea.org/t&c/

IEA. (2025). *Energy statistics data browser*. IEA. https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=NPL&fuel=Imports%2Fexports&indicator=CoalImportsExports

Kandel, P., Chapagain, P. S., Sharma, L. N., & Vetaas, O. R. (2016). Consumption patterns of fuelwood in rural households of Dolakha District, Nepal: Reflections from community forest user groups. *Small-scale Forestry, 15*(4), 481–495. https://doi.org/10.1007/s11842-016-9335-0

Kofman, P. D., & Kent, T. (2009). Storage and seasoning of conifer roundwood in the forest. *Coford Connect Note*, *19*.

Krajnc, N. (2015). Wood fuels handbook. In *Food and Agriculture Organization (FAO)*. FAO.

Kumar, B., Raj, A. K., Szepesi, G., & Szamosi, Z. (2023). A conspectus review on solar drying of wood: Regional and technical contrivances. *Journal of Thermal Analysis and Calorimetry, 148,* 9237–9261. https://doi.org/10.1007/s10973-023-12093-5

Lamrani, B., Bekkioui, N., Simo-Tagne, M., & Ndukwu, M. C. (2023). Recent progress in solar wood drying: An updated review. *Drying Technology, 41*(5), 605–627. https://doi.org/10.1080/07373937.2022.2112048

Malla, S. (2013). Household energy consumption patterns and its environmental implications: Assessment of energy access and poverty in Nepal. *Energy Policy*, *61*, 990–1002. https://doi.org/10.1016/j.enpol.2013.06.023

Malla, S. (2022). An outlook of end-use energy demand based on a clean energy and technology transformation of the household sector in Nepal. *Energy, 238,* 121810. https://doi.org/10.1016/j.energy.2021.121810

MFSC. (2014). *Scientific forest management guideline, 2014 (in Nepali)*. Ministry of Forest and Soil Conservation.

MFSC. (2017). *Forest investment program: Investment plan of Nepal*. Government of Nepal. https://www.climateinvestmentfunds.org/sites/cif_enc/files/fip_ip_nepal.pdf

Ministry of Finance. (2024). *Economic survey 2023/24*. https://giwmscdnone.gov.np/media/pdf_upload/MOF_Economic Survey ENG 2023-24 book Final_for WEB_miwtpw0.pdf

Mishra, R. K. (2017, November). Significance of wood seasoning. *Van Sangyan*, *4*(11), 25–31. https://www.researchgate.net/publication/321904144_Significance_of_wood_seasoning

Mohammad, K. (2023). Regional Statistics – Interlinkages between human development, residential energy consumption, and energy efficiency for the EU-27 Member States, 2010–2018. *Regional Statistics*, *13*(1), 37–54. https://doi.org/10.15196/RS130102

NEA. (2024). *A year in review-Fiscal year - 2023/2024* (Nepal Electricity Authority (ed.)). https://www.nea.org.np/admin/assets/uploads/supportive_docs/60896609.pdf

Nepal Rastra Bank. (2024). Annual report: Fiscal year 2023/ 2024. In *Nepal Rastra Bank*. https://www.nrb.org.np/contents/uploads/2025/07/Annual-Report-2023-24-English.pdf

Nepal, M., Nepal, A., & Grimsrud, K. (2010). Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. *Environment and Development Economics, 16*(1), 1–23. https://doi.org/10.1017/S1355770X10000409

Nepal Oil Corporation. (2025). *Import of petroleum products*. Nepal Oil Corporation. https://noc.org.np/import?type=import&offset=0&max=10

NPC. (2017). *Nepal's sustainable development goals, status and roadmap: 2016-2030* (Issue December). Government of Nepal.

NPC. (2020). *The fifteenth plan (Fiscal year 2019/20-2023/24)* (Issue March). Government of Nepal.

Paudel, D., Jeuland, M., & Lohani, S. P. (2021). Cooking-energy transition in Nepal: Trend review. *Clean Energy*, *5*(1), 1–9. https://doi.org/10.1093/ce/zkaa022

Pokharel, B. K., Stadtmuller, T., & Pfund, J.-L. (2005). From degradation to restoration: An assessment of the enabling condi-tions for community forestry in Nepal. *Intercooperation, Swiss Foundation for Development and International*, 1–10.

