Review Paper

Wood waste utilization and associated product development from under-utilized low-quality wood and its prospects in Nepal

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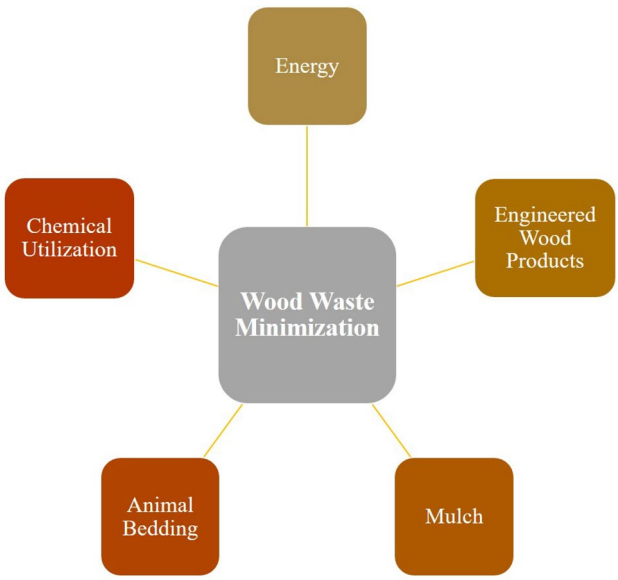
Abstract

Wood waste has the potential to be used in making a variety of goods, including engineered wood products, energy generation (heat and electricity), mulching, and animal bedding. These inexpensive and underutilized feedstocks have the potential to increase the added value of wood wastes. This paper aims to review the different possibilities on wood waste utilization and their prospects in Nepal. This information helps to find the proper way for future development of wood waste to deliver the best outcomes for the environment and economy. The review is based on an in-depth examination of credible literature and official statistical data. The study showed Nepal has not utilized wood waste except for firewood and a few engineered wood products. The problem with wood waste is the lack of adaptation of advanced technologies and the lack of institutions concerned with the benefits of utilization of those waste. This review concludes that wood waste can be a potential source for the production of different materials but the government should develop effective waste management rules to maximize the value of wood waste resources.

Graphical abstract



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Article Highlights

- Wood waste could be used as a potential renewable energy source.
- Wood waste utilization can play an increasing role in the production of a variety of wood-based products that can become a viable alternative raw material.
- The use of recovered wood waste in secondary products might be a valuable outlet.

Keywords Wood waste · Waste utilization · Low-quality wood · Engineered products

Abbreviations

OSB	Oriented strand board
NGO	Non-governmental Organization
DFRS	Department of Forest Resource and Survey
NTFPS	Non-timber forest product
MDF	Medium Density Fiberboard
ANSAB	Asian Network for Sustainable Agriculture and Bioresources

1 Introduction

Wood wastes is a category of wastes that includes discarded wood products from different sources such as wood packaging, demolition and construction, wood processing industry, and others such as private households and railway construction [1]. This waste can be a secondary source of raw material for energy production and production of a range of new potential product such as chemical, biofuel and other lignocellulosic materials [2]. Wood bark, for example, contains lipophilic and hydrophilic extractives that can be turned into high-value products like cosmetic chemicals or pharmaceutical products [3]. Likewise, Yang et al. [4] found bio-oil derived from waste wood resources as a good extender and modifier for petroleum asphalt binders in asphalt payment. Generation of biofuels and wood-based composites could be other high added value applications from wood waste. Also, preventing wood waste could assist the timber business in reducing environmental impact while also meeting the rising demand for wood without further harming the world's forests [5]. Therefore, reducing, recovering and enhancing the utilization of wood waste from harvesting and processing of wood should be the strategy of forest-based industries.

