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ScienceDirect

Procedia Manufacturing 35 (2019) 419–429

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Materials Processing and Manufacturing (SMPM 2019)

A review of timber waste utilization: Challenges and opportunities in Zimbabwe

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Abstract

This paper is a case study review of the timber waste problem and solutions that have been proffered in the Manicaland region of Zimbabwe. The study was conducted through primary data collected during site visits and a review of literature reports on the area. It revealed the absence of up to date quantitative and spatial data on timber waste, with literature reporting at least 70,000 tonnes per annum of sawmill waste. Most of the offcuts and chips are utilized at commercial sawmills for generation of steam for kiln driers, while others are used as firewood by workers and communities. With the growing agricultural hype, most bark is used in tobacco and flower seedbeds, while shavings are used for animal and poultry bedding. Sawdust and shavings represent the most underutilized waste fractions, with heaps scattered all over the region, marring its aesthetic appeal and posing various ecological threats. This waste accumulation, characteristic of timber producing developing nations, defies global best practices in the timber industry which have seen disposed waste reduce to ~1% after uptake by downstream industries like engineered wood products, pulp, paper and cogeneration. Efforts have been made to valorise the waste by making briquettes and compatible stoves, however, they have not been properly supported and promoted for a significant domestic uptake. Recommendations include use of briquettes for CHP at centralized or recommended sites, support of domestic cooking initiatives and consideration of biogas and biofuel potential alternatives, with the support of comparative cost benefit and feasibility studies.

Peer-review under responsibility of the organizing committee of SMPM 2019.

Keywords: bioenergy; biomass; timber; valorise; waste.

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2351-9789
Peer-review under responsibility of the organizing committee of SMPM 2019.
10.1016/j.promfg.2019.07.005

1. Introduction

In recent years, considerable attention has been turned towards the valorisation of biomass, especially its residues and waste into bioenergy and other products [1]–[3]. This comes at the backdrop of climate change issues raised by the continued use of fossil fuels, hence the call for greener approaches like the use of renewable biomass wastes/residues [4]. While global improvements in timber processing efficiency have enabled the recovery of at least 52% of the logs, there have also been great progress in the valorisation of wastes generated to produce engineered wood products, pulp, paper and energy in downstream industries [5]. However, in developing nations like Zimbabwe, the case is different as most do not have adequate downstream industries to utilize the waste. In these developing nations, Waste-to-energy (WtE) applications are usually limited to steam generation for kiln driers in the larger sawmills and domestic uses. As a result, the bulk of the waste is improperly disposed of, posing an ecological threat in many ways, as discussed in this review. Domestic and agricultural uptake of this waste, has not been able to significantly deplete the resource (especially the sawdust fraction) leaving it to accumulate in such developing nations [6]–[8]. Furthermore, as is the case for most Municipal Solid and Industrial Wastes in developing nations, there are little or no statistics available to quantify this waste inventory and its rate of accumulation [9]. This case study review focuses on a region in Zimbabwe and seeks to detail such challenges around timber waste accumulation. It explores the waste utilization trends and identified or potential opportunities, in comparison with global best practices.

2. Background

2.1. General background of the case study area

Zimbabwe is a Southern African developing nation, whose population stood at 16.2 million in 2017, with 67.6%of the population in rural areas [10]. Landlocked between four countries, it is typically vulnerable to both fuel insecurity and the volatility of oil prices. The nation has been experiencing an economic recession since 2000, due to political instability [11]. The nation is divided into 10 provinces as illustrated in Fig. 1. This case study review focuses on Manicaland, also known as Eastern Highlands, a province that stretches from Nyanga in the northeast to Chimanimani in the southeast and occupies 0.02% of the total land area of Zimbabwe. It is premised on primary data collected during visits to the area, interviews and desktop studies.

