Prospective Utilization of Wood Waste From Wood-based Industries in Ethiopia: Synthesis

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Abstract
Wood waste has the potential to be utilized for the production of various products like engineered wood products, for energy generation in the form of heat, electricity, and for mulching and animal bedding. Apart from international experience, wood waste utilization in Ethiopia is not being practiced except for firewood and engineered wood products in some cases. This review stated that the problem of wood waste management and utilization in Ethiopia is arising from the absence of relevant rules and regulations and a lack of institutions that are concerned about wood waste benefits. Institutional issues are related to the formulation of policy that encourages waste management, and involvement of investors in waste utilization, while the technical issues are concerned with the adoption of advanced technologies, the arrangement of relevant training for the workers, and the implementation of proper wood waste management. The result of the review concludes that government should formulate effective waste management policies to maximize the value of wood waste resources, because poor management and utilization of wood waste will lead to huge profit loss and, moreover, environmental pollution. Related policies should be introduced to support experience sharing and technology promotion, which will contribute to the efficient and effective utilization of wood waste resources to satisfy the growing demand for wood products. In addition to these, the policymakers should give special attention to the utilization of wood waste to adopt advanced techniques and technologies from experienced countries.
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1. Introduction

Wood waste represents the end-of-life products, failed products, shavings, offcuts, and sawdust of all wood and wooden products that generates when wood-based industries use wood as raw material (Taylor and Warnke, 2008). Despite the ever-rising demand in line with the highly increasing population, wood in developing countries like Ethiopia is underutilized or miss-used because of outdated sawmill and unskilled operators (Asamoah *et al.,* 2020). High volume of wood waste is generated by different wood-based industries that must be properly managed, efficiently utilized, marketed, or properly disposed of (Owoyemi *et al.,* 2016). Those wood-based industries include timber logging, sawmilling, manufacturing of wood-based panel products like plywood, fiberboard, particleboard, furniture making, paper making, and other wood industries (Pentti *et al.,* 2002; Owoyemi *et al.,* 2016). These are usually divided into two distinct industrial sectors. The first is the primary wood-products industry, which covers a wide range of operations from lumber production to the manufacture of finished products that are mostly or completely made of wood or composite wood materials (Burton *et al*., 2003). The second is the value-added or secondary forest-products industry, which manufactures products by processing raw materials or semi-processed materials. But, almost all wood industries in one or another way generate wood waste during the production of wood-based furniture elements (Christensen, 2011).

According to Skog and Rosen (1997) and Kiss *et al*. (2016), wood-based industries generate a large volume of wood waste in primary and secondary wood processing factories. For example, plain shavings, sawdust, and wood off-cuts are all wastes generated during wood processing in sawmills. On the other hand, sander dust, wood shavings and wood chips are generated in the furniture and particleboard industries while the plywood industries generate wood waste from bark, peeler cores, veneer wastes, and panel trims (Owoyemi *et al.,* 2016).

Wood waste can be a potential resource for the production of different materials by re-forming or creating new products (Lykidis and Grigoriou, 2008). The intended use of this waste can be categorized in to energy and non-energy applications. The use of wood waste for energy generation include in the form of combustion, cogeneration, pellet and briquette while non-energy uses include the production of composite boards, pulp and paper, land reclamation, animal bedding, and agricultural mulches (Murphy *et al.,* 2007).

Taylor *et al.* (2005) also categorized the wood waste re-utilization options in to direct and indirect reuses. Direct recycling is the manufacturing of new wood products such as finger joint and lamination, Medium Density Fiberboard (MDF) and particle board (chipboard), and wood-plastic composite material while indirect aids include animal bedding, landscape mulch, surfacing products, composting, and cement board.

Apart from international experience, wood waste is not effectively utilized in Ethiopia, mainly because of the low level of skills, knowledge, and backward technologies used for both production and processing activities. Poor coordination of wood waste generating factories and concerned bodies that ultimately utilized it is another limitation issue (Nemerow, 2006). In addition to these, lack of incentives for wood waste utilization, inadequate information on the economic benefit of wood waste utilization, poor enforcement of environmental regulations, absence of policies about wood waste management, lack of technical know-how on wood waste processing are the main problems. On the other hand, research activities in the area of wood science and technology are very limited. This indicated that there is a research gap in wood waste management and utilization practice in Ethiopia. To fill this gap and address the multidimensional economic and social benefits of wood waste, there needs a review of the globally best-experienced country's tendency on wood waste management and utilization practice, then introducing innovative wood waste management and value-added approach is believed to have a significant solution.

