Climate Change Adaptation: Opportunities for Increased Material Recycling Facilities in African Cities

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Abstract

Africa's urban morphology is expected to develop at a steady rate between 2020 and 2050. Population growth, rising urbanization rates, growing energy consumption, and industrialization are only a few of the reasons causing these changes. Likewise, waste production is projected to rise from 125 million tons in 2012 to 244 million tons annually by 2025. Around 60.0% and 80.0% of African waste is made up of organic material, which is a viable methane source. Fly tipping, free disposal, landfilling, and incineration have been used as a large-scale waste treatment system in most African cities. However, with the anticipated morphological changes, these solutions are no longer viable in the future due to lack of airspace, availability of urban land for new landfill sites, and concerns over carbon emissions. This chapter discusses the potential for improved adoption of material recycling facilities (MRF) in urban environments as an incentive to support waste diversion from landfills, decentralize waste separation activities, and increase the transformation of waste materials into valuable raw materials. A case study is discussed for Ethiopia, Ghana, and South Africa with the goal of explaining current processes, urban planning initiatives required for greater implementation, and how they can be interpreted as adaptation initiatives.

Keywords

African cities · Urban morphology · Waste management · Methane · Material recycling facilities

Introduction**Towards Zero Carbon Cities**

Africa has 1.3 billion people (Worldometer 2020) and is the second largest continent after Asia. Many regional studies consider the socio-economic promise of the continent, propelled by urbanization, industrialization, and demographic growth. Achieving this potential would be confronted with a variety of obstacles. Solid waste management is currently one such problem particularly in urban areas. Ten of the fastest growing cities over the next decade are expected to be in Africa. Such cities include Luanda (Angola), Yaoundé (Cameroon), Dar es Salaam (Tanzania), Kumasi (Ghana), Kampala (Uganda), Lusaka (Zambia), Douala (Cameroon), Mbuji-Mayi (Congo), Antananarivo (Madagascar), and Tshwane (South Africa) (Knight Frank 2017). When these cities expand, accumulation of industrial waste becomes expected. Most African cities are generally planned and organized based on colonial urban planning (Home 2015). Little or no town planning has been undertaken since independence. That means little or no concern other than landfills and open dumps built in the 1960s and 1970s for urban waste management.

The main issue is the effect on carbon emissions in all municipal solid waste and cities. The African continent is vulnerable to climate change impacts. Urban areas are critical for effective adaptation to climate change (Revi et al. 2014). More than 50.0% of the world lives in urban areas and these communities partake in industrial practices that generate greenhouse gas (GHG) pollution. Socio-economic inequalities have also seen a dramatic rise in informal settlements in regions that are vulnerable to climate threats, such as natural disasters, public health, damage to homes, and income disruption. Inadequate provision of infrastructure and service delivery are exacerbating risks, especially for low-income households (Revi et al. 2014), and the pace of urbanization has exceeded the ability of many governments to handle it. In 2018, nine African cities pledged to achieve zero carbon cities by 2050. The cities include Accra (Ghana), Addis Ababa (Ethiopia), Dakar (Senegal), Lagos (Nigeria), as well as cities of Cape Town, Durban, Johannesburg, and Tshwane (South Africa). Nairobi (Kenya) and Abidjan (Côte d'Ivoire) are still expected to pledge. Drastic policy, human intervention, and finances will be required to reduce emissions from transport, construction, energy production, and waste management sector (The Economist 2018).

Waste management practices in Africa are not the most effective. Landfill alone contributes between 3.0% and 5.0% of overall industrial emissions (Zhang et al. 2019). Much of the academia and industry focuses on encouraging recycling practices not only as a method of waste disposal from landfills and open dumps, but also as a measure of climate adaptation and mitigation. Africa recycles only 4.0% of its total solid waste (Mohee and Simelane 2015; UNEP 2018). Before landfilling, further exploration of waste collection, separation, and beneficiation is necessary. More Material Recycling Facilities (MRFs) should be considered to boost recycling practices, waste data collection, and alleviate African cities from disposal pressures. Countries such as the United Kingdom have state-of-the-art engineered facilities that divert approximately 50,000 tons of waste per annum from landfills (Ali and Courtenay 2014). In the African context, academic research pertaining to MRF adoption and implementation is far and few in-between while industry or commissioned research is available but restricted between client and supplier. There is a global motivation to dispose of waste from open dumps and landfills as well as to reduce the contribution to emissions. With growth and urbanization proliferating in the coming decade, it is our view that urban planning has a role to play in rising MRFs as a way of mitigating the projected volumes of waste in urban areas.

