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Sawmill Waste Management Practices in Ghana: Options for Sustainable Timber Resource Management and Utilization in the Bono Region

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Abstract
The wood industry generates substantial waste throughout the production chain; yet, much of it remains underutilized and poorly managed. This study evaluated sawmill waste management in five timber-processing districts located within the Bono region of Ghana, with the objective of documenting strategies and evaluating recycling levels that facilitate sustainable timber management. Data were gathered by semi-structured questionnaires and field observations, employing a descriptive cross-sectional approach. Fifty-one (51) respondents were purposively selected from 47 registered and 23 unregistered sawmills. From the study, the collection of wood waste is mostly manual, using wheelbarrows, tractors, or jute bags, while management practices include burning, open dumping, sales, giveaways, and recycling. Wastes generated from production were reused for mulching, biomass energy production, crafts, mushroom cultivation, medicinal, and soil improvement purposes. Just-in-time processing, segregation, and training are the strategies for reducing waste. Although some circular use exists, large quantities, especially sawdust, remain unused because of limited funding support, low awareness, technical challenges, and infrastructure gaps. The study recommends public-private collaboration, involving the Forestry Commission of Ghana and the Environmental Protection Agency, to regulate recycling policies. Further research is essential for optimizing sawmill recovery and ensuring the sustainability of timber resources.

Keywords
management, recycling and reusing, sawdust, sawmills, waste utilization, wood waste

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Contents

1. Introduction

Creating jobs and revenue worldwide (Akhator et al., 2017; Awusi & Ansah, 2021; Mydlarz & Wieruszewski, 2022; Imbrenda et al., 2023; Gc et al., 2024), the wood processing industry employs over 45 million people and generates over USD 580 billion in revenue annually, contributing to the global GDP (FAO, 2018; Li et al., 2019). Notwithstanding the advantages they provide, their activities and procedures pose difficulties with important social, economic, and environmental consequences, causing deforestation, unsustainable forest tree use, and forest degradation (Ogbu et al., 2022; Saal et al., 2022). Additionally, the wood industry accounts for approximately 60% of degraded forest and forest loss in Asia, Africa, and Latin America (Hosonuma et al., 2012) due to the increasing demand for wood products (FAO and UNEP, 2020), with an estimated annual forest loss of around 13 million hectares. The wood industry further generates large volumes of waste, 40% of processed wood at various stages of its operations (Owoyemi et al., 2016; Mydlarz & Wieruszewski, 2022; Saal et al., 2022). Efficient wood waste management has thus become a major concern

at the global, regional, and local levels (Nwankwo et al., 2023), especially processing operations with lumber yield of about 28-64% (Kolapo & Nafiu, 2020; Charis et al., 2019; Asamoah et al., 2020). This has made way for circular economy principles in advanced countries, which prioritize waste recycling and reusing (Adhikari and Ozarska, 2018), as well as employing advanced technologies to minimize waste generated, repurpose waste, and create value-added products, such as composite materials and energy resources (FAO, 2020). Although the management of wood waste globally focuses on recycling into other viable sources, as demonstrated by developed countries, many African nations, including Ghana, face serious environmental issues due to poor waste management practices at manufacturing centers (Agwu, 2012; Awusi & Ansah, 2021). They are unable to repurpose this waste, which causes environmental degradation and economic loss (MDPI, 2020). These developing countries fall far below the standards for best practices in utilizing harvested wood (Butarbutar et al., 2016; Pandey, 2022). Over 50% of the wood waste generated in Ghana is hardly reused, mainly because the adoption of sustainable and effective waste management practices is often hindered by a lack of well-equipped infrastructure, financial constraints, and weak policy enforcement. Most sawmills still rely on traditional methods such as burning and disposal to handle wood waste, leading to inefficiencies and significant loss of raw material (Ogunwusi, 2012; Adu et al., 2014; Effah et al., 2015).

