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Waste valorisation opportunities for bush encroacher biomass in savannah ecosystems: A comparative case analysis of Botswana and Namibia

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Abstract

Bush encroachment of savannah ecosystems in countries like Botswana and Namibia has been identified as a major problem threatening biodiversity, grazing land productivity and the generation of groundwater. Incidentally, the same problem presents a huge biomass energy resource opportunity which can be exploited through various technologies. This paper defines the scope of the problem in Botswana, comparing with the well documented and partly proven case of encroacher bush waste valorisation in Namibia. This biomass is therefore a large homogeneous sustainable *waste resource* base that is perennially available, due to the drought-hardiness of the encroachers. It is however, necessary to conduct preliminary studies to explore prospects and possibilities, benchmarking with globally renowned biomass experts like Germany and the United Kingdom. The study shows that the issue of bush encroachment in Botswana has been documented from as far back as 1971, though earlier studies were mostly evaluations from a natural resources perspective which did not proffer solutions. Besides a project by United Nations Development Programme to try and benchmark from Namibia's biomass to charcoal initiatives from their encroacher bushes, there is no documented effort by Botswana to derive value out of the vast resource which has invaded thousands of hectares of rangelands. Meanwhile, Namibia has recorded significant success in converting the encroacher bushes into wood chips for use in boilers (heat production) for a cement plant, charcoal for domestic and

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commercial heating/cooking and briquettes for power generation. Feasibility studies have been made for the possibility of scaling up these projects, while exploring other existing and emerging sustainable technologies like pelletizing, gasification, pyrolysis and engineered wood products. Essentially, a review of the existing problem in Botswana, experiences for various cases and recommendations by experts make this compilation valuable for the nation and other regions experiencing the same problem.

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Keywords: waste; encroacher bush; valorisation; energy.

1. Introduction: The bush encroachment problem and current solutions in Botswana

The problem of bush encroachment in savannah ecosystems due to increased anthropogenic activity like livestock husbandry has been discussed by a number of authors [1]–[3]. Such encroachment can lower land productivity and grazing pastures by more than two thirds, while reducing biodiversity and the generation of groundwater [4]. In Botswana particularly, drought hardy woody plants like *Acacia tortilis, A. mellifera, A. erubescens, Dichrostachys cinere*a and *Terminalia sericea* have been increasing in cover and density in rangelands and around selective areas like river banks, road ways and water sources [1]. This paper particularly focuses on *A. tortilis*, which has become notorious for its encroachment both in remote rangelands and in town or village centres, dominating regions with silty sand alluvium [5]. Together with other encroachers, *A. tortilis* has significantly reduced the size of quality rangeland available for both domestic and wild animals [6]. Moleele et. al demonstrated that there is a high correlation between cattle density in certain areas, nutrient proportions and the extent of woody biomass encroachment [1]. This has been the case for roadways and byways in towns and some communal and commercial rangelands [1], [6]. In some cases, grazing livestock have particularly displaced browsers such as kudu, putting extra pressure on the grass pastures while relieving woody plants, which flourish, consequently. Bush proliferation and growth have also been linked to rainfall rates, high atmospheric temperatures and carbon dioxide levels [7]. Notwithstanding the causative factors, it is apparent that bush encroachment from species like *A. tortilis* is a real socio-economic problem that costs local and national government millions of Pulas annually through various bush control programs like de-bushing. A sustainable solution is therefore the regeneration of rangelands and aesthetic appeal in villages, towns, cities and highways in a way that adds economic value and minimizes the impact on the environment or ecosystem [1]–[3].