Objectives and Chapter Outline

Urbanization and population growth are anticipated to be significant drivers of climate change and pollution in the Global South. Currently, cities accommodate over half of the global population, generate approximately 82.0% of global GDP, account for 70.0% of global energy consumption, and account for over 70.0% of greenhouse gas emissions (Godfrey and Zhao 2016). However, it is estimated that by 2050 global, urban population will exceed 6.7 billion and that nearly 80.0% of

population growth will take place in low and middle income countries, where populations are already rising by over one million people per week (C40 Cities Climate Leadership Group 2016). There is therefore an urgent concern to increase climate change mitigation and adaptation efforts in African cities. Thus, the main objective of this chapter is to determine how material recycling facilities can be used as tools to facilitate climate change adaptation (and mitigation) in African cities.

To this end, the approach used consisted of exploratory case studies of three waste disposal activities in Ethiopia, Ghana and South Africa, and a review of secondary data, consisting of project reports and scholarly articles. The report is organized as follows: section “[Literature Review](#)” addresses the evolution of urban planning in Africa and contextualizes the relationship between climate change and waste management in Africa as well as the rationale for improving waste management and introduces Material Recycling Facilities, how they are planned and designed. The aim is for readers to have an appreciation before going into the case studies. Section “[Research Approach](#)” discusses the exploratory case study approach. Section “[Case Studies](#)” discusses whether Ethiopia, Ghana and South Africa have urban, waste management, and climate change adaptation plans, strategies, and projects relating to MRFs. Section “[Proposed Recommendations and Conclusion](#)” offers climate change and waste management practitioners recommendations and concludes with an assessment of urban planners’ roles and responsibilities.

Literature Review

Evolution of Sustainable Urban Planning in African Cities

Africa’s towns and cities are shaped by laws imported from British colonial rule from the 1920s (Home 2015). Urban Planning, interchangeably referred to as Town and Regional Planning or City Planning, is a discipline within the built environment that is concerned with designing and developing land use (Lubida et al. 2019). It was officially recognized as a profession in the latter twentieth century (Home 2015). Key considerations range from transportation, engineered utilities (water, electricity, sewerage systems), infrastructure, communication, and social amenities (schools, hospitals, parks, economic activities). Spatial and land use planning are the most predominant specializations in the field of urban planning. This is a dynamic activity that requires juggling social, cultural, environmental, and political influences (Lubida et al. 2019). Decisions surrounding zoning, subdivision, and urban planning are taken by land use authorities, in consultation with different stakeholders (Home 2015). Amenities such as waste management have not been deliberate in planning strategies. While there is a global push for cities to become more environmentally responsive and to implement mitigation and adaptation initiatives through policies and strategies – Sustainable Development Goal 13, Target 13.2 – current urban systems are not conducive. A large part of African cities are still centered around colonial town planning principles and regulation, with a morphology characterized

by informalities – informal settlement, informal structures, and informal waste pickers.

Postindependence, there was very little evidence of the evolution of land use planning, especially the form that supports sustainability. Throughout the 1980s and 2000, several academics started to re-invent postmodern planning, one driven by economic development and environmentalism (Okeke and Nwachukwu 2019). An increasing body of literature on urban sustainability and innovative planning approaches has begun to shift urban development patterns (Lwasa and Njenja 2012). The term “green technology” was identified as a tool for modern urban planning. This includes deliberate coordination of activities that are energy efficient and promote renewable energy, recycling activities, and more. There are different technologies that contribute towards sustainable urban planning, such as the implementation of enhanced municipal waste management (Laffta and Al-rawi 2018). Four types of eco-technologies that urban planners can start implementing more are:

1. Environmental Technology: a range of technologies relating to waste management, access to water and energy
2. Information Technology: hardware and software coupled with environmental sensor technology to collect environmental data
3. Geographic Information Systems: collect, share, manipulate geographic data and incorporate with Urban Information Systems to guide design and development of land use and environmental plans
4. Communication Technology: software to transfer data and knowledge to different environments

Green technologies are most prevalent and commercialized in Denmark, Sweden, Japan, India, Iraq, Finland, Canada, and the United States of America, just to name a few (Laffta and Al-rawi 2018). Opportunities for African planners to leapfrog are bountiful. Such tools can be used not only for sustainable urban development and waste management but as part of climate mitigation and adaptation strategies. Kenya is not far from realizing the benefits of green technologies. Urban planners are responsible for solid waste management. The National Solid Waste Management Strategy is used to incorporate solid waste management and best practices into urban plans. The plans are then subjected to a Strategic Environmental Assessment, which assesses aspects such as sustainability, proposed waste management programs, as well as relevant services and facilities (Ozoike-Dennis et al. 2019). The authors further state that *solid waste management* (SWM) plans are included in the *Nairobi Integrated Urban Development Master Plan* (NIUPLAN). The SWM plans focus on “improving waste collection and transportation system, closing open landfills, and constructing Material Recovery Facilities, where waste material is to be separated to compost biodegradable material, and recycle non-biodegradable material.” In South Africa, municipal departments in charge of solid waste management are required to develop Integrated Waste Management Plans as stipulated in the National Environment Management: Waste Act (59 of 2008). The IWMPs include practical aspects of

managing waste in municipalities. It is one of the sector plans that feed into and is guided by the Integrated Development Plans (Sango et al. 2014).

Climate Change Adaptation

The mean annual temperature in Africa increased by 1.7 °C in the last two decades of the twenty-first century and temperatures are expected to increase faster than the global average in the last two decades (Revi et al. 2014). It negatively impacts on livelihoods, health and sanitation, access to water, agricultural production, and urban infrastructure as well as slows down sustainable development (Reda and Tripathi 2011). Climate change demands new sustainable development strategies through mitigation and adaptation measures. Africa generates just 4.0% of global pollution, but will suffer serious consequences (Reda and Tripathi 2011). Field et al. (2014, p. 1104) define adaptation as a “response strategy to anticipate and cope with impacts that cannot be (or are not) avoided under different scenarios.” Adaptation has to do with strategies and plans that can be implemented. They should be linked to development strategies and plans and disaster risk management. By doing this, developmental benefits are identified for the shorter term while reducing vulnerabilities in the longer term (Mimura et al. 2014). The importance of adaptation is influenced by how the issues are outlined (Mimura et al. 2014). They are heterogeneous and very few have been monitored and evaluated in great detail. The process of adaptation planning is a complex social process that can create unrealistic expectations. It is done at a national level and implemented at a local level. However, poor coordination as well as recent and quality data can also impede the transition from planning to implementation, as is the case for many developing and developed countries (Mimura et al. 2014).

Accordingly, adaptation responses differ from context to context and involve a multiscale perspective which takes into account cultural, social, environmental, and institutional factors. If climate change is moderate, sustainable development will be greater and if it is high, sustainable development has less impact (Field et al. 2014). It involves designing strategies in the sense of waste management which reduce generation. Given the expected population growth, waste generation is unavoidable. Several primary practitioners interested in adaptation responses are environmental planners as they are planning for physical environments, environments impacted by disasters of climate change (Mimura et al. 2014). They build land use plans enabling or avoiding climate-risk projects (Revi et al. 2014, p. 8). City planning and land management are important (but certainly not the only) resources for policymakers to create climate-resilient city systems and construct capacity for sustainable urban growth at local level, connecting adaptation and mitigation steps, and enhancing livelihoods and quality of life for urban communities. Attention should shift to integrated development planning (Reda and Tripathi 2011). Today, African cities face a critical urban situation marked by a failure of governance structures in the face of increasing waste production combined with strong demographic growth and proliferation of slums and poverty. Strengthening waste management capability is

critical for fostering smart urban growth and maintaining cities' democratic, economic, and social stability.