However, Asamoah et al. (2020) and Shibu et al. (2023) attested that despite the challenges in waste management in the wood industry, there are opportunities for effective wood waste management through the recycling and reusing of wood waste to mitigate environmental impacts while creating economic value and sustainable development. In Ghana, particularly the Bono Region, wood waste, representing both a challenge and an opportunity, is generated in significant volume along the value chain. Studies have been conducted to investigate wood waste generation, management practices, and possible uses of wood waste in various countries and Ghana (Asamoah et. al., 2020; Xinhua, 2021; Takase et al., 2023). However, insufficient attention has been paid to evaluating the existing uses and management practices and their optimization as a potential for sustainable resource management. To help bridge this gap, the study specifically (1) documented the practices employed by the sawmills to manage waste, (2) examined the current practices and strategies in sawmills to minimize wood waste generation and increase reuse and recycling, and (3) evaluated the extent to which wood waste is recycled or reused within the sawmills. The objectives were meant to help answer the following question: (i) How effective are wood waste management practices employed by sawmills in minimizing the generation of wood waste? (ii) What is the extent to which wood waste is recycled or reused within the sawmill? (iii) What waste management practices are employed by the small- and large-scale sawmills? This study provides important data, which could help to attain SDGs (7, 11, 12,13,15) if employed in the formulation of waste management strategies in the wood industry.

2. Materials and Methods

2.1 Study area description

Ghana, a resource-rich country with a robust forestry sector, a total land area of 238,533 km2, 16 administrative regions, a tropical climate, and diverse ecosystems, is home to a wide variety of tree species and has timber production as a key economic activity. Bordered by Côte d'Ivoire, Burkina Faso, Togo, and the Gulf of Guinea to the west, north, east, and south, respectively, Ghana is geographically divided into several ecological zones, with distinct vegetation and climatic conditions. The High Forest Zone (HFZ), comprising Wet Evergreen Forests, Moist Evergreen Forests, Moist Semi-Deciduous Forests, and Dry Semi-Deciduous Forests, and located in southern Ghana, covers about 8.2 million hectares (34% of the land area). The Savannah Zone (SZ): Occupying approximately 15.7 million hectares (66% of the land area) in northern Ghana, comprising Guinea Savannah, Sudan Savannah, Coastal Savannah, and the Forest-Savannah Transitional Zone, serving as a buffer between the HFZ and SZ, characterized by a mix of forest and savannah vegetation. Ghana's forest covers approximately 7.29 to 9.17 million hectares, accounting for 31% to 40% of the country's total land area. Acheampong et al. (2019) estimated that the average deforestation rate within the country's protected areas exceeds 32.2%. The current study was conducted in the Bono region, part of which lies in the Forest-Savannah Transitional Zone, supporting the large number of timber tree species in the moist-semi-deciduous forest vegetation. The region serves as a repository for wood and timber-related industries, including furniture manufacturing, wood processing, sawmills, and other sectors of over 60 formal and informal large and small to medium wood industries.

2.2 Sampling procedure and sample size

A descriptive cross-sectional research approach was used to investigate the methods used for managing wood waste at processing facilities (sawmills), including how waste is produced, processed, and disposed of. This method offered an in-depth understanding of contemporary data collection procedures. A purposive sample of 51 respondents was drawn from 47 sawmills registered with the Forestry Commission and 23 sawmills that were not, spread among five active timber processing districts in the Bono Region. Accessibility, active production, and willingness to participate were the criteria used for selection. One

respondent from each sawmill, being a production supervisor, machine operator, or finishing-line staff member with firsthand knowledge of waste handling processes, was engaged in consultation with management. Data collection was carried out in situ using a semi-structured questionnaire, supplemented by non-participant observation. The data collection process was done cross-sectionally. The questionnaire included both closed- and open-ended items, covering waste types, disposal methods, reuse, and facility-level management. Observations, guided by a checklist, were used to verify responses. All data were collected cross-sectionally. Quantitative data from the questionnaire were coded in Excel and analyzed using SPSS version 27.0, with results presented as frequencies and percentages. Data were also exported to Excel to create visual summaries through tables and charts. Qualitative data from observation notes were analyzed thematically following Braun and Clarke's (2006) six-phase framework. This helped identify recurring patterns in collection methods, reuse, disposal, and recycling practices. Overall, this design provided a comprehensive representation of wood waste management conditions across sampled sawmills, offering critical insights into current practices, challenges, and areas for improvement.