1.1. Current efforts to reduce the socio-economic impact of bush encroachment

Although de-bushing exercises have been carried out in rangelands, towns and cities, the major problem has been finding a proper way of disposing, or better still, valorising the waste [2], [4]. Since thorny bushes like *A. tortilis* are not desirable for use as fuelwood, the heaped cuttings are mostly burnt in open air, contributing to the release of greenhouse gases like carbon dioxide. The situation is worsened by the fact that the drought hardy *A. tortilis* shoots quickly spring up after de-bushing, with less competition for water and nutrients from the dwindling, overgrazed grass populations [3], [6]. Consequently, de-bushing in urban set ups has be carried out about 2-3 times in a year. In some areas, the heaps are collected and burnt centrally, adding to the logistical and labour costs. Efforts have been made to look for sustainable solutions beyond merely de-bushing and burning. The most attractive alternatives would be those that can bring out value from such waste biomass. Amongst these is a recently engineered solution, where UNDP engaged residents in Ngamiland to produce charcoal from the wood cut in de-bushing exercises around Ngamiland in a bid to regenerate grasslands. The initiative sought to valorise the waste wood into higher value products like charcoal and supply shops instead of just selling wood. Production started after residents were trained in Namibia and the pots for making the charcoal were fabricated. Projections anticipate that the biomass can sustainably support charcoal production for up to 20years with socio-economic and environmental benefits.

However, since the smaller branches and twigs cannot be used for charcoal production, there were plans were to compact them into feeding pallets for livestock[†].

Fig. 1. (a) *A. tortilis* shrubs and cut heaps besides a railway line; (b) Heaps of *A.tortilis* cuttings adjacent to a stream; (c) Heaps of cut *A. tortilis* behind industrial area.

1.2. The objectives of this study

This research seeks to explore sustainable waste valorisation opportunities for de-bushed, waste biomass. As such, reviews on the state of the art globally, around the utilization or valorisation of de-bushed biomass are carried out in section 3, with a particular focus on Namibia, whose experience in valorising de-bushed biomass is well documented [4], [7], [8]. Moreover, Namibia has an identical savannah ecosystem to Botswana with similar anthropogenic factors driving the increase of bush encroachment. Since there is a particular focus on *A. tortilis* prevalent in the North, South-East, South-West and Central parts of Botswana, a brief profile of this species is initially furnished in section 2 [6], [9]. Section 4 recommends selected opportunities identified for Namibia, which would be highly suitable in the context of Botswana. It also goes beyond the Namibia case to identify other sustainable technologies from a global perspective.

2. **Botanical, thermal and chemical profile for *A. tortilis.***

Acacia Tortilis (*local name: Mosunyana*) is a deciduous thorny tree that can reach up to 20m, though it usually occurs in heights of less than 10m. Young trees have rounded or flat-topped crowns, while older specimen have an umbrella shaped crown, hence the alternate name 'Umbrella thorn' [9]. It has bipinnately compound leaves that are probably some of the smallest among thorn trees, nonetheless, they still produce a dense canopy [3], [9]. *A. tortilis* has white or blackish spines which occur in pairs and can be are short and hooked, while others are long and straight. The pods have a contorted form and are a rich source of plant protein for livestock and wildlife species, along with the leaves and flowers [3]. Table 1 shows the chemical and fuel properties of *A. tortilis.*

Table 1. Results of ultimate and proximate analyses for Acacia, compared to the common Pine. FC- Fixed Carbon; VM- Volatile Matter; MC- Moisture Content

	Ultimate analysis (Thermo scientific flash 2000 CHNS-O analyser)				*Proximate analysis (Dry basis)* (Thermogravimetric analyser- Leco TGA 701)				**HHV** (MJ/kg) Bomb CAL2K-2
%	**C**	**H**	**N**	**O**	**Ash**	**FC**	**VM**	**MC**	
ACACIA	41.47	5.15	1.23	52.15	4.01	19.21	76.77	3.79	17.267
PINEDUST	45.76	5.54	0.039	48.66	0.83	20.00	79.16	65.41	17.568

[†] https://tsena.co.bw/undp-discovers-viable-charcoal-production-venture

Notably, the High Heating Value (HHV) for *A. tortilis is* not very different from that of pine dust; though the Acacia has a considerably higher ash content and a slightly lower fixed carbon.

3. The Namibia case

Bush encroachment in Namibian farms and rangelands has been tagged a high priority concern due to its impact on pastoral and agricultural productivity. Studies have revealed that there is approximately 26-30million hectares of land affected, costing the nation a loss of income of up to N$700million per year (~US$48,4million) [7]. Nevertheless, the encroacher species have been identified as a significant biomass resource useful for value added energy products (electricity, charcoal etc.), with a potential yield of 200million tonnes per annum (tpa) [4]. Essentially, bush control activities have presented both socio-economic and ecological benefits through increasing livestock productivity, adding to the renewable energy mix, industrial diversification, employment creation and economic growth [4]. Indeed, the thrust of these Namibian bush control programs has been to promote economic and environmental sustainability [8]. The main commercial solutions that have been working well include heat production for cement kilns, electrical power generation, charcoal production, while other initiatives like gasification, pyrolysis and engineering wood products have been tabled for consideration [8]. Table 2 is a summary of some of the major avenues that have been employed for the valorisation of encroacher biomass in Namibia. The opportunities cited border around industrial heat + power generation and soil conditioning applications.

