Waste to Energy Opportunities in Botswana: A case study review

Gratitude Charis, Gwiranai Danha, Edison Muzenda
Chemical, Materials and Metallurgical Engineering
BIUST
Palapye, Botswana

Edison Muzenda, Bilal Patel, Corina mateescu
Civil and Chemical Engineering
UNISA
Florida, Johannesburg, South Africa

Edison Muzenda
Chemical Engineering Technology
University of Johannesburg
Doornfontein, Johannesburg, South Africa

***Abstract*— The need for efficient solid waste management practices has become more pressing, especially in developing nations largely experiencing a population boom in urban areas. Currently, however, it is only developed nations that have embraced resource efficient practices and technologies to produce energy, heat, fuels and compost from solid waste. This paper reviews such global trends and best practices as a benchmark against current practices within the context of Botswana. It also reviews the opportunities for Waste to Energy (WtE) in this developing nation by taking a solid waste inventory. A literature survey revealed that Botswana is still operating in the previous policy direction of keeping the society clean to avoid the hygienic effects of waste. The collection and disposal of waste is partly decentralized with several private players. There is little recycling within the country; most private companies collect recyclables and send them to South Africa. Anaerobic digestion and incineration are the only WtE opportunities that had been previously identified with no major commitment on implementation. There are alternative WtE technologies, therefore the economic and technical requirements should be weighed against the corresponding capacity of the nation.**

Keywords- case study; conversion; energy; waste

I. INTRODUCTION

The global annual generation of waste was estimated at 1.3 billion tonnes by the World Bank in 2012, and projected to double to around 2.2 billion tonnes per annum by 2025 [1]. The need for efficient Solid Waste Management (SWM) practices has become more imminent than ever, especially in developing nations which are largely experiencing a population boom in urban areas [2]. Currently, however, it is actually in industrialized/developed nations that resource efficient SWM practices and technologies to produce energy, heat, fuels and compost from Municipal Solid Waste (MSW) are well established. Developing nations like Botswana, on the contrary are still grappling with challenges around collection and transport of waste, and management of landfills [2]. At this rate, Organization for Economic Co-operation and Development (OECD) countries could reach 'peak waste' by 2050, East Asia and Pacific countries by 2075, while waste will continue to grow in Sub-Saharan Africa (SSA) [3]. There is need for an urgent consideration for higher resource efficiency in SSA, comprising reuse, recycling and recovery of material and energy, perhaps starting at lower level investment entries. This proposal highlights some of these short to medium-term SWM opportunities for Botswana, especially from a Waste to Energy (WtE) and materials perspective.

A. *Methodology and scope*

This study covers the potential utilization of Solid Waste (SW) fractions that can be exploited to obtain energy products. The objective is to adapt best practice from global trends into the current SWM system in Botswana, after defining the current local trends and their inherent loopholes. It is mostly a desktop study, reviewing articles on recent global SWM trends within past 5 years. The study then also reviews local trends, though the frame used in this case is the past 10 years due to scarcity of SWM published information in this developing Southern Africa nation.

II. WASTE MANAGEMENT AND VALORIZATION: GLOBAL COMPARED TO LOCAL TRENDS

A. *The waste management evolution*

Over the years, waste management has evolved from simply providing waste volume reduction and public hygiene to encompass a wider range of objectives including waste utilization, conversion to energy and valuable products (up cycling) or less valuable products (down cycling) [5]. There has been a global, calculated shift towards a more circular economy, discouraging further unnecessary depletion of scarce natural resources and encouraging efficient use that reduces waste, reuse and recycling of waste (see Fig 1). In cases where waste is not recycled, it can still be down cycled or converted to energy or fuels, compensating for any gaps within the circular economy. Such a concept that eliminates simple disposal of waste and render it a useful input for other economic activities through material or energy recovery (industrial symbiosis) has become popular in developed nations. This is because it mimics natural ecosystems where the waste from some organisms is used up by other organisms and nutrients are cycled and preserved through such an ecosystem [6].

The waste management hierarchy already emphasizes such a recovery of material and energy as priority, rather that disposal at the very bottom (Fig 2).

B. *WtE market scope*

Indeed, obtaining energy and useful products/materials from waste has become a sensational topic attracting the interest of most developed nations, policy makers, industrialists, academics and the general public.