Table 1. Distribution of studied sawmills across selected districts

District	Number of sawmills
Sunyani Municipality	19
Sunyani West District	11
Dormaa Central Municipality	7
Berekum Municipality	14

3. Results

The findings in this section are based on respondents' opinions on the attributes of wood waste management modules within their respective sawmills and were validated through direct on-site observations conducted during data collection.

3.1 Wood waste management practices

Wood waste management practices employed by the sawmills included burning, disposal/sales/giveaway, and recycling/reuse. All 51 respondents reported that their respective sawmills disposed of, gave away at no charge, or sold their wastes, while 72.6% and 84.3% revealed reusing/recycling and burning of generated wood waste as handling modules among sawmills, respectively, as illustrated in Figure 1.

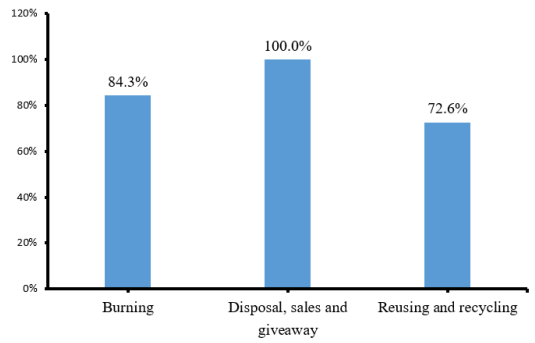

Figure 1. Wood waste management practices

3.2 Sales/giveaway and disposal outlets

Respondents were asked to list the typical wood waste disposal techniques used by the sawmills where they are employed. Four sources were found: open pits, open dumping, households, and farmers. Just 19.6% of respondents said they disposed of their waste in open pits; 100%, 94.1%, and 78.4% said they sold and/or gave their waste to families, dumped it in the open near their production plant, and sold and/or gave it to farmers, respectively.

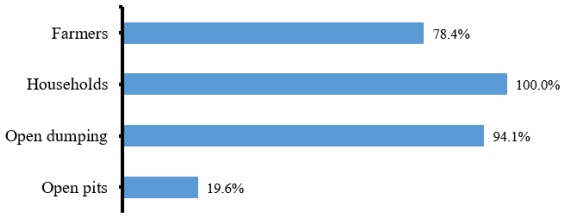

Figure 2. Wood waste disposal and sales and giveaway outlets

3.3 Wood waste collection modules

According to respondents, sawmills use the techniques shown in Fig. 3 to collect trash created during the wood processing process. Tractors and trucks were reported to be utilized by 9.8% and 19.6% of the sawmills, respectively, while air extractors were employed by only 3.9% of them. Wheelbarrows and manual clearance were frequently used in sawmill waste collection facilities. According to 91.3% of respondents, waste was usually bagged into sacks for collection, according to the survey.

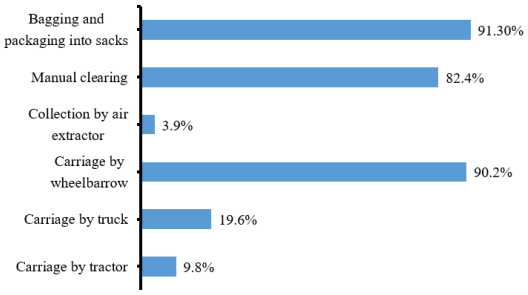

Figure 3. Wood waste collection outlets

3.4 Wood waste minimization methods and practices

Just-in-time processing, waste segregation and sorting, recycling, and reuse were the most popular methods used by 88.3%, 78.4%, and 72.6% of the sawmills, respectively, to reduce waste creation. Based on the semi-structured questionnaire responses, as shown in Fig. 4, sawmills engaged in energy recovery, environmental monitoring, employee training and engagement, and technology use in 9.8%, 9.8%, 21.6, and 39.2% of cases, respectively.