Wood waste and byproducts from wood-based industrial operations can be used to make a wide range of useful industrial products [6]. For every 1000 board feet of lumber produced, 1 ton of sawdust, shavings, slabs, and edgings is gathered in sawmills; approximately 75% of this useless material is wood content, and 25% is bark [7]. This can be converted into energy and non-energy applications. The use of wood waste for energy generation include form combustion, cogeneration, pellet and briquette while non-energy uses include the production of composite boards, surfacing product, composting, and cement board [8]. Several kinds of research have revealed a variety of value-added solutions for converting wood waste into other useful products. For example, research conducted in Finland indicated several emerging markets for wood-based products (textiles, chemicals, biofuels and plastic substitutes) [9]. Research conducted in Zimbabwe showed that the majority of offcuts and chips from wood-based businesses are used as firewood by local populations and are used at commercial sawmills to generate steam for kiln driers [10]. Another study in Japan found that furniture firms created 15 million cubic meters of wood waste, of which over 90% was recycled to make wood-based panels and fuel [11]. Under-utilized wood from paulownia (*Paulownia fortuniei*), a fast-growing species was found to comply with general-purpose oriented strand board (OSB) minimum value requirements of EN 300 Type 1 (1997) for use in dry conditions [12].

Wood is used for the construction of both large and small buildings around the world [13]. Nepal constitutes a significant portion of land use under forests and shrublands [14]. Timber utilization in the country provides significant input in the construction of residential houses, commercial and industrial buildings, livestock sheds and furniture [15]. The demand for timber is 3.37 million m^3 in 2011, 3.75 million m^3 in 2020 and projected to rise to 4.80 million m^3 in 2030 [15]. Despite the ever-rising demand with increasing population, wood in developing countries like Nepal is underutilized or misused due to an outdated sawmills and unskilled operators. Forest-based industries have the potential to contribute to better management of natural resources providing income and employment opportunities [16, 17]. The different wood-based sector generates large amounts of wood waste, which must be properly managed, repurposed, marketed, or disposed of [18]. However, lack of incentives for wood waste utilization, insufficient information on the economic benefits of wood waste utilization, poor enforcement of environmental regulations, and a lack of policies for wood waste management caused the main problems. This revealed a study needs in Nepal wood management and usages practices. Therefore, a review of the global experience in wood waste management and its utilization practice is necessary. This study aims to explore a variety of preferable

future developments from underutilized wood waste and their prospects in developing countries like Nepal. The review is divided into different headings with an overview of wood waste and its utilization. Section 1.1 provides an overview of forest and forest-based industries in Nepal. Section 2 shows different types of wood waste generated from industries. Section 2.1 is related to wood waste utilization and Nepalese wood waste management experiences. Lastly, the summary of the review is presented with prospects and recommendations.

1.1 Overview of forest and forest-based industries in Nepal

Forests are an important part of the world's ecosystem [19]. They also contribute to national economies by producing forest goods such as timber and non-timber forest products. According to DFRS [20], 40.36% of Nepal's land area is classified as a forest area with other wooded lands of 4.38% making a total of 44.74%. In recent years, the harvesting level of stem wood from Nepal's forests has been around 3.4 million m^3, as assessed from forest stumps [20]. A considerable portion of this is used as timber and poles with some used as fuelwood. According to Pandey et. al [21], 900,000 cubic meters of timber and 1.2 million m^3 of fuelwood could be sustainably produced annually and generate employment for about 4.8 million people.

In Nepal, the first mechanized wood-based industry, a match factory, was created in 1938. Since the mid-1950s, successive 5-year plans have stressed the need of developing indigenous-materials-based enterprises, accelerate industrial growth, and contribute forests to the country's economic, social, and industrial development. However, due to several restrictions, the wood-based sectors have not progressed much and are at a primitive stage. Forest-based enterprises are divided into four categories by Subedi et al. [22]: timber, non-timber forest products (NTFPs), ecosystem services (eco-tourism and carbon), and forest bio-energy. There are mainly small and medium forest enterprises that have been instrumental in providing rural Nepalese livelihood. Most of them are informal and unregulated constrained by a lack of value addition, technology and product supply capacity, as well as by the absence of a supportive policy and legal framework. A study conducted by ANSAB showed forest sector enterprises in Banke, Bajhang, Humla and Dolakha were in the informal sector and it was unlikely that their contribution was reflected in the official statistics [23].