Namibia seeks to keep up with the trend of increasing renewables' share within the energy market, in the process reducing their import budget for fossil based fuels. The encroacher bush has a pivotal role in this venture, with plans to build a number of biomass thermal plants, especially in remote places [8], [10].

Table 2. Opportunities identified for encroacher bush valorisation in Namibia.

	Waste wood valorisation prospects/opportunities	Implementation scenario & players	Remarks	Literature
1	**Charcoal**- Namibia is the 5th largest exporter of Charcoal. Barbeque charcoal local market is currently undersupplied.	Currently the most important value chain for the de-bushed wood.	Small diameters of some encroachers is not suitable for charcoal; alternative uses required. Short value chain & low skill requirements	[2], [4], [8]
2	**Wood Chips**- There is a big, growing global market currently at 35.1 million tons imported p.a. Logistic supply chain solutions required to access international markets. However, it is likely the chips will only be competitive in Namibia for short distances of up to 100km. Beyond that, higher energy density fuels will be required.	Currently being produced by Ohorongo Cement for its cement production facility. At full capacity, 75% of energy needs are met by biomass. Plans underway to build 20MW and 40MW biomass power plants around Otavi and Otjiwarongo areas respectively.	Domestic demand for power generation exceeds current capacity. Low risk and shorter value chain, requiring less skills. Not a good form of fuel when considering long distance transportation. Stronger wood chippers customized to harsh Namibian climate are required.	[2], [4], [8]
3	**Wood briquettes**. There is a large domestic and international market. Logistic supply chain solutions are required to access international markets	Already being produced, however demand in RSA and Namibia alone exceeds production. There is currently, only 1 producer of compressed wood (briquettes).	Low to medium skill requirement in industry. A better form when considering long distance transportation	[2], [4], [8]
4	**Wood pellets**. Large, increasing international demand at 12.2 million tpa imports. Benefits being the higher energy efficiency &. bulk density than wood chips	Research investigated technical feasibility and concluded there is too much sand in wood chips which interrupts pelletizer, producing low quality products.	Logistic supply chain solutions required to access international markets. A better form when considering long distance transportation	[8]
5	**Composting & mulching**. Biomass used in its green form without processing to biochar	Current small commercial production exceeds demand.		[8]
6	**Bio-oil** from pyrolysis of dried wood chips. Fast pyrolysis has high yields of up to 80% in less than a minute. Bio-oil can substitute or complement fuel oil or diesel in many static applications including boilers, furnaces, engines and turbines for electricity generation. Bio- char used in Agriculture.	Current applications in Namibia next to nil. Globally, pyrolysis oil can be used directly in boilers, gas turbines or in slow/medium speed engine for heat/power.	Bio-oil is more easily transportable and storable than solid fuel. Needs to be blended with a little methanol for stability. Technical skill requirement relatively high.	[8], [11]
7	**Bioethanol**. Global demand of ethanol was at 24.6 billion gallons in 2014. Future major	Currently not being produced in Namibia. Technology globally	Ethanol production from woody biomass is complex and expensive	[8], [12], [13]

	importers include China, EU, US and Japan. Regional market also promising	commercialized but implementation requires high technical expertise and is economic at high throughputs.	compared to starch, requiring enzymatic hydrolysis of the more stable cellulose.	
8	**Syngas** (calorific value is 10-15% of natural gas). Applications include the conversion into power, heat and fuels. For power generation, an Internal combustion engine with generator (or pump) is used. Gas burner required for direct heating purposes in kilns and boilers.	A single pilot plant to convert biomass to syngas, then to electricity was established at Pierre farm. No plants or prospects yet for fuels.	Requires highly skilled technical expertise. Upstream issues like ruggedizing the chippers would still need attention.	[8], [14], [15]

4. Recommendations for Botswana

Initially, we will make a quick comparison of the two nations along lines that include encroacher bush resource, policy issues, capacity (financial & technical) and socio-economic concerns. The implications of such differences are drawn out as recommendations for Botswana, which is still to develop encroacher bush valorisation programs.