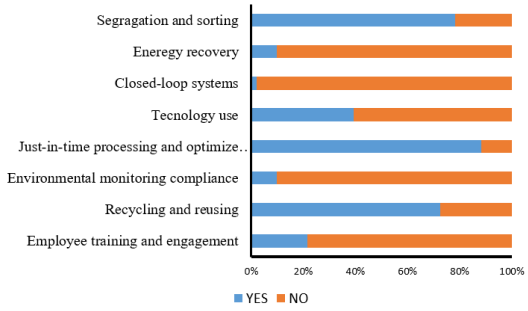

Figure 4. Wood waste minimization practices

3.5 Type of wood waste

According to the respondents' reports presented in Figure 5, sawdust is the most prevalent kind of wood waste produced in all sawmills (100%). Additionally, 96.1% of sawmills produced shavings, while 90.2% and 68.6% produced edgings and slabs, respectively. Of the sawmills, 80.4% used offcut, while 49.09% used bark waste. At just 15.7% and 13.7%, respectively, trimmings and chips were the least prevalent forms of wood waste produced at sawmills.

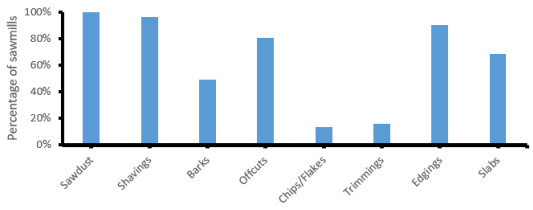

Figure 5. Types of generated wood waste

3.6 Waste recycling and reuse options

As shown in Table 3, according to 88.2% of respondents, bark is mostly utilized in mulching and gardening to control weeds. Furthermore, 49.0% of respondents mentioned utilizing it as biomass to produce energy, 29.4% said using it for decorative purposes in gardens, and 2.0% mentioned using bark for medicinal purposes. Edgings, offcuts, and slabs are most frequently used for small woodworking projects (90.4%), and 6.8% of sawmills reported using bark to make mulch. All sawmills (100%) claimed that sawdust plays an important part in the production of mushrooms and cattle bedding material. Additionally, 5.9% mentioned using sawdust as biomass fuel for heating systems, and 7.0% mentioned adding burned sawdust to soil for gardening.

Table 2. Description of waste minimization strategy adopted within sawmills

Practice/strategy	Description
Segregation and Sorting	Wood residues were systematically separated by a number of facilities, which regularly separated shavings, offcuts, slabs, fine sawdust, and other wood waste according to size and type. This technique was usually conducted utilizing guided workflows or simple manual procedures at or close to the point of generation. Such segregation enabled more effective reuse, reduced contamination between waste streams, and allowed specific waste categories to be channeled toward targeted recovery or disposal channels.
Energy Recovery	Some sawmills used wood waste as a biomass fuel source for their internal thermal systems. Boiler units used mostly for kiln drying were fed sawdust, wood chips, and smaller offcuts. In addition to reducing the amount of disposable waste, this energy recovery procedure also reduces reliance on outside energy sources. Especially in medium- to large-scale enterprises, the incorporation of energy conversion devices showed a circular approach to resource utilization.
Technology Use	More industrialized sawmills were found to have technologies designed to increase process efficiency and waste management. These comprised moisture-controlled drying equipment, automated sorting conveyors, and dust extraction devices. In order to guarantee waste recovery and efficiency, air extractors and an efficient management module were especially successful in lowering airborne particle waste.
Recycling and Reuse	Several facilities are actively engaged in the on-site reuse of wood wastes. Small off-cuts and shavings were treated and used again to make finger-jointed boards and plywood, two examples of composite wood products. These reuse techniques showed alignment with sustainable production principles and decreased the requirement for virgin timber inputs. The value-added potential of materials that are often wasted was reinforced by certain facilities' specific stations for repurposing or reshaping usable waste into secondary components.
Employee Training and Engagement	Sawmills, particularly in large-scale operations, conducted periodic internal briefings or training sessions focused on best practices for sorting, material handling, and residue management as these efforts contributed to uniformity in procedures, reduced cross-contamination between waste streams, and improved compliance with internal waste protocols.
Environmental Monitoring and Compliance	Monitoring systems were used at establishments with official environmental policies, particularly those governed by the Forest Stewardship Council, to evaluate particulate emissions, air quality, and the efficiency of waste containment practices. Internal audit procedures, designated waste zones, and stationary air quality sensors were among the methods that were seen. These procedures promoted adherence to national environmental standards and enhanced organizational responsibility for the responsible management of wood waste.