Several studies have shown different value-added options for the conversion of wood waste to other valuable products. For example, the research held in Zimbabwe revealed that 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 (Charis *et al.,* 2019). Another study in Japan stated that 15 million cubic meters of wood waste were produced from furniture factories, then over 90% of which was recycled for producing wood-based panels and fuel (Hirmatsu *et al*., 2002).

This review was designed to address the multidimensional utilization of wood waste and fill the gap in general. According to Shahidul *et al*. (2018), some literature revealed that two major ways of utilization of wood wastes. The first one is recycling that helps to produce new wood products for building and manufacturing products, and the second option is to produce energy in line with the concept of waste to energy. But recycling of wood waste is not applied in all wood industries, particularly in small scale enterprises.

This review paper does not encourage recycling as the best option for wood waste from an environmental and economic perspective; it is always preferable to not produce or minimized waste in the first place. Globally best-exemplified countries, North American and Australian timber industries are considered by high recovery rates of at least 52%, thereby reducing the waste produced at source (Charis *et al.,* 2019). However, a degree of wood waste is unavoidable when making furniture, so this review is assumed to help to introduce innovative management and effective utilization of wood waste from wood-based industries. Basically, the management and utilization of wood waste in developed and developing countries are not the same. Furniture factories in developing countries defy best practices in wood waste management and utilization while efforts have been made in developed nations by making engineered wood products, pulp, and paper and energy in the form of combustion, cogeneration pellet, and briquette (Charis *et al*.,2019).

The information is retrieved from various recent publications such as journals, reports, books, conferences, research papers, and workshop reports. To review the potential utilization of wood waste, the following specific issues are treated in separate, on the basis of information found from different sources, in relation to wood waste handling and utilization: general approaches in wood waste management, technologies of manufacturing engineered wood from wood waste, methods of energy generation from wood waste, utilization of wood chips for mulching and animal bedding.

2. Experiences in Wood Waste Management

2.1 International experiences in wood waste management

Wood waste is the remainder part after any operation done in any wood-based industry (Barua *et al.,*2014). It generates from primary and secondary wood processing industries that are normally discarded as useless or unwanted product in former times, but it has many other uses now a day.

Wood waste management can be defined as the discipline associated with the control of generation, storage, collection, transportation, processing, and disposal of wood wastes in a consideration of public health, economic feasibility, conservation, and public response. Wood waste management enables to obtain economic benefit from material that has regarded as waste. It can be achieved through reusing, recycling, conversion, and energy recovery methods (Tadesse, 2004). The majority of wood waste in different wood-based industries will go to landfill or energy (Sommerhuber *et al*., 2015). Appropriate policies and incentives need to be in place to encourage wood waste utilization and prevention from its indiscriminate disposal (Akhator *et al.,* 2017). For example, a number of UK Government policies have a great role in the recovery of wood waste. These include waste management policy, the renewable heat incentive and the renewable transport fuels obligation.

Since wood is among the most recyclable, and reusable materials now a day, there is a growing concern about wood waste recycling and utilizing practice in the world (Barua *et al.,*2014). It has been reported that wood waste reprocessing for the production of new products is an economically viable plan (Carpio *et al.,* 2013). Wood recycling is one of the basic steps towards a circular economy regenerative system that can able to minimize resource depletion and energy consumption (Keskisaari and Kärki, 2018; Castaldo *et al*., 2019). It also guaranteed the sustainability of the forest conservation in the emerging economies (Bergeron, 2014). When wood recycled, it increases the economic, environmental, and social benefits. For example, recycling of wood waste in Nigeria reduced pressure on forest, it also reduced environmental pollution, and it created wealth and employment opportunities (Owoyemi *et al.,* 2016).