2 Wood waste from forest industries

The manufacture of timber products requires multiple processes, from log extraction to finished goods, all of which can pollute the environment in the form of land, air, and water pollution. Approximately 50% of wood is turned into valuable products, and the rest becomes waste [24]. Bark, slabs, sawdust, chips, coarse residues, planer shavings, peeler log cores, and end trimmings are examples of wood waste generated during main industrial processes (Table 1). Therefore, appropriate wood waste utilization significantly help to reduce the environmental impacts without damaging the world forest. According to Dionco-Adetayo [25], roughly half of every 1 m^3 of tree cut and taken from the forest is wasted as damaged residuals, followed by abandoned logs (3.75%), stumps (10%), tops and branches (33.75%), and butt trimmings (2.5%). Germany produced 11.9 million tonnes of wood wastes in 2015 arising from wood packaging, demolition and construction, wood processing industry [26]. In Finland, approximately 207,000 tons/year of waste wood is produced from packaging with a recovery rate of approximately, 31,000 ton/year and the remaining fraction is utilized for energy purposes (176,000 tons/year) [27]. According to the Wood Recyclers Association 2021 (https://woodrecyclers.org/), about 4.5 million tonnes of wood waste is generated in the UK of which 1.3 Million tonnes are recycled. Sweden with 1% of total global forest cover, accounts for more than 10% of the global forest industry business that includes swan timber and pulp and paper products [28].

In Nepal, sawn wood is the main product of hardwood species (*Shorea robusta*). However, due to over-exploitation government of Nepal banned the export of the species along with *Michelia* and *Acacia catechu*. In Nepal, due to poor data-keeping information on wood chips, wood residues and other minor items are difficult to obtain as they are considered sawmill waste [29].

2.1 Wood waste utilization

Wood waste can be minimized by improving the efficiency of primary wood utilization and by using the raw wood materials originating from a sustainable forest management without further impacting the world's forests [30]. There are a number of potential uses which offer possibilities for the utilization of a large proportion of wood waste from harvesting to processing. Eshun et al. [31] purposes five different measures for wood waste utilization i.e. technological change, good operational practice, recycling, reuse and recovery and a combination of technological change, good operating practices and recycling. Technological changes are very expensive but this reduces wood

Table 1 Analysis of residues generated in wood processing

Source	Types of residues
Forest operation	Branches, needles, leaves, stumps, roots, low graded and decayed wood, slashings and sawdust
Sawmilling	Bark, sawdust, trimmings, split wood, planer shavings, sander dust
Plywood production	Bark, core, sawdust, veneer clippings and waste, panel trim, sander dust
Particleboard production	Bark, screening fines, panel trim, sawdust, sander dust

waste production from plywood production by 6%, veneer production by 9% and furniture part production by 19% [5, 32]. Loehnetz et al. [33] found some selected sawmills in tropical countries like Venezuela (60–70%) and Malaysia (54.5%) recovered sawn wood of commercial dimensions.

According to Lykidis and Grigoriou [6], wood waste can be a potential resource for the production of different materials by re-forming or creating new products. In Zimbabwe, most of the offcuts and chips from wood-based industries are utilized at commercial sawmills for the generation of steam for kiln driers and used as firewood by local communities [10]. Likewise, Japanese furniture factories produced 15 million cubic meters of wood waste of which 90% is recycled for producing wood-based panels and fuel [11]. According to Bruns [34], Australia utilized wood waste at a large scale with yearly revenue of about 7.3 million Euros. From the wood waste various building materials and engineered wood produced such as plywood, laminated veneer lumber, and glued-laminated lumber particleboard are manufactured [35]. This showed that wood waste utilization for the production of new products is an economically viable plan [36]. Different techniques used for utilization of wood waste are;

2.1.1 Wood waste as a source of energy

Wood waste from furniture factories is used for energy conversion. The study showed that the lumber, plywood, pulp and paper industries burn their wood residues in large furnaces and boilers to supply 60% of the energy needed to run factories [37]. In the UK, each year around 10 million tons of waste wood are utilized for energy generation [38]. Canada exports 1 million tons of waste wood pellets to Europe as a raw material for power plants as substitutes for fossil fuel [39]. Wood pellets are compressed or compacted sawdust that can be used as fuel which in turn reduces the pressure on the forest. According to Goetzl [40], wood pellets are increasingly being utilized at an industrial scale for electric power generation, power in industrial and commercial applications in developed countries. Now, many developing countries are also producing wood briquettes as an efficient form of energy compare to firewood [41]. Charis et al. [10] stated that between 2013 and 2017 there has been the production of modified 'smokeless' briquettes by using new densification techniques in Zimbabwe. In Peru, wood waste from timber industries showed a perfect substitute for fuels by 55.81% of families in the region [42].