Table 3. Utilization potentials of sawmill-generated wood waste

Type of wood waste	Uses	Frequency	Percentage of sawmills (%)
Bark	Biomass for energy production	25	49
	Decorative purpose in gardens	15	29.4
	Mulching and gardening to suppress weeds	45	88.2
	Medicinal purpose	1	2
Edgings, offcuts and slabs	Mulching production	3	6.8
	Small wood workings	46	90.4
	Livestock's bedding material and mushroom production	51	100
Sawdust/shavings	Biomass fuel for heating systems	3	5.9
	Burnt and incorporated into soil for gardening	4	7

3.7 Challenges of Effective Waste Management

The major challenges faced by sawmills in the wood waste management chain, as shown in Figure 9, are a lack of finance, which affects all sawmills (100%) the most. High processing costs, technological obstacles, infrastructure and logistical challenges, and a lack of knowledge and education were cited at 97.07%, 94%, 84.63%, 68%, and 58.69%, respectively. As seen in Figure 9, just 17.37% of respondents identified market demand and economic feasibility as a barrier or difficulty.

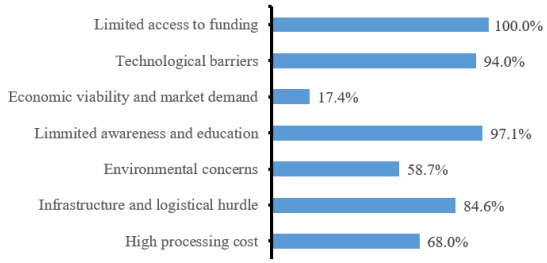

Figure 6. Challenges hindering effective wood waste management

4. Discussion

The wood waste value chain includes generating, collecting, reusing/recycling, and disposing of. Sawmill operations inevitably generate waste at various levels. However, actions to minimize or manage the amount of waste generated vary for different sawmills and are very important for sustainable resource management in the timber industry. Subsequent to current climatic and environmental issues, new economical and sustainable waste management approach have emerged globally (Aiguobarueghian et al., 2024), with effective strategies being adopted to manage wood waste, especially in, countries having circular economy principles, which promote resource efficiency and waste minimization, repurposing waste, and creating value-added products and energy resources (Adhikari and Ozarska, 2018; FAO, 2020; MDPI, 2020). Wood waste management challenges, however, differ across regions, especially in Africa, where it is influenced by various factors. Although sawmills in Southwestern Ghana employ some waste management practices, including disposal/giveaway/sales, burning, recycling/reuse, some of these practices are considered inefficient and limited due to the ineffectiveness, incoordination, and their unsustainable nature. However, some of them reflect a circular approach to resource use and can serve as a guide to efficient management if largely considered and understood in light of the local applications.