Poudel, K. C. (2018). Silviculture for forest management in Nepal. *Banko Janakari*, *4*, 15–20. https://doi.org/10.3126/banko.v27i3.20537

Poudyal, B. H., Maraseni, T., & Cockfield, G. (2020). Scientific forest management practice in Nepal: Critical reflections from stakeholders' perspectives. *Forests*, *11*(1). https://doi.org/10.3390/f11010027

Poudyal, R., Loskot, P., Nepal, R., Parajuli, R., & Khadka, S. K. (2019). Mitigating the current energy crisis in Nepal with renewable energy sources. *Renewable and Sustainable Energy Reviews, 116,* 109388.

https://doi.org/10.1016/j.rser.2019.109388

Ranabhat, C. L., Kim, C. B., Kim, C. S., Jha, N., Deepak, K. C., & Connel, F. A. (2015). Consequence of indoor air pollution in rural area of Nepal: A simplified measurement approach. *Frontiers in Public Health*, *3*(JAN), 1–6. https://doi.org/10.3389/fpubh.2015.00005

Raspanti, G. A., Hashibe, M., Siwakoti, B., Wei, M., Thakur, B. K., Pun, C. B., Al-Temimi, M., Lee, Y. C. A., & Sapkota, A. (2016). Household air pollution and lung cancer risk among never-smokers in Nepal. *Environmental Research*, *147*, 141–145. https://doi.org/10.1016/j.envres.2016.02.008

Reeb, J. E. (1997). Drying wood. In *University of Kentucky Cooperative Extension Service*.

Ritchie, H., & Roser, M. (2020, November 28). *Energy*. Our World in Data. https://ourworldindata.org/energy

Rogers, B. (2020, January). *The science is clear on renewable wood energy*. http://biomassmagazine.com/articles/16697/the-science-is-clear-on-renewable-wood-energy

Salas, C., & Moya, R. (2014). Kiln-, Solar-, and air-drying behavior of lumber of Tectona grandis and Gmelina arborea from fast-grown plantations: Moisture Content, Wood Color, and Drying Defects. *Drying Technology*, *32*(3), 301–310. https://doi.org/10.1080/07373937.2013.829087

Sasaki, N. (2021). Timber production and carbon emission reductions through improved forest management and substitution of fossil fuels with wood biomass. *Resources, Conservation and Recycling*, *173*(June), 105737. https://doi.org/10.1016/j.resconrec.2021.105737

Singh, D., Tassew, D.J., Nelson, Jordan, Chalbot, M.G., Kavouras, I.G., Tesfaigzi, Y., Demokritou, P. (2023). Physicochemical and toxicological properties of wood smoke particulate matter as a function of wood species and combustion condition. *Journal of Hazardous Materials, 441,* 129874. https://doi.org/10.1016/j.jhazmat.2022.129874

Sreevani, P. (2018). Wood as a renewable source of energy and future fuel. *AIP Conference Proceedings*, *1992*, 1–3. https://doi.org/10.1063/1.5047972

Sulaiman, C., Abdul-Rahim, A. S., & Ofozor, C. A. (2020). Does wood biomass energy use reduce CO_2 emissions in European Union member countries? Evidence from 27 members. *Journal of Cleaner Production*, *253*, 119996. https://doi.org/10.1016/j.jclepro.2020.119996

Szulecka, J. (2019). Towards sustainable wood-based energy: Evaluation and strategies for mainstreaming sustainability in the sector. *Sustainability, 11*(2), 493. https://doi.org/10.3390/su11020493

Thornley, P., Gilbert, P., Shackley, S., & Hammond, J. (2015). Maximizing the greenhouse gas reductions from biomass: The role of life cycle assessment. *Biomass and Bioenergy*, *81*(0), 35–43. https://doi.org/10.1016/j.biombioe.2015.05.002

Tun, M. M., Juchelkova, D., Win, M. M., Thu, A. M., & Puchor, T. (2019). Biomass energy: An overview of biomass sources, energy potential, and management in Southeast Asian countries. *Resources*, *8*(2). https://doi.org/10.3390/resources8020081

Water and Energy Commission Secretariat. (2022). *Energy sector synopsis report – 2022.* Government of Nepal. https://wecs.gov.np/source/Energy%20Sector%20Synopsis%20Report%2C%202022.pdf

WBA. (2019). *Global bioenergy statistics 2019*. World Bioenergy Association.

WHO. (2018). *Household air pollution attributable death rate (per 100 000 population)*. https://www.who.int/data/gho/data/indicators/indicator-details/GHO/household-air-pollution-attributable-death-rate-(per-100-000-population)

Yang, C., Kwon, H., Bang, B., Jeong, S., & Lee, U. (2022). Role of biomass as low-carbon energy source in the era of net zero emissions. *Fuel*, *328*(March), 125206. https://doi.org/10.1016/j.fuel.2022.125206

Yasami, Y., Dahal, G. R., & Khanal, D. (2016). *Forest tenure policies in Nepal: Status, gaps and way forward.* Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i6247e.pdf