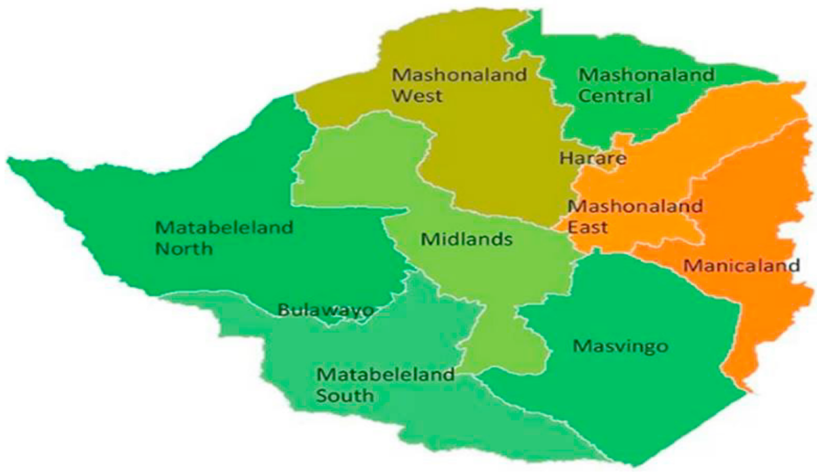

Fig. 1: Location of Manicaland region in Zimbabwe

2.2. The timber production industry in Zimbabwe

Zimbabwe is both a mineral resource-dependent and agro-based economy, with large stretches of land dedicated to agriculture and forestry [12]. The timber industry is currently premised on roughly 69,892 hectares of timber plantations, with at least 93% (65,168 hectares) based in Manicaland province, close to the border of Mozambique [13]. These plantations, which were established in the 1960's comprise pine (~70%), eucalyptus (~20%) and wattle (~10%) [14]. Manicaland is an ideal location for these exotic timber species which can only thrive at high rainfalls, cool temperatures and high altitudes [15]. Timber production provides the largest number of jobs in this region, taking in approximately 25,000 people in plantations, sawmills and contract work [16]. Overall, the industry contributes approximately 3% revenue to the Gross Domestic Product [16]. Three large companies, including one State-owned actor (Allied Timbers) occupy about 87% of the production of processed lumber, while the remaining 13% is produced by medium and small mills in the region [14]. The objective of this study is to explore the waste utilization challenges, review current solutions and proffer recommendations in keeping with global best practices, for the timber industry in Manicaland.

3. The waste problem

3.1. Continuous accumulation of waste, with low utilization rates

It is approximated that the timber industry is responsible for 50-80%of the waste in Manicaland [17]. It should be possible to recover 60% of input raw timber as a finished product, however due to the use of obsolete technology, the percentage of round wood recovered is only 40-45%, resulting in more waste losses. This waste comprises approximately 10% bark, 5% sawdust, and 45% offcuts and chips [18].

There is actually a lot unquantified waste left from harvesting, pruning or thinning of timber in the form of tree offcuts, lops and tops. Although a part of this waste is taken up by local communities for firewood, they do not always have a ready access to plantations for security reasons [15]. Consequently, both plantation owners and communities cannot keep up with their rate of accumulation. When this waste is left lying on the ground, it can provide abundant fuel for a ground fire that could destroy a large area of the forest. This is an important fact in this nation, where vast tracks of forestry plantations have been lost through fires, most of them caused by acts of arson or inadvertently, by illegal settlers (miners and farmers) [13]. There is therefore a need for large, systematic commercial uptake of the waste.

Sawmilling, the largest sector of the timber industry has maintained an upward growth trend, while potential downstream pulp, paper and board industries have either ceased or been on the decline, due to the economic recession [19]. Consequently, the demand for sawmill waste is less than the amount produced, depending on its form. Table 1 shows how various forms of timber waste are utilized, as obtained from the survey.

Table 1: Utilization of various forms of sawmill waste in Manicaland

Form of wood waste	Current utilization avenues	Comments
Bark	Bought by dealers for onward sale to tobacco farmers, who use it as good manure for the tobacco seedbed. Also used for horticulture (flowers).	A lot of bark is now being used given the growth of tobacco and horticultural activities
Shavings	Collected by middlemen or farmers who use it as bedding for poultry and animals.	Demand not so high. Shavings are the second most unutilized form, after sawdust
Offcuts	Most commercial sawmills send these to a chipper to produce chips that are used as boiler fuel	Not all offcuts get to be chipped, in some sawmills. A good fraction is taken up by communities for firewood, furniture, building or fencing.
Chips	All commercial sawmills with kiln driers utilize most of their chips.	Bush sawmills have no kiln driers, therefore they heap sawmill wastes or burn them.
Sawdust	In some commercial sawmills it is mixed with chips for boiler fuel; using sawdust alone would require specialized boiler designs which are still in development.	Still, 20-70% of the sawdust has to be disposed, usually by incineration, along with some shavings and spilled chips

The saw dust and some chips that accumulate in such sawmills with kiln driers have to be incinerated for at least 2 days of the week, as in the case of the Border Timbers owned Sheba estates†. Table 2, by comparison, shows how timber waste was utilized just over a decade earlier [15]. There has not been a similar, quantitative research since then, which enumerates waste utilization, accumulation, spatial and temporal dynamics.