Table 3. Recommendations from a comparative analysis

	Namibia	**Botswana**	**Recommendations for Botswana from the similarities or differences**
Bush encroacher resource	*Quantities & distribution*		
	Namibia has extensive resources (200million tpa) that can be obtained within adjacent regions. Programs to quantify the resource have been carried out [4].	In regions like Ghanzi (SW) and Ngamiland (N), adjacent rangelands can have a good resource quantity. However, the encroachers from towns/villages byways are scattered. The biggest hurdle- encroacher biomass resource is unquantified, both spatially and collectively [9].	There is need to quantify the encroacher bush available spatially for rangelands, then for the urban setting. It is most likely that rangeland feedstock's bulky quantities within a smaller area will attract projects like thermal plants, which can be built close to those areas. Feasibility and sustainability of projects have to be determined.
	Quality & dimensions		For Botswana case, there would then be a need to distinguish between waste valorisation in rangelands and in the urban set up. Charcoal programs can apply in rangelands, while chipping & briquetting can be used in both cases; though light duty equipment can be used in town/city set up.
	Since most woody biomass is from rangelands, large diameter trees are largely available. Small diameter shrubs also available. A wide range of species are available [7], [8].	Large trees suitable for charcoal production, are available in rangelands. However, it is mostly smaller shrubs available from de-bushing activities in towns, cities and villages.	
Policy and energy utilization landscape	Namibia's energy framework has expanded to consider renewable biomass encroachers. Advanced planning the construction of biomass thermal power plants; a good move since Namibia does not have many coal reserves and is importing >50% of its electricity needs [10].	Though both nations are net importers of power (Botswana 20-30%, Namibia ~66% of electricity needs), Botswana Power Corporation's Morupule B thermal plant has capacity to meet 100% of nation's demand if fully utilized [10], [16].	Feasibility assessments for a biomass thermal power plant should be done, after quantities and spatial distribution is determined. However, with coal currently dominating the power production space, co-firing options and other valorisation alternatives should be considered
Financial &Technical Capacity	Investment and technical requirements for Charcoal production, wood chipping, briquetting, composting and pelletizing systems are fairly low to medium and affordable. Pyrolysis is a medium to high skill system, while gasification, bioethanol production and digestion would demand high technical skills and medium to high level investment, depending on downstream processes or use of the products [8], [17]		Botswana can start off at the low investments-low skills end. However, a proper market study should be conducted to assess the potential economic returns from following certain product lines.
Socio-	Encroacher bush valorisation will enhance domestic livestock productivity and		Thorny tree shrubs are prevalent in

economic issues	incomes. There will be more firewood and charcoal for domestic use, along with employment opportunities along the value chain. Alternative uses for the thorny branches from trees like *A. tortilis* which cannot be used for charcoal or firewood should be considered [2], [4], [8].	towns/villages/cities of Botswana. Chipping, densification and pyrolysis could be attractive initial considerations. Technical and economic feasibility have to be assessed (e.g., would the shrubs' bark not significantly affect quality of pellets/briquettes?)
Other factors	*Emerging technologies* like pyrolysis and gasification can be considered, especially for boiler and static engines applications. A mobile fast pyrolysis plant, for instance, can be able to process heaps at various locations, with ease of transport for the bio-oil [15], [18], [19]	Bio-oil for instance, can be used to supplement coal in thermal power plant, with slight modifications. Particular consider for smaller shrubs not suitable for charcoal.

4. Conclusions

The survey of the Namibian case shows the dual impact that encroacher bush valorisation can have: restoring grazing land and livestock populations, while providing a valuable material or energy resource. However, for any waste management program to succeed, the starting point should be assessing the waste resource spatial quantities, then the feasibility of intended projects [20]. For Botswana in particular, there would also be need to demarcate between rangelands and town/city areas since the encroacher bush quality, type and distribution will vary in these areas. Charcoal making, chipping, briquetting and pelletizing would be quick entry options for rangelands; however the urban resource would not be suitable since it comprises thin-branched shrubs. Transportation of this bulky form would be costly, therefore options like chipping, densification and mobile pyrolysis can be good considerations. A market study would also need to be carried out to find out if the products would be attractive in Botswana.