	Previous Policy Direction		New Policy Direction
Policy Circumstances	**Worsening Pollution due to Waste**		**Climate Change, Raw Material and Fossil Fuel Exhaustion**
Objective	**Create Clean Living Conditions**	⇒	**Construct a Resource Recycling Society**
Implementation Strategy	Reduction → Recycling → Treatment and Disposal	⇒	Effective Production/Consumption → Material Recycling → Energy Harvesting → Advancing Treatment and Disposal
Main Task	Volume-Rate Garbage Collection System,Extended Producer Responsibility Policy and Treatment Facilities	⇒	Resource recyclability Evaluation, Recycled Product Quality Certification, Waste-to Energy, Large-Scale Treatment
Core Concept	**"Waste"**	⇒	**"Resource(Recyclable / Natural)"**

Fig 1: The evolution of global policies on waste [4]

Even in the case of landfill disposal, efforts to recover methane should be made [7]. While developed nations have adopted the new policy direction towards waste management and the higher levels of the waste management hierarchy, most developing nations like Botswana are still operating in the 'previous policy direction' (Fig 1). The focus of this previous policy is keeping the society clean to avoid, especially hygienic effects of waste- a lower level basic objective compared to encouraging resource efficiency though reducing, reusing and recovery of materials/energy from waste.

Ultimately, developing nations have been passive with regards to global new policy directions stipulating the valorization of urban and industrial waste [8]. For instance, a survey of Southern African nations energy policies in 2014 revealed that only South Africa had come up with a detailed Renewable Energy policy; one such instrument that covers WtE initiatives [9]–[11]. Similarly, developing nations are also stuck to old environmental and waste disposal policies, as in the case of Botswana, whose Waste Management Act and Botswana's Strategy for Waste Management have not been adjusted in keeping with the higher resource efficiency objectives [7]. Besides the obsolete policies and relaxed control measures characterizing waste management for developing nations like Botswana, other challenges include the absence of spatial and quantitative statistics; under-organized structures and strategies, little allocated financial resources, booming urban populations and the associated system complexity and multidimensionality.

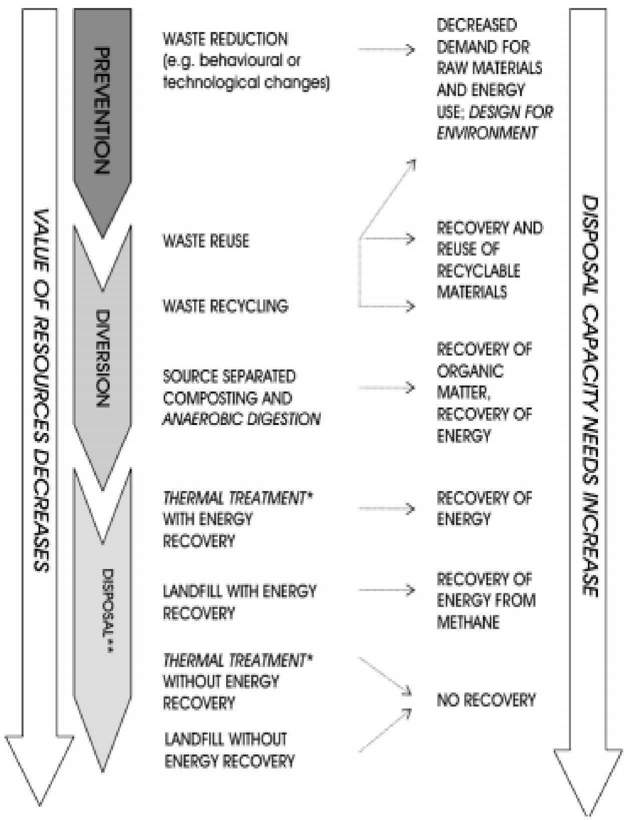

Fig 2: The waste management hierarchy [6]

The global WtE market was valued at US $25.32 billion in 2013, having grown by 5.5% from 2012. It has then been projected to grow by a compound annual growth rate (CAGR) of over 5.5% from 2016, reaching a value of US$40 billion by 2023 [3]. Statistica provides a slightly different CAGR projection of 6% for the period 2018-2023, starting from a recorded US$28.43 billion in 2017[1]. The main drivers for WtE growth are the hype towards increasing the share of renewable energy sources (RES) and reducing greenhouse gas (GHG) emissions, rising environmental consciousness, global efforts towards a circular economy, government policies and an improved public perception.