Australia has also utilized her potentials in the recycling of furniture waste at a larger scale with yearly revenue about 7.3 million Euros (Bruns, 2017). It was explained that six companies in Australia operate for recycling furniture wastes to produce different high-value-added new products (Daian, 2009). Different kinds of wood wastes like solid wood offcuts, sawdust, engineered wood offcuts, shavings, veneers flakes, wood chips, and fibers can be recycled to manufacture those newly value-added products (Liang *et al.,* 2012). And also by using those wood elements, various building materials and engineered wood products such as plywood, laminated veneer lumber (LVL), glued laminated lumber, particleboard and medium-density fiberboard are manufactured (Davids *et al.,* 2017). This utilization of wood waste in the construction industry would enhance the growth of local economy (Ramage *et al.,* 2017).

2.2 Local experiences in wood waste management

Ethiopia currently has no specific bidding rules and regulations in the management and utilization of wood waste, although the country has clearly defined environmental laws. Wood industries of the country are found at a lower level in all aspects including technology and skilled manpower, which are considered as the major causes for the current generation of the huge amounts of waste by wood industries. Due to these and related factors, wood industries irresponsibly generate and dispose of such materials everywhere in the city. For instance, wood waste can be found on roadsides, in rivers crossing the areas, between residential houses, and many other places of Addis Ababa, which is not different for other big towns, where wood-based enterprises are available.

As institutional issues there is no good policy in the country that tries to improve effective and efficient wood waste management, there is also no functional structure set up at the grassroots level communities and institutions. There is no linkage between the waste generating industries and concerned wood waste utilizer stakeholders. Therefore, the waste from wood industries to-date is not only potentially polluting the environment as told above, but also negatively influences the productivity of the enterprises themselves; as such waste materials normally occupy large areas of spaces that would have been used for other production purposes.

3. Utilization of wood waste materials for other needs

3.1 Producing engineered wood products from wood waste

3.1.1 Global experiences in production of engineered woods

Engineered wood products are man-made products from smaller pieces of wood that are bonded together by using different types of adhesive. Large panel engineered wood products are constructed from smaller trimmed wood deliberated as a waste; in this case, a small piece of wood, low-value species, and wood that has defects can be used in engineered wood products, like a particle and fiber-based boards.

Engineering wood products are more expensive to produce than solid lumber in terms of time, money, and energy, but they have an economical advantage (Macleod, 2011). Wood waste is an excellent feedstock for the production of engineered wood products. Reusing wood waste for the production of engineered wood products and other products has positive impact on climate change. It gives indirect benefits to reduce emissions of carbon dioxide. This is mainly due to the avoidance of additional tree harvesting and continued storage of carbon in the dimensional lumber or engineered wood products that are reused. Now a day more trees are being cut for the production of lumber, resulting in deforestation, climate change, environmental degradation, and extinction of some indigenous tree species. That is the reason why utilizing less desirable species, smaller trees, and lowers quality trees in addition to wood waste for the production of excellent engineered wood products. Examples of engineered wood include oriented strand board, particleboard, Medium Density Fiberboard (MDF), glued-laminated timber, laminated lumber, and others (Williamson, 2002). Small sized different types of wood panels can be produced from wood waste that can be used for many applications; they have great role in construction for siding, sheathing, flooring, stair treads and risers, furniture, and boats.

Structural wood panels are the most widely used engineered wood products. Major types of structural wood panels are oriented strand board (OSB) and plywood. These products are manufactured by laminating various wood-based materials to improve the panel's strength, stiffness, and stability (Stark *et al.,* 2010). Wood-based composites are non-structural. They are not designed to carry loads; instead, they are typically used in interior applications as substitutes for solid wood (Braghiroli and Passarini, 2020). Non-structural engineered wood Products are produced by using wood waste and adhesives. The most significant non-structural engineered wood products are Particleboard and Medium Density Fiberboard (MDF).

Production of Particleboard from wood waste: Particleboard is an engineering wood product that consists of wood particles of various sizes that are bonded together with a synthetic resin or binder under heat and pressure. It is used widely in the manufacture of furniture, cabinets, floor underlayment in home construction, and in many other applications (Williamson, 2002). It is manufactured by collecting wood wastes and mixing wood particles or flakes together with a resin and forming the mixture into a sheet. According to Braghiroli *et al.* (2020), particleboard which is manufactured in USA consists more than 50% of its wood elements from planer shavings, followed by other mill residues, such as sawdust residues and wood chips.