References

[1] N. M. Moleele, S. Ringrose, W. Matheson, and C. Vanderpost, "More woody plants? The status of bush encroachment in Botswana's grazing areas," *J. Environ. Manage.*, vol. 64, no. 1, pp. 3–11, 2002.

[2] N. Lukomska, "The Economic Value of Real Options in Biodiversity Management - The Case of Bush Encroachment Control in Semi-Arid Rangelands.," University of Zurich, 2010.

[3] S. Kabajan, K. Kaunda, and K. Matlhaku, "Shoot Production by Acacia tortilis under Different Browsing Regimes in South-East Botswana," no. January 2011, 2016.

[4] D. Honsbein, "Survey development and implementation in preparation of a De-bushing Advisory Service (DAS) May 2015," 2015.

[5] M. J. Tedder, "Dry Woodland and Savanna Vegetation Dynamics in the Eastern Okavango Delta, Botswana," 2012.

[6] E. Kgosikoma, "Grazing management systems and their effects on savanna ecosystem dynamics: A review," *J. Ecol. Nat. Environ.*, vol. 5, no. 6, pp. 88–94, 2013.

[7] L. Harper-Simmonds *et al.*, "Development of an inventory of ecosystem services in Namibia," 2012.

[8] DECOSA, "Support to De-Bushing Project Value Added End-Use Opportunities for Namibian Encroacher Bush," 2015.

[9] S. Moffat P and F. Venter, "Trees of Botswana: names and distribution," 2003.

[10] Governmernt of Namibia, "The National Integrated Resource Plan Review and Update," 2016.

[11] D. Bradley, "European Market Study for BioOil (Pyrolysis Oil)," 2006.

[12] G. Tembo, F. M. Epplin, R. L. Huhnke, G. Tembo, F. M. Epplin, and R. L. Huhnke, "Integrative Investment Appraisal of a Lignocellulosic Biomass-to-Ethanol Industry Integrative Investment Appraisal of a Lignocellulosic Biomass-to-Ethanol Industry," vol. 28, no. 3, pp. 611–633, 2018.

[13] D. Kennes, H. N. Abubackar, M. Diaz, M. C. Veiga, and C. Kennes, "Bioethanol production from biomass: Carbohydrate vs syngas fermentation," *J. Chem. Technol. Biotechnol.*, vol. 91, no. 2, pp. 304–317, 2016.

[14] D. Verma, A. Singla, B. Lal, and P. M. Sarma, "Conversion of biomass-generated syngas into next-generation liquid transport fuels through microbial intervention: Potential and current status," *Curr. Sci.*, vol. 110, no. 3, pp. 329–336, 2016.

[15] V. S. Sikarwar, M. Zhao, P. S. Fennell, N. Shah, and E. J. Anthony, "Progress in biofuel production from gasification," *Prog. Energy Combust. Sci.*, vol. 61, pp. 189–248, 2017.

[16] S. Chingoiro and S. Mbulawa, "Electricity Consumption and Economic Growth in Botswana: A Vector Error Correction Approach," *Adv. Manag. Appl. Econ.*, vol. 7, no. 2, pp. 105–122, 2017.

[17] IRENA, "Innovation Outlook Advanced Liquid Biofuels," p. 132, 2016.

[18] P. Badger, S. Badger, M. Puettmann, P. Steele, and J. Cooper, "Techno-Economic Analysis: Prelimiary Assessment of Pyrolysis Oil Production Costs and Material Energy Balance Associated with a Transportable Fast Pyrolysis System," *BioResources*, vol. 6, pp. 34–47, 2011.

[19] S. Leduc, D. Schwab, E. Dotzauer, E. Schmid, and M. Obersteiner, "Optimal location of wood gasification plants for methanol production with heat recovery," no. March, pp. 1080–1091, 2008.

[20] G. Halkos and K. N. Petrou, "Efficient waste management practices: A review," *MPRA*, no. 71518, 2016.