The World Energy Council (2016) also points out that WtE technologies can lead to development of remote areas through provision of energy [3]. The plants built would also provide jobs for the local community and lead to infrastructure development. There is a rising government impetus supporting the use of advanced processes to dispose solid and municipal waste while generating alternative, clean energy or fuels and a low carbon economy [12]. Waste valorization creates an opportunity to balance environmental, socio-cultural and economic aspects of sustainability by reducing the ecological impacts, increasing value chains and enhancing enterprise developments.

C. Taxonomy issues: Classes and categories

It is easier to define a roadmap for waste valorization when the waste origins, quantities, identity and properties are adequately profiled. According to Halkos and Petrou (2016), one cannot manage waste effectively until it is measured and classified appropriately [13]. The classification of wastes varies according to key policies driven by various regions and nations.

Fig 3 and Table 1 are examples of some of the criteria used to classify waste.

Considerable global attention is given to MSW, which is solid waste collected by or on behalf of municipal authorities from residential, commercial, industrial (non-process wastes) and institutional sectors [6]. This definition excludes liquid, hazardous, construction and demolition wastes. The MSW is then further separated at source or after collection, into organics, recyclable inorganics like paper and glass, and food-waste. However, specific industries, institutions and agro-forestry sectors produce large quantities of certain solid wastes that warrant proper management strategies. These include medical waste, various forms of agricultural waste and forestry trimmings

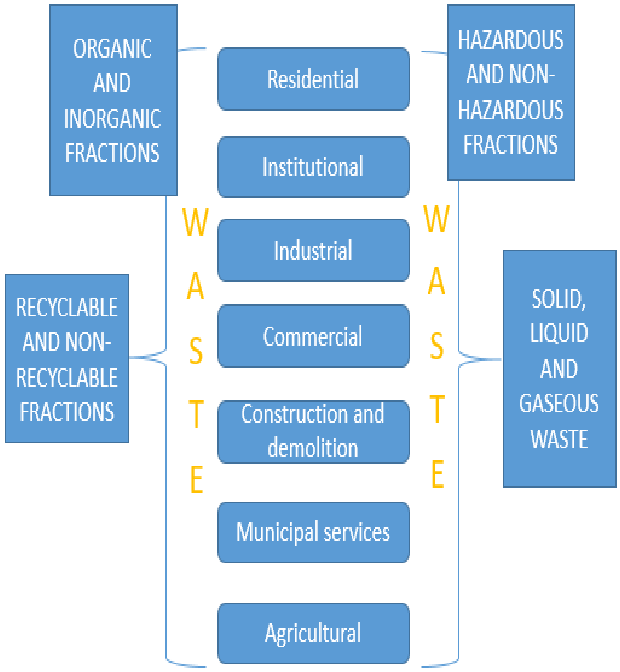

Fig 3: MSW sources and fractions (adapted from [6])

TABLE 1: CLASSIFICATION OF WASTES [13]

Source/type		Composition
MSW	Residential	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, household hazardous wastes and special wastes (e.g. bulky items, consumer electronics, white goods, batteries, oil, tyres).
	Industrial	Housekeeping wastes, packaging, food wastes, wood, steel, concrete, bricks, ashes, hazardous wastes.
	Commercial & Institutional	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes, e-wastes.
	Construction & demolition	Wood, steel, concrete, soil, bricks, tiles, glass, plastics, insulation, hazardous waste.
	Municipal services	Street sweepings, landscape & tree trimmings, sludge, wastes from recreational areas.
Process waste		Scrap materials, off specification products, slag, tailings, top soil, waste rock, process water and chemicals.
Medical waste		Infectious wastes (bandages, gloves, cultures, swabs, blood and bodily fluids); hazardous wastes (sharp instruments, chemicals); radioactive wastes; pharmaceutical wastes
Agricultural waste		Spoiled food wastes, residues, pesticides, animal dung, soiled water, silage effluent, plastic, scrap machinery, vet-medicines
Forestry waste		Sawmill residues, invasive species, fruit residues

.