The production process of particle board starts by screening out of oversized or undersized wood wastes followed by particles are dried then the resin is sprayed on the particles. There are several types of resins that are commonly used. Amino-formaldehyde based resins are the best performing when considering cost and ease to apply. Urea Melamine resins are used to offer water resistance with increased melamine offering enhanced resistance. Once the resin has been mixed with the particles, the liquid mixture is made into a sheet. A weighing device notes the weight of flakes, and they are distributed into position by rotating rakes. In graded-density particleboard, the flakes are spread by an air jet that throws finer particles further than coarse ones. Two such jets, reversed, allow the particles to build up from fine to coarse and back to fine. The sheets formed are then cold-compressed to reduce their thickness and make them easier to transport. Later, they have compressed again. This process sets and, hardens the glue. The boards are then cooled, trimmed and sanded. They can then be sold as raw board or surface improved through the addition of a wood veneer or laminate surface.

Production of Medium Density Fiberboard (MDF) from wood waste: Medium Density Fiberboard (MDF) is one of the engineered products manufactured for substituting solid wood for interior applications. It is good product for machining and finishing techniques for superior products, such as stereo cabinets and relieved door fronts, moldings, table and furniture tops having profiled edges. MDF is made in much the same way as particleboard; however, the surface is flatter, smoother, more uniform, and generally denser. MDF is an excellent substitute for solid wood in many interior applications except where the higher stiffness of solid wood is required. Because of its smooth surface and edge finishing qualities, MDF becomes a premier substrate for wood veneer, vinyl films, and heat transfer foils (Stark *et al*., 2010).

The production process of MDF starts from collection of wood chips, flakes, shavings, chipping, and feed through a disc chipper, creating the chip that will become a fiber. Chip pile, chip wash, pre-heating, refiner, wax and resin applied, dryer cyclone, mat-forming, pressing, sanding, grading, cut to size, packed and use as a raw board.

3.1.2 Local experiences in production of engineered woods

Engineered wood products have a history of not exceeding more than 30-40 years in Ethiopia, and the numbers of engineered wood producing companies are few still today. The production of engineered wood products from massive wood is common in Ethiopia, but as the finding of several studies indicated that the utilization of wood wastes for similar production of engineered wood products is not yet put into action. Technologies used are outdated and the types of machinery are operated by unskilled workers who have learned doing by trial and error through many years of practice. Raw materials are also` poor quality that is a result of poor quality products. For instance; the Ethiopian plywood enterprise which is located in Addis Ababa produces relatively low-quality plywood for the local market because of the above limiting factors.

The other chip wood producing company located in Addis Ababa is ECAFCO, which is known for the production of chip wood for different purposes like for selling, partition, and as a base hessian for bed under the mattress. Other engineered wood producing factories are Hawasa and Maichew chip wood producing factories. These factories are a pathfinder for the production of engineered wood products in Ethiopia; they use locally the abundant tree species called *Eucalyptus* for the production of chip wood. Apart from this, the manufacturing of engineered wood products from wood waste in Ethiopia is less known due to related reasons. And also demand for such products is extremely high in the country. Lack of appropriate technologies, skill and knowledge, rules and regulations, lack of awareness for management, and utilization of wood waste, triggered by lack of research-based reliable information has put the country not to make benefits from such materials.

3.2 Energy generation from wood waste

3.2.1 Global experience on energy generation from wood waste

Developed countries have got advanced technologies and skills in the aspect of energy generation from wood wastes. Direct energy supply from wood is minor in the European countries (Aina and Adekunle, 2004). The wood waste from furniture factories to energy conversion method is familiar in line with the concept of waste to energy. Around 10 million tons of waste wood being produced and utilized in the UK each year (Steierer *et al.,* 2007). In recent publications, wood waste is identified as one of the best row material for the production of energy. It was reported that more than a million tons of Canadian waste wood pellets have been exported to the EU for use in the power plants as substituted for fossil fuel (Edo *et al*., 2016). Generating of energy from wood waste in different forms has significant benefits on energy recovery and carbon emission. Wood waste can be used to generate energy in the forms of heat and electricity by combustion in boilers, cogeneration, producing pellets & briquettes (Murphy *et al.,* 2007).