Greenhouse gas emissions from urban waste in developing countries are expected to increase drastically in future (Friedrich 2013) which may result in increased emissions from the waste sector. Increasing recycling, anaerobic digestion, and composting activities can reduce emissions. Waste material is not the only aspect of the value chain contributing towards emissions. Collection and transportation consume approximately 5 dm³ (liters) of diesel per ton of waste, which accounts for 15 kg CO₂e emissions from landfilling alone range from 145 to 1,016 kg CO₂e per ton of wet waste. Aerated and turned windrow composting releases between 172 and 186 kg CO₂ per ton of wet waste (Friedrich 2013).

Globally, landfills contribute 3.0% to 5.0% of total global emissions (Zhang et al. 2019) because methane gas is the main carbon emission (Couth and Trois 2012). In Africa, it remains the cheapest and most common disposal method. Landfills are categorized as controlled or uncontrolled dumping or semi/medium/highly engineered facilities. The status of landfill classification structures in sub-Saharan Africa between 2000 and 2018 was evaluated by Idowu et al. (2019). To name a few, they identified 31 landfill sites across South Africa, Botswana, Cameroon, Ghana, Uganda, Kenya, Tanzania and found that 80.0% were listed as 0 and 1 (where 0 was classified as open dumpsites and 1 as controlled tipping). Classifications as non-engineered landfills make it difficult to benefitiate waste and manage environmental impacts such as leachate, groundwater contamination, air borne particulates, and pollution. Vaccari et al. (2019) conducted a technical review of leachate characteristics in landfills and open dump engineering in developing countries. The authors found 21 engineered landfills and 13 dumpsites across Africa as well.

State of Waste Management in Africa

Local authorities in developing countries are facing significant waste management problems as a result of an increasingly rapid rise in locally generated quantities and the complexification of the forms of waste to be handled. Informal waste collection is also used as an external constraint: it usually takes place under unstable social and environmental circumstances and, a priori, makes waste disposal more complex, managed by a multitude of minor actors. Moreover, data on waste quantities, characteristics, and source is a major impediment particularly for proper planning, implementation, monitoring, and evaluation. Most of the data in this section is based on 2005 and 2012 statistics, which was also used to forecast waste proliferation by various regional bodies, namely, the United Nations Environmental Programme. The daily ratio is the amount of waste generated per capita and per day. Its knowledge is a crucial phase in the introduction of waste management approaches. The amount of waste produced is always very heterogeneous and variable depending on the region, the lifestyles and culture, and the socio-economic level. Changes in lifestyles, living habits, consumption, and demographic growth have a significant effect on the quantity and typology of waste generated. This development often varies from one

city to another within the same region, or from one district to another within the same city also according to peoples “living conditions.” In sub-Saharan Africa, though per capita waste production rates are lower than in other areas of the world, high population growth, combined with increasing urbanization, would increase unbearably waste generation beyond existing capacities. In this regard, Kaza et al. (2018) forecasts that the overall quantity of waste in Africa will double from 174 million tons per year in 2016 (2.1 billion tons globally) to 269 million tons by 2030 (3.4 billion tons per year in 2025). Africa’s waste generation accounts for 9.0% of total global waste generation (Kaza et al. 2018). Developing countries generally have an average annual production of waste per capita ranging from 180 kg to 240 kg, a quantity that is likely to double as a result of industrialization and the evolution of production and consumption patterns if adequate measures are not taken to influence this progression.

Waste Services and Infrastructure: Municipalities are responsible for providing waste related services in most African cities (Friedrich 2013; UNEP 2018). Infrastructure includes but not limited collection, transportation, recycling, treatment, disposal, and beneficiation in some cases. However, expensive and insufficient capacity limits their ability to provide sound infrastructure and quality services to all its customers. Lack of payment by customers has a direct impact on municipalities’ waste management budget, which restrains their ability to ensure quality services and infrastructure. To deal with this issue, private sector companies and community based organizations partner with municipalities (UNEP 2018). There is a relationship between Willingness to Pay (WTP), affordability, and quality of services rendered.