[1] https://www.statista.com/statistics/480452/market-value-of-waste-to-energy-globally-projection/

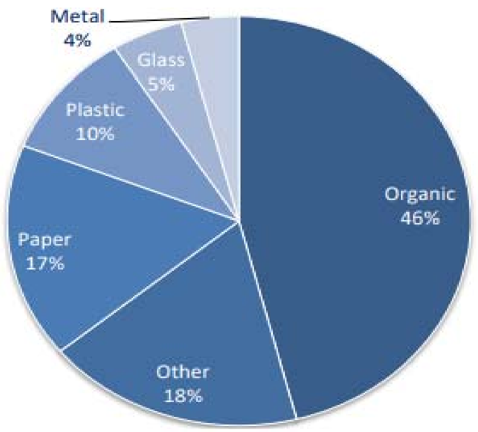

Fig 4: Global composition of MSW [6].

In developed countries like Sweden, material recovery and recycling is done for most of the inorganic waste stream; the Swedish Environmental Protection Agency, actually claims that 90% of the household waste that are generated in the nation has been recycled in some way [7]. Fig 4 shows the global composition of MSW. However, various nations/regions will have different MSW compositions depending on socio-economic status, consumer habits, natural resources available and SWM practices.

III. Opportunities for Waste Valorization in Botswana

Previous studies and recommendations on SWM and valorization opportunities have been made on Botswana. Besides sources quoted in this section, the United Nations Development Programme (UNDP), through its office in Botswana, published a document titled 'The Botswana Recycling Guidelines: Advice on Valorization for Middle-Income Countries' [14]. This was a market study and situational analysis, mainly focused on the demand and opportunities for materials recycling. It reported that there is a robust market for recyclables in Botswana, due to the presence of established recycling companies. There is also a ready market in neighboring, well industrialized nations like South Africa and Zimbabwe, where some of the recycling companies sell or send their collections for final processing. The document provided useful guidelines under the following sections:

- Modernizing the Enabling Environment- Policy level reforms (e.g. updating the 1998 Solid Waste Act)
- Planning and organizing valorization- Quick improvements in landfill based valorization, planning for recycling and valorization, market study for organics and recyclables.
- Technical and operational guidelines- buy back and drop off centers, source separation and collection, Material recovery facility, recycling for classified materials (types 1, 2 &3).
- Guidelines for fees and financials: (UNDP Botswana, 2012).

The guidelines, however, did not discuss in detail the recovery of energy from waste, especially unrecyclable fractions and organics. This is a key objective that this study covers.

A. Current waste management practices

As in other developing nations, there has been a marked increase in MSW generation in Botswana due to a boom in urban population. This is caused by rural-urban migration and a large influx of immigrants attracted by the stable economy and peaceful political environment. The main disposal route for the MSW is landfilling, which is the most discouraged level in the global best practices [15]. This is because landfills take up large land space and have various environmental ramifications including emission of methane, possible leak of leachate into groundwater and hazardous air pollutants (HAPs) like vinyl chloride, ethyl benzene, toluene, and benzene.). Table 2 catalogues the activity of some of the organizations involved in SWM in Botswana, as documented by Nagabooshnam (2011) and Suresh (2011) [7], [15].

TABLE 2: Organizations Involved in Waste Collection & Recycle [7], [15]

Company	Type	Activities
Skip Hire	Private company	Collects waste from private organizations, institutions, commercial and industrial sectors.
Collect-A-Can	Private company	Collects metal cans from institutions such as the Botswana Defence Force (BDF), commercial & industrial sectors. Also buys from scavengers. Cans are compressed then transported to SA for recycle.
Scrapcor Ltd	Private company	Collects metal scrap from large institutions, households and individuals
Dumatau Trading	Private company	Collects paper for recycling in SA.
Simply Recycle	Private company	Collecting plastic waste (PET and PP), and processing it into new raw material.
Somarelang Tikologo, Kalahari Conservation & others	NGO's	Supporting waste management and minimization through grants, project and technical bridges.