Table 2: Utilization of various forms of sawmill waste in 2003 [15]

Sawmill estate	Waste user	Bark	Chips	Off-cuts	Sawdust
Charter	*Charter*	None	100% used as fuel for boiler	75% used as fuel for boiler	None
	Community	None	None	25% used for fencing and horticulture	None
Chimanimani forest	*Chimanimani*	None	100% used as fuel for boiler	None	100% used as fuel for boiler
	Community	None	None	Fencing, furniture and building	None
Gwendingwe	*Gwendingwe*	None	100% used as fuel for boiler	60% chipped for boiler	None
	Community	None	None	Fencing, furniture and building	None
Erin	*Erin*	None	100% used as fuel for boiler	30% chipped for boiler	None
	Community	~ 3% used for horticulture	None	Furniture and firewood	3% used for horticulture
Wattle company	*Wattle company*	None	100% used as fuel for boiler	None	100% used as fuel for boiler
	Community	None	None	None	None
Stapleford	*Stapleford*	None	100% used as fuel for boiler	95% chipped for boiler	20% used as fuel for boiler
	Community	None	None	5% used for firewood	None

Table 2 shows that, back then, bark was virtually unutilized. However, it is now at a high demand from various players in the agricultural sector, accumulating in very remote areas where it cannot be easily accessed. Clearly, chips have always been 100% utilized by commercial sawmills, while offcuts and sawdust have always been partly utilized. Only 2 of the companies were utilizing all their sawdust; the third only utilized 20%. Not much has changed for sawdust, as its utilization as boiler fuel for steam requires a considerable capital investment, afforded only by larger commercial players. However, they have not been using all of it since their steam requirements are met by the large volumes of chips and offcuts, leaving out considerable amounts of sawdust to be incinerated.

3.2. The ecological threat

The sawdust is a worse waste menace for the smaller timber sawmillers who do not have kiln drying, especially the many bush mills and Chinese sawmills scattered all over Manicaland [20]. It is estimated that only 10% of the total amount of sawdust generated in Manicaland gets to be used for kiln drying, while a small fraction is incinerated, releasing GHG emissions [21]. The remainder has been accumulating at a rate of over 70,000 tonnes per year since 2013 and was forecasted to have doubled by 2018 [8], [22]. There is already a huge, unquantified inventory of sawmill waste at abandoned and functional sawmill sites (see Fig. 2). These heaps are scattered all over Nyanga, Mutare and Chimanimani, spoiling the aesthetic appeal of the region and releasing unpleasant odours. Moreover, they pose a fire hazard since they can spontaneously ignite due to hot spots characteristic of such large outdoor heaps [23]. Sawdust, in either wet or dry state, is notorious for burning ravenously with fires that can take up to 3years to burnout‡, depending on the size of the heap. Such heaps continue to burn underneath, spurred by the

† From interview with an operator at Sheba sawmill estate

‡ From interviews

heat incubated at the centre. A number of sawmill estates in Manicaland have been gutted by fires emanating from sawdust; not to mention the damage on ecological balance.

Current waste disposal methods include dumping at sawmills, municipal dumpsites, plantation property, burning in tee-pee incinerators, or in open-air. Open air burning is even worse since it nets out uncontrolled emissions. In the rainy season, outdoor heaps generate wood residue leachate containing high concentrations of Dissolved Organic Matter (DOM) which can mobilize transition metals such as Iron and copper from soils and also contain toxic pollutants for aquatic life [7], [24]. Moreover, the decomposing residues encourage microbial or insect activity; the former can be a threat to nearby aquatic niches by increasing Biochemical Oxygen Demand (BOD) levels in water bodies [7].