In Nepal, 77% of energy consumption of Nepal is supplied by traditional biomass energy, which includes firewood, cattle dung and agriculture residues. Among these alternatives, wood waste briquettes could be an alternative to fuelwood for cooking and other purposes [43]. Pandey and Regmi [44] conducted a study on briquettes from sawdust and found that the reduction of emission of harmful gases ultimately reduces indoor air pollution. Apart from this, some brick kilns are using wood waste as a source of fuel. The most limiting factor for using wood waste as fuel for power generation in developing countries like Nepal is technology and transportation cost and its energy content.

2.1.2 Using wood waste to create engineered wood products

Engineered wood products are objects created from tiny pieces of wood that are glued together with various adhesives. The use of wood waste in the manufacture of engineered wood products helps to mitigate climate change by avoiding additional tree harvesting and continuous carbon storage [45]. Example of engineered wood includes oriented strand board, particleboard, Medium Density Fiberboard (MDF), glue-laminated timber, laminated lumber and others [46]. Structural wood panels (plywood, oriented strand board) are manufactured by laminating various wood-based materials to improve the panel's strength, stiffness, and stability [47]. Usually, they are not designed to carry loads instead are typically used in interior applications as substitutes for solid wood. According to Braghiroli et al. [48], planer shavings account for more than half of the wood elements in particleboard manufactured in the United States, followed by other mill leftovers such as sawdust residues and wood chips. Several types of resins like Amino-formaldehyde, Melamine are used as cost-effective and water resistance properties. Medium-density boards (MDF) are used for superior products like stereo cabinets, moulding, table and furniture tops with profiled edges. MDF becomes a premier substrate for wood veneer, vinyl

films, and heat transfer foils due to its smooth surface and edge finishing qualities [47]. In 2013 and 2014, Italy re-used 95% of waste wood to produce particleboard, while Germany and United Kingdom shared the account to 34 and 53% respectively [26]. Alongside these benefits, the production of engineered wood products is expensive due to time, money and energy.

Nepal forest industries have no long history in manufacturing engineered wood products. There are few engineered wood producing companies and most of them are using wood products from massive wood rather than using wood waste. The technology adopted by industry is outdated and mostly operated by unskilled labour causing to have poor quality products. Lack of skill knowledge, rules and regulations on utilization of wood waste triggered by lack of research-based reliable information has put the country behind in wood waste utilization.

2.1.3 Wood chips for mulch

Mulches are layers that are placed on top of the soil to help control weeds, protect roots from temperature fluctuations, reduce water loss from the soil, and look attractive. Wood chips that are rich in lignin, tannins and other complex compounds supply nutrients and absorb significant amounts of water slowly [49]. Therefore, developed countries recognize woodchips mulches as environmentally sustainable for gardens and green spaces. In Nepal, using wood ships and shaving for mulching is not common however, the country has to adopt technology from a developed nation.

2.1.4 Wood chips for animal bedding

Bedding materials represent any material that provides comfort for animals in their enclosure. They can alleviate negative environmental impacts in the livestock facilities and improve animal comfort by absorbing excess moisture and reducing ammonia (NH_3) emissions [50]. Also, wood chips for animal bedding are easy to handle, cost-effective, and absorbent providing a clean, warm and dust-free environment [51]. The bedding can be combined with cattle dung and utilized as compost manure.

In Nepal, the utilization of wood waste as animal bedding is not common due to a lack of awareness. In rural households, utilization of wood waste for goats is common and often merchants of animals use those wastes as bedding during the transportation of animals.