Giving away or sales of waste was predominant and engaged by all sawmills, but done informally, is uncoordinated and lacks structured policies and incentives

specifically for sawmill wood waste management. This limits the sawmill's capacity to reduce waste accumulation and hinders the sawmill from economically benefiting. This finding aligns with Larine et al. (2018), who reported that in Nigeria, between 45% and 58% of the wood waste consumers reportedly acquired wood leftovers from sawmills for free for purposes such as animal bedding and fuel. Thus, for efficient use of wood waste within this region, both the wood industry and other industries whose operations necessitate the use of wood waste require cooperation that results in economic gains for both partners. The study further revealed that sawdust is the most cited wood waste type due to its production at all levels of sawmill operations, similar to findings by Nnaji & Udokpoh (2022). Shavings, edgings, slabs, and offcuts were also dominant, with bark, trimmings, and chips as the marginally named. A similar waste type pattern was observed by Calva et al. (2018) and Udokpoh (2020). Different uses were reported for the various types of wastes identified; sawdust generated was reported to have a significant role in livestock bedding material and mushroom production, and minorly as biomass fuel for heating systems or burned for soil enhancement. Edgings, offcuts, and slabs were used predominantly for small wood works, and barely for mulch production, while bark was also primarily used in gardening to suppress weeds, moderately as biomass for energy production and decorative purposes in gardens, and scarcely used for medicinal purposes. These uses promote circular use of biomass and thus help to conserve forest resources, as well as promote organic farming and reduce synthetic fertilizer dependency, and enhance animal welfare.

However, observations, as well as responses, showed that substantial amounts of these wastes, especially sawdust, are still left in the sawmill yards, discarded openly or burned, serving as environmental pollutants. Similar findings were reported by Ogunbode et al. (2013), who noted that in southwestern Nigeria, approximately 96% of sawdust is incinerated. As a large amount of wood waste accumulates in production sites as production continues, external consumers, including farmers, are identified as disposal outlets. Consequently, reuse and recycling activities engaged by the sawmills and external consumers, who buy or receive freely, are limited, but can be largely engaged to reduce the accumulation and detrimental effects of the waste. For instance, wood waste in energy production for heating and kilning systems as a fuel source to produce energy for necessary operations like wood drying and others, and also to produce energy to power the sawmills and communities, should be promoted actively. Owebor et al. (2023), in a study, estimated that in Nigeria, sawdust could support the power generation capacity of up to 42.56 MW annually and supply clean energy to sawmills and their surrounding communities. Akintande et al. (2020), Takase et al. (2023), and Tereshina et al. (2024) also established that wood waste could be effectively converted into biomass energy to reduce dependency on fossil fuels. Even though the current study did not estimate the volumes of sawdust in the yards, their amount cannot be overlooked, pointing to a huge resource base. Burning of wood waste engaged by sawmills, known to be unfriendly to the environment and human health (Nnaji, 2022; Nwankwo et al., 2023), could be managed and done under controlled conditions to serve as a sustainable recycling tool to use wood waste for biochar production for other useful purposes. The use of sawdust as an alternative source of fuel, either directly or compacted into briquettes or other based products, will reduce reliance on charcoal and firewood and is a better alternative to the use of fossil fuel and has GHG emission reduction of compared to the fossil fuel (Haus et al., 2020; Morales-Máximo et al., 2022). Similarly, wood waste that is discarded in open spaces, pits, and surrounding areas by sawmills could be converted into compost for agricultural purposes, or used for afforestation and reforestation projects by engaging intentional and simple methods at the local and communal levels as done in countries like Nigeria, who engage cooperatives to reduce pollution and health problems arising from wood waste by converting them into economically useful products such as briquettes through simple technologies fabricated and built by the local workforce (UN Climate Action Awards, 2023).