The major statutory instruments used for the SWM in Botswana are the Waste Management Act and the Botswana's Strategy for Waste Management, which were published in 1998 [7]. Household waste is collected by city and town councils or their subcontractors, then transported to landfills without any pre-treatment, since Botswana currently has no recycling or treatment units [15]. Even so, residents are not mandated to subscribe for waste collection; they can opt to dispose on their own by burning or burying, especially in the smaller towns and in villages. There is very little source sorting, a few drop-off centers for inorganic waste streams and no deposit-refund system for recyclables such as plastic bottles, metal cans, and glass bottles [15]. Commercial, industrial and institutional waste is normally collected by subcontractors, some of which have specific streams they collect for recycling in South Africa. Efforts to process some recyclable waste in

Botswana have been made by companies like Pula steel (for scrap metal) and Choppies (carrier bags).

The current waste valorization activities have focused on inorganic recyclables, while the only considered energy recovery options have been anaerobic digestion and incineration (see Table 3). However, there is a large fraction of organics and non-recyclable inorganic fractions that could be pegged for recovery of energy through alternative WtE technologies. Table 3 shows a number of waste valorization opportunities that have been identified, especially for Gaborone, the capital city [15]. Evidently, these opportunities have largely excluded most WtE alternatives, which are considered in greater detail in the next section. Although cow dung may be included in the anaerobic digestion alternative, it is useful to mention that this is an abundantly available waste of at least 22,803 tonnes per year[2] [16]. Another recently identified, unquantified waste valorization opportunity is the use of the Marula empty nut, after extracting the kernel. This follows the success of an indigenous company, Blue Pride, in producing export quality Marula oil from Marula nuts, with customers in the US and a large looming market in Southern Africa[3]. Though Blue pride has a well-knit raw material sourcing strategy from villages with large Marula tree populations, they do not yet have a good disposal or valorization plan for the tonnes of empty nuts remaining after extracting the oil bearing kernels. There is also a potential for the use of encroacher bushes/trees like the Acacia species from rangelands for these WtE purposes. A good case in point being Namibia, which has been valorising its encroacher waste into charcoal, wood chips and briquettes, with many other identified WtE opportunities [17].

IV. WASTE TO ENERGY CONVERSION TECHNOLOGIES AND SELECTION CONSIDERATIONS

WtE conversion technologies are largely divided into thermochemical, physicochemical (chemical) and biochemical methods (Fig 5). The choice of the conversion technology depends on a number of factors, among them are the nature and composition of the waste, pre-treatment requirements, thermal properties and overall costs [18]. Biological treatment is reserved for the biodegradable organics, while thermochemical treatment is quite universal for all waste feedstocks, as long as there are no toxic emissions that cannot be contained. Chemical treatment on the other hand, is selective to especially extractable oils that can be hydro-treated or esterified into biofuels [19]. In selecting options for short and mid-term application from these opportunities, it is important to consider both technical and socio-economic aspects. For instance, the thermochemical methods are gaining a lot of attention due to their ability to utilize a large range of feedstock and whole parts of lignocellulosic residues while ridding the environment of the waste nuisance. Combustion is the simplest and widely practiced, with many commercialized applications, however, its disadvantages are the low efficiencies and the extra investments required to curb emissions- a step which developing regions often skimp. Gasification is highly efficient; however it is characterized by high investment costs and is technically intensive. Pyrolysis and torrefaction are relatively simpler to operate, with lower investment costs, therefore these are attractive entry level opportunities for developing nations. Moreover, the solid and liquid products from these are easier to store, handle and transport than gas, providing quick income generation opportunities. Before choosing and implementing any of the WtE options, however, a detailed statistical database of the wastes should be compiled. Thereafter, a holistic assessment of the feedstock capacity requirements, costs, and benefits associated with various WtE alternatives for the country should be evaluated, as well as how well these options fit the social and economic status of the country.

TABLE 3: WASTE VALORIZATION OPPORTUNITIES IDENTIFIED FOR GABORONE, THE CAPITAL CITY.

Waste category	Quantity generated annually (tonnes)	Potential treatment method	Environmental potential
Paper	15000	Material recycling	-Potential saving of 45-60GWh of electricity -Savings of up to 34×10^3 of landfill space. -Saves energy equivalent of 365 terrajoule of gasoline & *ca* 255×10^3 trees
Combustible waste (paper, textile, plastic & wood)	28500	Incineration with energy recovery	Potential generation of 15GWh electricity
Organic waste	18000 (2011) ; cow dung only 22,803 (2015)	Anaerobic digestion (AD)	$18\text{-}36\times10^6$ biogas can be produced
Metals (Aluminium)	3000	Material recycling	Saves 18 kilotonnes of bauxite, 12 kilotonnes of chemical & 42 GWh of electricity.
Glass	3000	Material recycling	36×10^2 tonnes of raw material are conserved. 945 tonnes of CO_2 emission are reduced by the facility
Plastic	7000	Material recycling	Saves 396×10^2 cubic metres of landfill space.