Waste Generation: In 2012 Africa generated an estimated 125 million tons, 65.0% of which was sub-Saharan Africa (80 million tons), and by 2016 it was an estimated 174 million tons. Waste generation is expected to more than double to 244 million tons per annum by 2025 (UNEP 2018) to 269 million tons in 2030 and 516 million tons by 2050 (Kaza et al. 2018). Some of Africa’s big economies, comprising of Algeria, Nigeria, South Africa, Ethiopia, and Egypt, are expected to be some of the biggest generators of waste. The forecasted growth is likely to adversely impact the climate if adaptation and mitigation measures are poorly implemented (Fig. 1).

Waste Composition: Waste composition has direct implications about how it is collected and disposed. Increasing raising living conditions are correlated with a qualitative shift in waste. As a country’s income rises, the biodegradable ratio of the waste often declines as plastic, paper, and other industrial material waste rises (Hoornweg and Bhada-Tata 2012). The environmental effects of such a qualitative mutation are negative as nonbiodegradable waste takes more time to decompose. For Africa, the organic component is still the largest and emits a lot of methane, but it is likely to decline with the economies “industrialization movement.” Fifty seven percent (57.0%) of MSW comprises of organic matter (Couth and Trois 2012; Mohee and Simelane 2015; UNEP 2018), followed by plastic (13.0%), paper and cardboard (9.0%), glass and metal (4.0%each), and other material (13.0%). However, composition varies from country to country, depending on economic activities, income level, consumer attitudes, and culture (UNEP 2018) (Fig. 2).

Fig. 1 Total MSW generation (10³ tons/year) of African countries in 2012 (a) and 2025 (b)³ (UNEP 2018)

Fig. 2 Municipal solid waste composition (UNEP 2018)

Waste Collection: Uncollected waste remains very large in Africa. It might be necessary to note, however, that certain African cities have adopted improved management selection techniques. Some work has shown a spike in private-sector collections (UNEP 2018). Choosing a treatment method entails multiple economic, social, and environmental factors such as waste generation, population density, and location of waste collection centers (Mohee and Simelane 2015). Unregulated landfills and informal recycling are the main waste disposal methods in African countries and there is a high demand for waste services and low supply. Majority of the budget for MSW in developing countries is spent on waste collection yet only 55.0% of total waste generated was collected. Although waste collection is expected to increase to 69.0% by 2025 (UNEP 2018), where it will be disposed remains a

concern. Collection services are most present in urban areas compared to suburban and rural areas. A common practice is door-to-door collection, by both public and private sector contractors. In peri-urban areas, community-based organizations are very important.

Disposal Methods: Landfilling and open dumping are the most common waste practice on the continent because both are considered the cheapest forms of disposal (UNEP 2018). Landfills are categorized differently, but the most common categories are controlled and uncontrolled. The nature of landfills and open dumps have little to no consideration for human health and the environment. Poor sanitary engineering and waste treatment results in groundwater contamination, leachate overflow, and an unpleasant stench. Across most landfills and open dumps in Africa, scavenging activities are inevitable (Idowu et al. 2019). Households near disposal sites are exposed not only to waste-borne diseases, but sharp objects and dangerous chemical excretions. Furthermore, GHG emissions are exacerbated due to poor waste minimization prior to disposal and open burning (9.0%). As the sites become full, the disposed waste is burned in order to reduce volumes and create more space (Fig. 3).

Opportunities for waste recycling: Most literature about recycling acknowledges the opportunities presented by such activities. In the African context, a lack of empirical data is one of the reasons why it is not a common practice particularly within the public sector. Recycling is not a well-known method in most municipalities, and this may be attributed to a lack of knowledge. Recycling activities are done by private contractors and informal waste pickers and they represent only 4.0% of total recycling activities on the continent (UNEP 2018). Although these are positive strides, waste material from developed countries continues to be dumped and lead to new waste streams, and most municipalities are not well equipped with the necessary logistics required for handling recycling. The informal sector, which comprises of mainly waste pickers, largely practices recycling for economic reasons. They play an important part towards reducing

Fig. 3 Methods of end-of-life MSW disposal in Africa (UNEP 2018)

carbon emissions (Nzeadibe 2013; Oduro-Appiah et al. 2019). Recyclables such as plastic, glass, paper, and metals are supplied to commercial businesses. Organic waste which releases the most emissions due to its CH⁴ composition is seldom recovered for large-scale impactful composting. Waste pickers in South Africa save municipalities an average of US\$30 – US\$70 million annually in landfill airspace, with little to no financial or operational support (Godfrey et al. 2016).