2.1.5 Chemical utilization of wood waste

Wood waste and byproducts provide a potential source of a great variety of green chemicals. A typical softwood, such as spruce or fir contains about 67% carbohydrates, 27% lignin and 6% extractives. Likewise, hardwood such as maple contains about 73% carbohydrates, 22% lignin and 5% extractives [52]. A study showed the sulfite pulping process can utilize only half of the wood as pulp whereas the other unusable half consists of about equal parts of carbohydrates and lignin [53]. The carbohydrates portion of wood includes two types of materials i.e. alpha-cellulose and hemicellulose. Alpha cellulose comprises 50% wood is resistant to mild chemical treatment and is made of polymers of glucose. Hemicellulose is made up of simple sugars like pentoses and hexoses, uranic acids and acetylated substances. The greatest utilization of wood residues is realized by converting it into fibre for paper and paperboard. The chemical utilization of wood residues may involve various stages and the economic factor is the big problem. Usually, wood residues are hydrolyzed using acid into simple sugar and lignin. A study showed that lignin can be utilized for any commercial purposes i.e. for storage of batteries, tanning agents, adhesive, road construction, and dispersing agents in cement.

In Nepal, there is no proper utilization of particular chemicals derived from forest waste. In rural households, chemical extract from sal tree (*Shorea robusta*) is used for dying households walls. However, the extraction process is cumbersome and the natural dye colour easily fades. Therefore, there should be proper technology for extraction and application in Nepal textile small scale enterprises.

2.1.6 Nepalese waste wood management experiences

There are no specific rules and regulations for the utilization of wood waste in Nepal. Nepal's forest industry sector is primitive therefore wood waste is not effectively utilized mainly because of the low level of skills, knowledge, and backward technologies used for both production and processing activities. Moreover, lack of incentives for wood waste utilization, insufficient information on the economic benefits, poor enforcement of environmental regulations, and lack of technical know-how in wood waste processing are the other major issues. This makes wood industries irresponsible generating and disposing of anywhere in the city.

3 Conclusion

The study provides an overview of the utilization of forest waste from the timber industry. In developed countries like North America, and Australia timber industries are considered as high recovery rates of at least 52%, thereby reducing the waste produced at the source [10]. When

creating furniture, however, some wood waste is unavoidable, thus this evaluation is expected to aid in the introduction of creative management and effective exploitation of wood waste from wood-based sectors. The management and utilization of wood waste in developing countries are poorly developing and regarded as waste. However, the management provides challenges to eliminate, reduce or manage waste effectively. This review provides an overview of different strategies that can be adopted to coverts waste for economic and environmental benefits. In Nepal, future studies should be directed toward developing good scientific research capacities in the timber sector. These enhanced capabilities will increase data quality, allow for better scenario integration, and ultimately provide more insight into the timber sector's potential for reducing wood waste. Thus, our research should focus on addressing the multidimensional economic and social benefits of wood waste.

4 Prospects and recommendations

Timber waste utilization should quantify spatial (space) and temporal (time) dynamics of the waste as this would ascertain sustainability of future supply, cost of transportation, optimal location and sizing of energy conversion facilities [54, 55]. A study conducted by Borzecki et al. [56] in European countries showed wood waste is not uniformly distributed due to proper law and regulation in different countries making a significant impact on the development of the bio-economy sector in all the associated countries. Similarly, seasonal variation of wood waste hampers the supply with an increase in cost and its optimal uses. The reluctance to invest in and support waste utilization might not be due to a lack of resources only, but also a lack of understanding of the potential gains of valorising the waste and the impacts of not doing so [57]. Developing nations are passive in the utilization of urban and industrial waste as they do not have spatial and qualitative statistics on wood waste.

- In recent decades, there is ever-increasing market demands and production of natural fibre-based composites. Therefore, we can initiate research on extracting green values (clothing, paper, packaging etc.) at affordable biomass resources.
- The government, policymakers, NGOs, the private sector and stakeholders in environmental management should openly support existing and planned efforts to valorize waste. Nepal's government has initiated using briquette but not been widely disseminated due to inadequate support.
- The waste can be utilized with fast pyrolysis into bio-oils which can be converted into fuels or speciality chemicals.
- In Nepal, there is no well-organized data on wood waste management and its utilization therefore, the government should make comprehensive information and database of wood waste which help policymakers to plan and formulate wood waste management policy.
- Modern techniques and experience from developing countries should be learned in utilizing wood waste consequently educating forest industry workers and staff through research workshops and seminars.
- Education and research on the utilization of engineered wood should be made among the people to make the demand for the products.

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Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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