[2] Total population of cattle: 2,073,000. 11kg dung/cow

[3] http://www.nepadsanbio.org/biofisa-two/project-portfolio/marula-kernels-extraction-natural-seed-oil

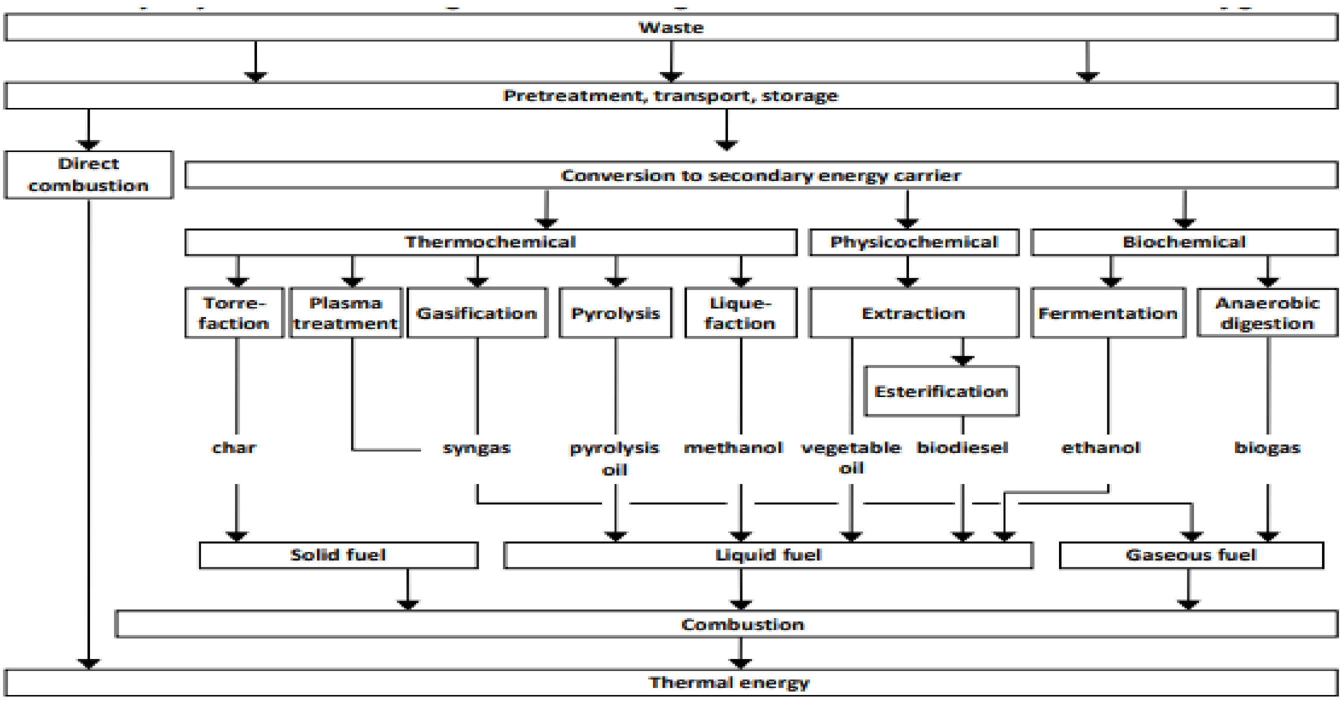

Fig 5 : WtE conversion technologies [20]