Evidently, this problem of wood waste disposal which has spanned at least 2 decades could remain a major environmental problem and hazard for this region unless there is a large scale utilization of this resource.

Fig. 2: Sawmill waste scenes from Manicaland [Photos taken during tour around the area]
1. Receiving and sorting bay where bark is peeled off 2.Bark and small chip from receiving bay 3. Sawmill shop floor 4. Chipping machine and conveyor delivering chips & sawdust mixture to boiler 5. Spill over of chips, shavings and sawdust from conveyor 6.Waste offcuts 7&8. Sawdust mound of around 5000t at a dysfunctional sawmill in Mutare. Many such mounds exist in Nyanga and Chimanimani.

3.3. Forecasted growth of the timber industry

Furthermore, the timber industry is expected to grow following the stabilization of the nation's economy, rejuvenation of plantations and increased security around existing plantations. The growth should also be spurred by an increasing regional demand, encouraged by a booming construction industry in developing Southern Africa [25]. This should naturally lead to a growth in timber production since Zimbabwe is the only SADC country that exports timber [26]. There is therefore a large potential that this will translate into a similar proportionate growth in timber waste production, assuming that not many sawmillers will be able to afford kiln driers. It will therefore become more imminent to have systemic and sustainable waste utilization strategies to curb these problems.

3.4. Lack of up to date, accurate spatial data on waste generation and inventory

Like many developing, one of the problems in Zimbabwe is the lack of accurate data on biomass waste, and the timber industry is no exception [27], [28]. Authors like Bailis et al. (2002) have emphasized on the need to obtain reliable statistics on current wood waste inventory before commercial opportunities beyond the borders of individual sawmill estates can be explored [21]. The value of such knowledge would also emanate from the fact that there is a recent proliferation of bush mills that is leaving a spate of unaccounted waste at various locations. These are contracted by the state owned commercial timber producer, Allied Timbers, since 3 of its dysfunctional sawmills were vandalized [29]. There are also significant waste heaps at Chinese sawmills and dysfunctional mills like Stapleford. Presently, there are only estimates, with some sources claiming that the sawdust generated is 70,000 tonnes per annum (tpa) [10], [30], while some claim that there are millions of tonnes of sawdust produced annually [31]. The absence of spatial data on the quantities of waste makes it difficult for any commercial plan on the waste resource, for instance, a centralized cogeneration unit.

4. A cue from global best practices

This section is a brief survey of strategies that have been employed globally to derive value from sawmill waste, as presented in literature. The utilization of sawmill waste will always draw from the original properties of wood that render it useful in the various applications. Table 3 shows the properties of wood and associated global applications of sawmill waste [24], [32]–[34].

Table 3: Properties of wood waste and potential applications

Physical and chemical properties of wood	Associated applications
Stored chemical (internal) energy that can be converted into thermal, electrical or kinetic energy.	**Combustion** of the carbon complex to yield heat which generates steam for heating or power generation.
	Gasification to obtain syngas to fuel a boiler or Internal Combustion (IC) engine for power generation; syngas can also be used to produce bio-fuels
	Pyrolysis to produce bio-oil or char products. Bio-oil is used to make fuels and chemicals while bio-char has gained popularity as a soil additive.
	Pelletizing and briquetting: To make a dense fuel for domestic heating or fuelling a small scale power plant.
Source of organic polymers: conversion into useful chemicals	Useful components can be extracted directly from particular wood species. Otherwise, waste can be pyrolyzed or gasified to yield bio-oil and syngas respectively, which can be used as feed stocks in chemical syntheses.
Mechanical/structural properties of the fibrous cellulosic structure.	Chips, fibres, shavings and sawdust are used to manufacture engineered wood products like panel boards.
	Soil erosion control, mulch.
Source of organic material for biological feed; water retention abilities	Soil additives in agriculture. Bark has special application in horticulture and seed beds.