Combustion in boilers: There are different combustion systems available to burn wood wastes. Those are generally classified as traditional and modern combustion plants. Under the traditional method combustion system, there are two types of boilers, namely fire tube and a water tube for steam or hot water production. Fire tube boilers are principally used for the heat requirements of the mechanical wood-based industry (Trozzi *et al.,* 2010).

When we compare traditional combustion systems with standard oil or gas-fired units, larger combustion chamber capacity with a high furnace is necessary because there is a difference between standard oil or gas-fired boilers and those for firing wood waste. The other types of combustions are the modern combustion system. Under this, there are pile burners, suspension and cyclone burners, and fluidized bed combustion system. Pile burners burn the fuel in piles either on a refractory floor or grid. They are divided into two classes, namely: heaped pile burning furnace and thin pile furnaces.

The other type of modern combustion is suspension and cyclone burners. A suspension burner burns fine wood particles which are not more than 6 mm in size and a maximum moisture content of 15 percent for maximum efficiency in suspension, in either special combustion chambers or boiler fireboxes, in a highly stormy environment caused by forced combustion air. In the case of cyclone burners, pulverized wood fuel, of a maximum 3.5 mm size and 12 percent moisture content, is mixed in the first stage of the burner and combusted in an external cyclone burner.

The last modern combustion is fluidized-bed combustors; it consists of inert particles through which air is blown so that the bed behaves as a fluid. Wood waste passes in the space above the bed and burns both in suspension and in the bed. Fluidized beds can handle fuels with moisture contents up to 70 percent, because of the large thermal mass represented by the hot inert bed particles. Apart from the end-use of the heat, particle size plays an important role in influencing the combustion plant.

Cogeneration: Cogeneration is the immediate generation of both electrical power and thermal energy, such as steam. To achieve this, first, we generate high-pressure steam in a hog-fuel boiler, which would then be passed through a turbine generator for power before being used as exhaust steam in drying or process heating. The limited finance available to the small and medium-scale mills tends to be a major determinant in their contemplating cogeneration as an option worthy of consideration, regardless of the possible long term gains.

Production of wood pellets and briquettes from wood waste: Wood pellets are made from compressed or compacted sawdust and they are the most common type of pellet fuel. The use of briquettes or wood pellets will decrease the demand of wood for fuel and in turn reduce the pressure on the forest (Aiyeloja *et al.,* 2013). Wood pellets and briquettes shape and size allow automatic feeding to a burner by auger feeding. Their high density also permits compact storage and rational transport over long distances. They can be conveniently blown from a tanker to a storage bunker or silo on a customer's premises (Pirraglia *et al*., 2010). According to Goetzl (2015), wood pellets are increasingly being utilized at an industrial scale for electric power generation, combined heat and power in industrial and commercial applications.

In the 1990s global wood consumption was not too much because of the efficient recycling of timber and paper. In 1997 fully automatic wood pellet boilers with similar comfort levels as oil and gas boilers became available in Austria. When the price of fossil fuel increases since 2005 the demand for pellet heating has increased in Europe and North America. Since pellet fuel is renewable and clean-burning with optimum price, it is currently needed throughout the world. The global production of wood pellets has shown exponential growth from 2 million tons of wood pellets in 2001 to 4 million tons in 2006, to 9 million in 2008, to 16 million in 2010, and 20 million tons in 2013 (Bais *et al.,*2015). Many investors are interested in the investment of wood pellet production because of global demand. The largest producers are the US, Canada, Europe, and Australia.

Wood waste pelletization process contains raw material pre-treatment, pelletization and post-treatment. Under this process it includes drying, grinding, and extruding wood fiber with high pressure and temperature. The natural lignin in the wood fiber helps to bind wood particles together and form solid biomass when exposed to high temperature and pressure. The raw materials are sawdust, wood chips, wood shavings, and other residues from furniture manufacturing industries. Even though sawdust doesn't have much application due to its low burning efficiency it is the best raw material for the production of solid fuel like briquettes and pellets (Kiss *et al.,* 2016).