Material Recycling Facilities

There are many alternative waste management options available but not all are economically or contextually viable for the continent. Recycling activities and energy recovery technologies are currently being implemented but both on a very small scale. Technologies that can be reviewed are biological treatment, mechanical biological treatment, thermal treatment (incineration, gasification, and pyrolysis), and material recycling facilities (UNEP 2018). As mentioned in previous sections, Africa's recycling rate is only 4.0% annually. Municipalities are impeded by financial and infrastructure costs and private sector recyclers' business models do not cater to all waste producers due to affordability. Informal sector recyclers are an important aspect of the waste value chain (Godfrey et al. 2016). Material recycling facilities are an integral part of an integrated waste management model and offer a great opportunity for all the role-players to converge. The study focuses on material recycling facilities due to their ability to be implemented immediately, contextually, and cost-effectively.

Defining MRFs: An MRF is a plant where waste is received, sorted, and processed for revenue generation and to reduce negative environmental externalities (Hosansky 2018; Zafar 2019). The plants can be classified either as dirty or clean. Dirty MRFs process mixed waste which requires a lot of manual labor while clean MRFs tend to process waste that was separated at source and reduces waste contamination. MRF sizes vary from context to context. Zafar (2019) states that small MRFs process less than 10 tons per day and price ranges between US\$500,000 and US\$1 million. Price determinants are costs of building material, location, and the level of automation required. Large MRFs process more than 100 tons per day and are usually located in large cities. Due to the high automation process, the budget runs into millions of dollars. In a study by South Africa's Department of Environmental Affairs (2019), large MRFs can process between 1,200 and 1,500 tons of waste per month while small MRFs can process between 300 and 500 tons per month. Despite the varying sizes, MRFs have an important role within the waste value chain, primarily to improve waste separation and reduce waste streams before implementing additional management methods – see Fig. 4.

Role-players and Decision-Makers: there are many role-players along the waste value chain and their level of involvement is based on different contexts. Traditional actors include municipalities, private sector (business and industry), the informal market, waste producers, and civil society. Effective or noneffective coordination determines the level of successful implementation. During the planning stages, different levels of planning and decision-making constituencies in municipalities

Fig. 4 Integrated waste treatment system (Trois 2014)

are involved. They need to be aligned to ensure sustainable waste management is implemented. According to Sango et al. (2014, p. 223) “*stakeholders in solid waste management include, but are not limited to, solid waste managers, technical/utility managers, municipal managers, chief financial officers, mayors, councillors and the public at the local municipal level.*” Their lack of involvement can negatively or positively impact technical design due to incorrect data, poor policy, and regulation considerations and accurate budgeting for building material and equipment. This is seen in the growing body of literature encouraging informal waste pickers to be integrated into solid waste management strategies.

Technical Design Considerations: Good knowledge and data on waste quantities and characteristics are imperative to an MRF’s efficiency. However, 100.0% material recovery is not guaranteed due to the quality of materials and sorting efficiency as well as market conditions. Figure 5 presents a technical design for a proposed dirty MRF in South Africa. When waste arrives at the plant – either in waste bags or trucks – it is taken for preliminary treatment where waste volumes are reduced. Equipment such as bag splitters is used together with manual laborers to tear waste bags in preparation for sorting. At this stage, recyclables are sorted depending on the waste characterization (paper, plastic, glass, and metal). The quantities determine whether sorting will be entirely manual, semi-automated, or fully automated. Manual sorting is still important particularly for quality control purposes (Cioca et al. 2018; Department of Environmental Affairs 2019). The recyclables are then compacted and prepared for the market, for composting, and anaerobic digestion or residual is taken to the landfill.