From the literature survey made, it is evident that the utilization of sawmill waste vary from once region to the other, along socio-economic lines. As Warnken (2008) reports, the challenges of processing wood waste in its various forms can be technical in nature, requiring significant capital investments [35]. This is where most developing nations fallout in this regard, especially when the benefit of processing this waste is not clear to them compared to the cost of investment. For instance, in Ghana, Kumasi, 30% of raw logs are recovered and most of the waste (especially sawdust) is dumped or burnt in open air. Nigeria also has similar cases of high wood waste disposal rates from sawmills, because downstream industries like engineered wood products, pulp and paper are too few to take up all the waste generated, and also have their own share of waste [6], [7]. Global best practices, as exemplified by North America and Australian timber industry are characterized by high recovery rates of at least 52%, thereby reducing waste produced at source. Generated waste is subsequently taken up by downstream industries that utilize *ca.* 36% of the waste, including engineered wood, pulp and paper industries. Most of the remaining waste is converted to energy in CHP plants, leaving only 1% unutilized [5], [33], [35]. Developing nations that do not have pulp, paper and engineered wood industries should at least aim to recover energy industrially, given the energy poverty characteristic of these countries. Currently, they fall a long way behind global best practices where up to 99% of the harvested timber, including waste, is used (Fig. 3).

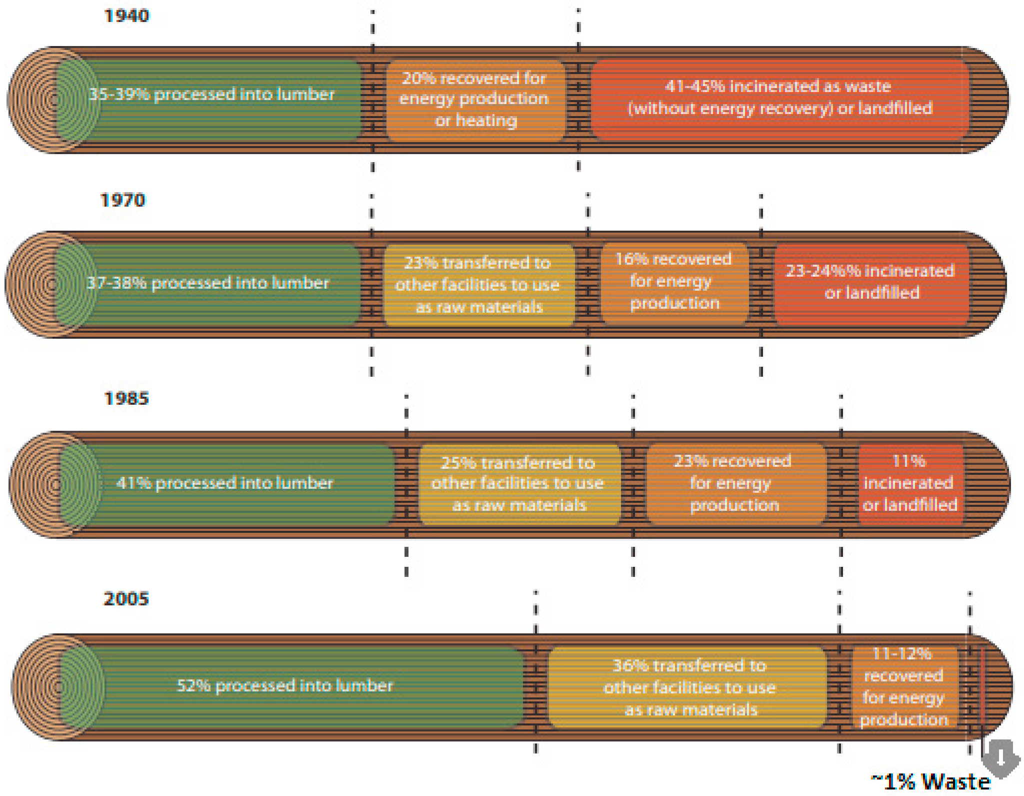

Fig. 3: Utilization of Harvested Wood by the North American Forest Products Industry, 1940 – 2005 [5]

Since for developing nations like Zimbabwe that have an electricity deficit, it is also necessary to benchmark on bioenergy conversion plants and supply chain dynamics [36], [37]. There are also prospects for second generation biofuel production from the wood residues, though energy recovery by cogeneration is currently the cheaper and more pressing need [8], [27]. In this regard, there has been a lot of development in biomass quantification techniques and subsequent supply chain modelling, especially in cases where the bioenergy conversion plant is centralized. Emphasis has been placed on correctly modelling the spatial and temporal dynamics of the timber waste across various locations, using Geographical Information System (GIS) based techniques [38]–[41]. Such models would then be used, especially, for strategic level optimization of facility location and/or size with respect to the spatial arrangement and quantities of the waste deposits. Authors like Panichelli and Gnansounou (2008), Celli et al. (2008), Kinoshita et al. (2009) and Kanzian et al. (2009) have reported on the use of GIS modelling alone, or its integration with other models to solve the centralized bioenergy facility sizing and location problems [38], [39], [41], [42].