Briquettes are compressed materials that can be produced from wood wastes such as sawdust in the densification process. This process is the physical conversion of loose raw materials or wood wastes into high-density materials which helps to increases the calorific value and combustion efficiency of the product (Sharma *et al*., 2015). Briquettes can be used for domestic cooking, large scale cooking, and in industries for production purpose. Studies indicated that wood waste briquette has been used in many developed countries and has shown the potential to alleviate energy-related problems (Asresu, 2017). The use of wood waste in the form of pellets generates more energy and it is cost-effective than the direct utilization of non-modified wood wastes (Braghiroli and Passarini, 2020).

Charis *et al.* (2019) stated that between 2013 and 2017 there has been the production of modified 'smokeless' briquettes by using new densification techniques in Zimbabwe. According to (Kazimierski *et al.,* 2020), furniture waste is a favorable material for smokeless fuel production through the densification process. The densification process reduces the moisture content of the wood waste, increases the bulk density, increases the calorific value of the fuel, and as well as improving the handling and transporting characteristics (Rominiyi *et al.,* 2017).

Burning a wood briquette is more efficient than burning firewood. Correspondingly, burning of wood waste biomass in the form of pellet is more cost-effective than the direct use of non-modified wood wastes for energy generation. This is because of their higher density, higher calorific value, as well as their suitable size and shape for handling and transportation (Obernberger and Thek, 2010). Moisture content of a briquette can be as low as 4%, whereas green firewood may be as high as 65% (Kiss *et al.,* 2016).

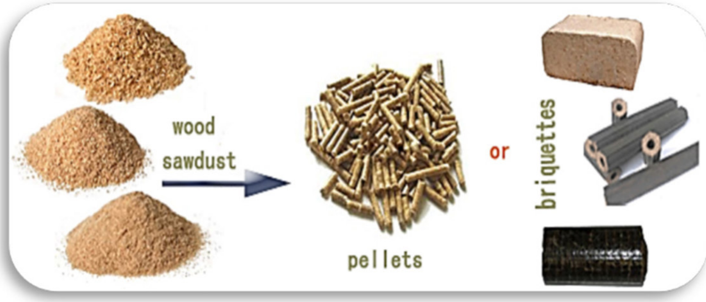

Figure 1. Process of Converting Wood Wastes into Briquettes or Pellets (Kiss *et al.,* 2016)

3.2.2 Local experience in energy generation from wood waste

Ethiopia's energy consumption is mainly based on traditional biomass such as agricultural residues, firewood, dung and charcoal. The growing demand for the traditional use of biomass energy and lack of access to modern energy services is expected to impose pressure on the limited biomass and forest stock of the country. Hence there is a need for the adoption of alternative modern biomass conversion technologies from wood waste to briquettes and pellets that can have an efficient and eco-friendly energy supply. Briquettes produced from wood wastes have the potential to alleviate cooking energy deficiency and yielded environmental and socio-economic benefits in developing countries (Grover and Mishra, 1996).

Ethiopia introduced the first briquette production technology in the 1980s. This briquette production factory was a low-pressure piston machine. The raw materials were primarily sawn dust (60%) and the rest 40% were coffee husk and cotton-seed husk (Asresu, 2017).

Woody biomass supplies from forest account for the highest proportion of biomass in Ethiopia. As a result total national consumption of wood, including charcoal, is estimated to be 105.2 million tons per year with 5.7 million tons of charcoal which cover more than 95% of biomass consumption in the country (Geissler *et al*., 2013). This biomass is used for traditional burning with very low energy efficiency and the majority of the energy is lost during conversion.

As far as it's well known the Ethiopian plywood factory which is found in Addis Ababa was generated energy in the form of steam in the boiler by using a combustion boiler which enabled them to dry the veneer they produce. Adopting developed countries' experiences will enable factories to generate energy for their own consumption and for the local community.

3.3 Wood chips for mulch

3.3.1 International experience

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 decompose slowly, because their tissues are rich in lignin, tannins, and other complex natural compounds. Thus, wood chips supply nutrients and absorb significant amounts of water slowly (Chalker, 2015).