Financing and Economic Instruments: It is important to standardize what a big and small MRF design will look like. The design should consider waste generation quantities and offtake markets for recyclables, supply and demand principles. Although mechanical MRFs are considered more economic because they can process 3.0 tons per hour with approximately seven operators compared to manual MRFs that process 1.0 ton per hour with 12 operators (Cioca et al. 2018), labor intensive activities should be highly considered in the African context because of job creation opportunities. Financing models range from public-private partnership, to fully publicly owned and operated. The proposed model is a public-private partnership where risks are shared and efficiency is maximized (Department of Environmental Affairs 2019). Economic instruments such as subsidies and taxes are designed to change consumer behavior. In the case of waste, they aim to reduce waste generation or induce waste diversion from landfills and dumps to recovery and recycling activities. Furthermore, they can also be used as a source of revenue for municipalities and implement service delivery (Nahman and Godfrey 2010).

Research Approach

An exploratory case study research approach was used. This involved empirical investigation of current consideration of MRFs in urban, waste management, and climate adaptation plans and strategies in selected African countries. The exploratory approach is intended to provide an understanding of what is available and set

Fig. 5 Material recycling facility process (Department of Environmental Affairs 2019)

precedent for future investigation with participants and be more descriptive. Ethiopia, Ghana and South Africa were identified as targeted case studies based on three primary criteria: countries with the fastest growing cities in the respective regions, cities that committed to become zero carbon by 2050, and cities with some data on recycling, landfills, and open dumps – see Table 1. Selecting a case study

Table 1 Case study selection criteria of cities

Fastest growing	Committed to be carbon free	With landfills and open dumps
Angola (Luanda)	<i>Ethiopia (Addis Ababa)*</i>	Botswana
Cameroon (Douala)	<i>Ghana (Accra)*</i>	Cameroon
Cameroon (Yaonde)	Ivory Coast (Abidjan)	Dem.Rep of Congo
Dem.Rep of Congo (Mbuyi-Mayi)	Kenya (Nairobi)	<i>Ethiopia*</i>
<i>Ghana (Kumasi)*</i>	Nigeria (Lagos)	Gambia
Madagascar (Antananarivo)	Senegal (Dakar)	<i>Ghana*</i>
<i>South Africa (Tshwane)*</i>	South Africa (Cape Town)	Guinea Bissau
Tanzania (Dar es Salaam)	South Africa (Durban)	Kenya
Uganda (Kampala)	<i>South Africa (Johannesburg)*</i>	Namibia
Zambia (Lusaka)	South Africa (Tshwane)	Nigeria
		Sierra Leone
		<i>South Africa*</i>
		Tanzania
		Uganda
		Zimbabwe

KEY: * = countries with the fastest growing cities that are committed to being carbon free and have landfills/open dumps

per region allows for a comparative exploration. Secondary and grey literature provided further support and rationale for selecting these three countries. Two challenges experienced with Francophone and Lusophone countries were firstly, limited availability of recent data and secondly, some available data is presented in French and Portuguese.

Case Studies

Based on the range of impediments identified in section “[Literature Review](#),” the case studies explore whether the identified countries have urban, waste management, and climate change adaptation plans, strategies, and projects relating to MRFs. Discussions are themed according to factors used to determine suitable MRF design and adaptation planning, such as (1) Urbanization Dynamics, (2) Urban Waste Impediments, (3) Current and Proposed Strategies, (4) Role of Informal Waste Collectors, as well as (5) Nationally Determined Contributions (NDCs) focusing on waste management technologies.

Urbanization Dynamics

As in many African countries, rapid urbanization in Ethiopia, Ghana, and South Africa is a result of increasing economic activities particularly in large cities. Addis

Ababa is the capital city and seat of the Federal Republic of Ethiopia. It has a current population of 3.3 million (23.8% of all urban dwellers) and extends across 540 km² of land space. The administration is known as a City Government and it has 10 subcities known as *Kebele*. In Western Africa, the City of Accra – which is part of the Greater Accra Metropolitan Assembly – is the capital city of Ghana and accounts for 20.0% (1.5 million) of the country's total population (The World Bank 2017). More than 53.0% of Ghana's total population currently reside in urban areas and this figure is projected to reach 65.0% by 2030. The Accra Metropolitan Assembly (AMA) is responsible for all local government activities within Greater Accra. Further down south, the City of Johannesburg (CoJ) is the largest city in South Africa. With a population of 5.6 million (66.4%) spanning across 11 regions and 1,645 km² of land space. Like its counterparts, the City of Johannesburg Metropolitan Municipality is responsible for service delivery. Provision of basic amenities and infrastructure has not kept up with the urbanization rates in all three cities, thus resulting in more urban tensions such as social unrest and sprawling which induce climate change impacts.