5. Innovative strategies employed in the utilization of sawmill waste

Given such modern timber waste valorisation examples, Manicaland has a number of options to consider. This section will review some of the progress that has been made toward large scale utilization rather than the current subsistent small scale use of timber waste, which has not been able to significantly deplete the resource. Sawdust heaps are the most abundant because the rate of utilization of this form of waste is much lower than that of bark, shavings, chips and offcuts. This challenge can however be turned into an opportunity given the presence of a huge supply of such a homogeneous form of waste that can be processed evenly using a repeatable system.

A number of proposals have been tabled for the utilization of this sawdust to obtain energy, beyond the avenues that were already being explored (Table 1 &2). Various newspapers from 2013 held interviews and reported on a couple of ‘inventions’ made by locals to try and make use of this resource. Between 2013 and 2017, there has been reports of modified ‘smokeless’ briquettes made using densification techniques using new or modified machinery. One ‘inventor’ even went on to make patented briquette stoves, to be used with this handy fuel [17]. The briquettes have enjoyed better marketing with some local hardware dealers displaying these cylindrical fuel solid fuels along with charcoal. At some outlet, a kg of briquettes (~4.214kcal/kg) was selling for $0.50/kg while charcoal (7.5kcal/kg) was selling at $0.77/kg [43]. One Allied Timbers officer mentioned a potential deal in which they will contract one of these ‘inventors’ to produce large quantities of briquettes, a fuel form they prefer to use for their cogeneration projects.

Fig. 4: Sawdust briquette manufacturing outlet in Manicaland [17]

The cook stoves and briquettes’ major target, to date, has been domestic use. The major problem such inventions have faced is low promotion and uptake by communities; an initiative that could have been promoted by government and Non-Governmental Organizations (NGOs). Even so, it is doubtful that they would have been able to meaningfully consume the large volumes of existing waste and more that is being generated. On the other hand, from an energy point of view, it does not make economic sense for sawmills to be incurring a huge power bill when they could use the idle waste to generate bioenergy. This has been the drive behind initiatives to move beyond generation of boiler steam to the construction of cogeneration plants to utilize the bio waste. The Department of Energy (DoE) through the National Biomass Strategy recommended three potential co-generation projects in Manicaland, as illustrated in Table 4 [8].

Table 4: Potential cogeneration sites in Manicaland

Potential co-generation site	**Generation capacity**
Nyanga Sawmill Wood Residue Project, Wattle company site	3.5MW
Chimanimani Sawmill Wood Residue Power Project, Allied Timbers site	3MW
Charter Sawmill Wood Residue Power Project	10MW
Total	16.5MW

This survey, however, does not take into consideration the scattered bush mill, Chinese sawmills and dysfunctional sawmill sites where a lot more of the sawmill waste is heaped. Such additional volumes could perhaps substantiate claims that, overall, utilization of timber waste generated in the region could generate 10-25MWe [19]. This should, at the least, offset the power requirements in the timber industry and possibly inject a surplus into the national grid. Depending on the location of the bio-energy facility, there is also a possibility of socio-economic transformation if the facility(s) are located in remote areas. The co-generation avenue has been receiving a lot of attention due to the national calls to shift towards renewable energy and reduce forex expenditure on the import of electricity [16], [30]. The nation currently imports up to 35% of its electrical energy demand from Southern African nations to meet the local deficit [36].

6. Gaps, opportunities and recommendations

The starting point for a comprehensive timber waste utilization strategy should be the quantification of available resources, covering the spatial and temporal dynamics of the waste. This would ascertain sustainability of future supply, costs of transportation, optimal location and sizing of energy conversion facilities, profitability of such ventures and optimal raw material management strategies. All these upstream supply chain factors are important in optimizing the socio-economic viability and sustainability of any WtE venture. From an environmental perspective, this would also give a more accurate inventory of this important solid waste, whose value comes from both its potential as a renewable energy source and its threat to the environment.