V. CONCLUSION

Warnken (2008) reports that processing waste in its various forms can be technical in nature, requiring significant capital investments [21]. However, some technologies are within the reach of developing nations like Botswana. What may have been lacking could have been enough socio-economic justification for an investment in some technologies. Moreover, consistent research and development in WtE and materials has rendered many technologies affordable, more efficient and accessible since 2008. Meanwhile, more technologies have also been commercialized, presenting a plethora of waste valorization alternatives. In Botswana's case, the solid waste feedstocks that are abundantly available and accessible include MSW, cow dung, Marula seeds and invasive/encroacher bushes like Acacias. Besides the already considered incineration and anaerobic digestion, the WtE technologies that could be considered first are pyrolysis and torrefaction. These have a higher overall efficiency, are cost effective, have less technical demands, have lower investment costs and their products are relatively easier to handle, store and transport. Perhaps one reason why developing nations fall short in waste valorization is that the socio-economic gains and impacts of not doing so are not clearly understood. These benefits of a circular, resource efficient economy are incalculable including reduced natural resource depletion, reduced process energy use, reduced emissions, reduced imports & costs increased employment and enterprise development. For developing nations like Botswana to compete and grow in this 21st century of globalized, emerging economies, there is need to get the most out of its resources like waste- not just bury it in landfills!

REFERENCES

[1] D. Hoornweg and P. Bhada, "What a Waste. A Global Review of Solid Waste Management," *Urban Dev. Ser. Knowl. Pap.*, vol. 281, no. 19, p. 44 p., 2012.
[2] D. Moya, C. Aldás, D. Jaramillo, E. Játiva, and P. Kaparaju, "Waste-To-Energy Technologies: An opportunity of energy recovery from Municipal Solid Waste, using Quito - Ecuador as case study," *Energy Procedia*, vol. 134, pp. 327–336, 2017.
[3] World Energy Council, "World Energy Resources: Waste to Energy," vol. 2015. 2016.
[4] United Nations, "Waste Management in South Korea," 2011.
[5] L. A. Hadidi and M. M. Omer, "A financial feasibility model of gasification and anaerobic digestion waste-to-energy (WTE) plants in Saudi Arabia," *Waste Manag.*, vol. 59, pp. 90–101, 2017.
[6] G. Davidson, B. Gillis, M. Gillis, B. Kenney, and M. Wilkinson, "Waste Management Practices : Literature Review," no. June, 2011.
[7] S. Suresh, "Waste Management in Botswana," Linkoping, Sweden, 2011.
[8] L. Abarca, G. Maas, and W. Hogland, "Solid waste management challenges for cities in developing countries," *Waste Manag.*, vol. 33, no. 1, pp. 220–232, 2013.
[9] E. D. Deenanath, S. Iyuke, and K. Rumbold, "The bioethanol industry in sub-Saharan Africa: History, challenges, and prospects," *J. Biomed. Biotechnol.*, vol. 2012, 2012.
[10] A. Gasparatos *et al.*, "Biofuels in sub-Sahara Africa: Drivers, impacts and priority policy areas," *Renew. Sustain. Energy Rev.*, vol. 45, pp. 879–901, 2015.
[11] Netherlands Enterprise Agency, "Renewable Energy Market Study Zimbabwe 2017," 2017.
[12] P. Stanchev, E. Katsou, S. Pons, A. Vlasopoulos, N. Spencer, and R. Krzy, "Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe," vol. 141, 2017.
[13] G. Halkos and K. N. Petrou, "Efficient waste management practices: A review," *MPRA*, no. 71518, 2016.
[14] UNDP Botswana, "The Botswana Recycling Guidelines: Advice on Valorisation for Middle-Income Countries," 2012.
[15] J. K. Nagabooshnam, "Solid Waste Generation & Composition in Gaborone , Botswana . Potential for Resource Recovery," *Master Thesis,*

Dep. Manag. Eng. Linkoping Univ. Sweden, 2011.
[16] Statistics Botswana, *Botswana Agricultural Census Report 2015 Statistics Botswana*. 2018.
[17] DECOSA, “Support to De-Bushing Project Value Added End-Use Opportunities for Namibian Encroacher Bush,” 2015.
[18] M. Patel, X. Zhang, and A. Kumar, “Techno-economic and life cycle assessment on lignocellulosic biomass thermochemical conversion technologies: A review,” *Renew. Sustain. Energy Rev.*, vol. 53, pp. 1486–1489, 2016.
[19] IRENA, “Innovation Outlook Advanced Liquid Biofuels,” p. 132, 2016.
[20] L. Helsen and A. Bosmans, “Waste-to-Energy through thermochemical processes : matching waste with process,” *Int. Acad. Symp. Enhanc. Landfill Min.*, no. January 2010, 2010.
[21] J. Taylor and M.Warnken, “Wood recovery and recycling : A source book for Australia,” 2008.