Manual waste collection methods recorded in this study, such as carriage by wheelbarrow and bagging into sacks, consequently suggest the promotion of waste collection and processing methods that do not require sophisticated and advanced technologies, as well as high processing cost, to effectively manage waste, which will contribute to efficient waste management. This can be achieved with adequate awareness creation, education, training, and collaborations between the industries, local communities, and regulatory bodies (Kusumaningrum et al., 2023). Benefits of such an initiative would include effective waste management, rural economic development by job creation in collecting, processing, and maintenance of production equipment (Pomberger et al., 2021; Mokhtar et al., 2022) by recycling centers and community engagement (Lata et al., 2024). Despite the inefficiencies in waste management practices, the sawmills studied employed various ways to minimize wood waste generation and increase the reuse and recycling of waste in the wood processing chain. Among the practices, just-in-time processing, optimizing cutting patterns of logs, segregation and sorting of waste, as well as reusing materials for other products, were recorded. According to Acevedo et al. (2015), Balewa et al. (2024), and Saputra et al. (2024), segregation, just-in-time processing, and optimized cutting patterns, as well as reuse and recycling, alongside staff training and education, are not only necessary but also important and effective techniques

for waste minimization. Thus, findings from the study suggest a level inclination of some sawmills for resource efficiency and maximization, however, challenges such as limited funding, limited awareness and education, technological barriers, infrastructural and logistical hurdles, as well as high processing were dominantly stated as constraining their efforts, similar to findings by (Awoyemi et al., 2021). On the other hand, economic viability and market demand were hardly indicated as limitations in the management of wood waste, suggesting a clear economic potential and market demand for wood waste products. However, none of the sawmills, small-medium or large-scale, held a certification specifically for wood waste management, pointing to a clear deficiency in waste management policies, programs, and standards that guide its effectiveness to enhance sustainable resource use. In view of this, Awogbemi et al. (2022) recounted that effective waste management, specifically zero waste management, is achievable but requires necessary legislation, policies, and programs that are dutifully enacted and implemented. Similarly, Zaman and Lehman (2011a), Zaman Lehmann (2011b) and Zaman (2014) established the willingness of governments to invest in training, sensitization, education, and research into innovative ways in waste management as a non-negotiable necessity.

5. Conclusion

Wood waste management practices, employed by sawmills in Southwestern Ghana, include burning, disposal (open pits and dumping openly), sales/giveaway to farmers and households, and recycling/reuse. Collection methods are mainly by manual clearing, carriage by wheelbarrow and bagging into sacks, while air extractors, carriage by tractor and truck are done by a few sawmills. The sawmills also employ strategies such as just-in-time processing, segregation and sorting of waste, as well as recycling and reuse of waste, with a few sawmills adding energy recovery, environmental monitoring, employee training and engagement, as well as technology use to minimize waste generation. Different types of waste from the sawmills are used in various applications; bark is primarily used in mulching and gardening to suppress weeds, as biomass for energy production, decorative purposes in gardens, and for medicinal purposes. Edgings, offcuts, and slabs, for small wood works, mulch production, Sawdust for livestock bedding material and mushroom production, biomass fuel for heating systems, and soil amendment. However, substantial amounts of these wastes, especially sawdust, are still left in the sawmill yards due to limited funding, awareness and education, technological barriers, infrastructural and logistical hurdles, as well as high processing cost. On the other hand, economic viability and market demand were hardly indicated as limitations in the management of wood waste, suggesting a clear economic potential and market demand for wood waste products.

Even though not very efficient due to the ineffectiveness, incoordination, and their unsustainable nature, the waste management practices adopted by the sawmills reflect and promote circular use of biomass to help conserve forest resources, and serve as a potential guide to efficient management if largely considered and understood in light of the local applications and context. Additionally, not even one of the sawmills visited had any certification or standards to ensure effective wood waste management. Therefore, legislation, policies, and programs, as well as training, education, and innovative research, need to be diligently enacted and implemented by all levels of government for effective and sustainable wood management in Ghana. The study thus recommends that the government, through the Forestry Commission and the Environmental Protection Agency, partner with private entities to collaboratively educate and invest, implement, and enforce policies on sawmill wood waste recycling and reusing outlets to ensure sustainable and effective waste management that optimizes ecological, sociological, and economic potential from waste utilization. Additionally, the study recommends further research on the recovery factor of sawmill wood processing to determine the amount of utilizable and waste products from the production.

6. Acknowledgement

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