Secondly, the government, policy makers, NGOs, the private sector and stakeholders in environmental management should openly support existing and planned efforts to valorise the waste. For instance, the briquettes and briquette stove initiative has not been widely disseminated due to inadequate support. Initiatives to use such briquettes for industrial CHP production by companies like Allied Timbers would be a welcome move that can spell socio-economic benefits like enterprise development for the 'inventor', job creation, electrical power generation and reduction of expenses for the sawmill. In the same vein, institutional support should be extended to identify potential WtE generation sites (Table 4). However, subsequent to the waste inventory audit, a feasibility survey for the installation of a centralized CHP plant should also be carried out. This is because there have been many other waste generation sites by bush mills, abandoned sawmills and Chinese sawmills, whose waste deposits are not captured by the sites identified in Table 4.

An attractive alternative in the near future, would be to convert this ubiquitous resource in the region into biofuels like ethanol or methanol through cellulosic fermentation or thermochemical routes [8]. This may be a capital intensive venture, however, given the policies and infrastructure already supporting bioethanol and blending mandates, the conversion could complement government efforts to reduce fuel imports. A proper cost benefit analysis should however be made, considering the competing CHP alternative, since it may not be logistically feasible to run both projects given waste supply constraints. The analysis should also factor in plans underway to expand the nation's ethanol production capacity by growing more sugarcane under an irrigation scheme covered by the completed Tokwe Mukosi dam [10]. Although the conversion technologies for biofuels are still in development, global trends are pointing in the direction of 2nd generation biofuels from such lignocellulosic waste, with growing policy support and markets in the US, EU China and Japan [4], [28], [44].

Other opportunities for utilization of this waste include fast pyrolysis into bio-oils which can be converted into fuels or speciality chemicals. This route has a great potential since it is quite cheap for the pyrolysis stage, however, most downstream upgrading technologies are capital intensive and mostly, under development [45], [46]. Manyuchi et al. (2016) also looked into the feasibility of digesting sawdust from this region using Acti-zyme, then subsequently upgrading it into methane for sale or power generation. For 4,000 tonnes of sawdust processed per day, their plant could produce 24m^3 per day, with a 2 year payback period and return on investment of 48%. They concluded that the project was technically, economically and environmentally feasible [47].

On the other hand, the quantification challenge can be tackled by using contemporary GIS techniques discussed in section 4, which can capture both special and temporal characteristics of various heaps. Such models can be configured to be able to identify optimal facility locations based on vector and raster data from satellite imagery, digital elevation model data, topographic data and operational environment[48], [49]. This is effected by predefining the site selection suitability model that then scans through available geographical locations [48], [49]. Most literature around GIS use (see sec 4) seems to span agricultural residues and MSW, probably because the locations concerned did not have significant timber waste deposits or they were sufficiently utilized [48], [50], [51]. It would be interesting to apply this technique to the Zimbabwean case, both for spatial and temporal quantification of timber waste and for identifying optimal locations for prospective bioenergy conversion facilities. These could cater for scattered wastes outside large sawmills and identified potential cogeneration sites.

7. Conclusion

The challenges of timber waste disposal and use in Manicaland are characteristic of developing nations that produce timber. The reluctance to invest in and support waste utilization might not be due to lack of resources only, but also a lack of understanding on the potential gains of valorising the waste and impacts of not doing so. Generally, developing nations have been passive with regards to valorisation of urban and industrial waste; in many cases, they do not even have spatial and quantitative statistics on such waste. Perhaps the starting point should be enactment of renewable energy policies (including WtE); a feature that has been lacking in most Southern African countries [10], [28], [52]. There should also be a support of local initiatives to solve problems like timber waste accumulation, and a willingness by stakeholders to learn from global best practices, including the systematic quantification of the waste. Evidently, the world has adopted a zero waste policy in this industry and many others, with so many socio-economic benefits. Potential solutions should be weighed against prevailing socio-economic needs, for instance energy poverty and fuel challenges. However, their adoption will also depend on technical and economic capacity of stakeholders.

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