Some companies have introduced colorful mulches to add value to the product. In the developed countries landscape mulches are increasingly recognized so as to environmentally sustainable gardens and green spaces. Solid wood off-cuts are required to produce mulches and surfacing products. The chipping process will seek to produce relatively long fibrous chips which are more Pliable than the chips typically produced by machines such as wood combustion huggers. Sawdust is a useful factor in agricultural industry in making fertilizer called sawdust compost as well as food in chicken brooders (Rominiyi *et al*.,2017).

3.3.2 Local experiences

Using wood chips and shavings for mulching is not common in Ethiopia, even though it has many advantages. Since the technology of using wood mulch is simple it is something we have to adopt from the developed and well experienced countries.

3.4 Wood chips for animal bedding

3.4.1 International experience

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 (Ahn *et al.,* 2020). Selective wood wastes, like wood chips, shavings and sawdust are best bedding materials.

Wood chips are generally a mixture of bark, sawdust, and post peelings (Munir *et al.,* 2019). Wood chips for animal bedding are easy to handle, cost-effective, and very absorbent. They provide clean and dust free environment while wood shavings offer warm, clean and healthy environment to the animals (Panivivat *et al.,* 2004). Sawdust is basically a waste of small particles available in saw-milling industries, pulp and paper industries as well as in wood processing industries (Rominiyi *et al*., 2017).

From an environmental and economic point of view, the benefits of using wood waste as bedding do not have to end after its first utilization. Sawdust bedding combined with cattle dung can be used for compositing. The compost has been re-used as bedding and as a growing medium for tree seedlings. The compost is dry, clean, and free from weeds and pathogens because of its high composting temperature and it is used as a soil improver.

3.4.2 Local experience

Wood waste for animal bedding has multipurpose. It gives comfort for animals in their enclosure and during transportation, and the wastes from bedding are used as a fertilizer for mulching, for decorating the house with plants, and for the waste-producing industries for income generation. Having this kind of benefit the utilization of wood waste for animal bedding and mulching in Ethiopia is not well adopted due to lack of awareness. But, starting from recent time, merchants of animal uses those wastes for animal bedding during transportation of animals from a remote area to the market center and to the port for export purpose.

4. Conclusion and Recommendations

4.1 Conclusion

This review presents the research outcomes published in various scientific journals on wood waste management and potential utilization practice. It concludes that wood waste can be a potential resource for the production of different materials like for the production of engineered wood products, for energy generation, for mulching and animal bedding, etc. It is known that developed countries have very advanced technologies in aspects of wood processing and utilization experiences. They have rules and regulations for the management and utilization of wood waste that helped to make considerable economic and social benefits. The collaboration of strong experience, technology, skilled manpower, and policy enables those countries to do more in an aspect of wood waste management and utilization.

Ethiopia has clearly defined environmental policy but no specific rules and regulations to manage and utilized wood waste. As a result, in many Ethiopian wood-based industries wood waste is highly generated and occupying free space. The root cause of generating this high volume of wood waste is mainly because of using backward technology, unskilled manpower, low-quality input, and poor management approaches. Generally, there is no organized mechanism of wood waste management and utilization action taken because of the absence of relevant rules and regulations and a lack of institutions that are concerned with wood waste management and utilization practices. This indicated that there is a research gap in wood waste management and utilization practice. To fill the gap and address the multidimensional economic and social benefits of wood waste, take a lesson from globally best-experienced countries is the key. Then introducing innovative wood waste management and value-added approach is believed to have significant solution for proper management and potential utilization of wood waste resource.

4.2 Recommendations

At present, well-organized data about Ethiopian wood waste management and utilization trend is not available. There must be comprehensive and timely statistical information in a database because this will enable policymakers to plan and formulate wood waste management policy. This policy will help people to use the existing forest resource efficiently and effectively in addition to utilizing wood waste.

Ethiopia should have to attempt utilizing waste that is produced from wood processing industries by adopting advanced techniques and technologies from developed and well-experienced countries, so as to attain the benefits and to satisfy the demand of the local community’s wood consumption.

In order to ensure the efficient use of wood wastes from furniture factories in Ethiopia, sawmilling industries would have to educate their staff and operators through research, workshops and seminars about recycling, management, and proper utilization of wood wastes. They should form a partnership that would facilitate the transportation, storage, and marketing of wood wastes. They could also consider value-added manufacturing processes of solid wood wastes such as finger joints, crafts, toys, and garden fencing.

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