Urban Waste Impediments

Waste management and poor sanitation infrastructure are a few of the services that governments continue to grapple with especially in low income areas. In 2013 Accra was generating 2,200 metric tons of waste per day and approximately 1,500 to 1,800 tons was collected by private sector. Between 2017 and 2018, generated quantities increased to 3,000 tons per day (Accra Metropolitan Assembly 2019). Waste collection and transportation alone cost the metropolitan GHC 450,000 (approximately US\$77,000) per month and an additional GHC 240,000 (approximately US\$41,000) to maintain dumpsites, resulting in 58.0% of waste and sanitation budget being spent on collection and transportation (Accra Metropolitan Assembly 2019). One of the factors that made collection and transportation difficult was the city's spatial planning. Oteng-Ababio et al. (2013) stated that *“Accra did not have the advantage of being a wholly planned city, since spatial planning was introduced after the town had developed on its own. Spatial planning is inconsistent at best, with semblances of colonial-era planning in (some) indigene areas such as Old Accra and Korle Gonno in Ga Mashie while migrant communities such as Nima, Sabon Zongo and Old Fadama continue to grow unplanned. Such unplanned settlements tend to be classified as ‘poverty pockets’ in the city, with a history of poor municipal investment in infrastructure services and under- and unemployment (particularly among the youth)”* (p. 98), resulting in lasting impacts on sanitary service delivery. Tuani (2008) resonates with the authors by stating that the unplanned nature of the city increased waste management issues, in particular land acquisition for landfills/open dumps and waste disposal sites. Additional challenges include poor separation at source, limited recent data, and limited optimization of other disposal plants.

Similarly, in Addis Ababa, waste collection and disposal are poorly managed. Citizens generate 730,000 metric tons of waste per annum (between 2,200 and 3,000 tons per day). Koshe landfill is the only landfill and biggest one in the city. It is located 13 km in the outskirts of Addis Ababa and the travel distances from other parts of the city make it inaccessible and costly. This results in poor collection and disposal in the nearest area. Just over 65.9% is collected by the metropolitan municipality and the remainder is disposed in unauthorized areas such as open fields, streets, ditches, and any available space within the city. Citizens do not have conviction in the metropolitan's ability to deliver waste management services, resulting in limited to no cooperation with waste related operations. Urban development and sprawling are occurring at a rate that government cannot service all households (Geda et al. 2011). Poor urban and road infrastructure make it difficult to collect data in highly dense settlements, further exacerbating effective implementation. The same sentiments are shared by Johannesburg where residents generate 1,492,000 tons of waste per annum and the four landfills cannot continue taking (City of Johannesburg Municipality 2011). Although other disposal measures such as recycling and composting are part of the city's management strategy, effective implementation is challenged by urbanization dynamics. In 2015, the Department of Environmental Affairs estimated that Johannesburg had between 5 and 8-years landfill airspace remaining (Department of Environmental Affairs 2018). Fast track to 2020, at least 5 years are up and pressure is increasing with population growth.

Current and Proposed Strategies

In Accra, AMA introduced two collection methods to help streamline collection and transportation: Communal Container Collection (CCC) and HtH (house-to-house). Households were required to pay a monthly collection fee, but those residing in low-income areas were daily and weekly wage-earners, they could not afford the service. Furthermore, areas where CCCs were located had bad road infrastructure. This presented locality and accessibility challenges. Since then there has been an increase in private sector participation, particularly waste collection. Affordability remains an impediment. Because waste was poorly collected, it was difficult for AMA to promote source separation. The ripple effect was poor planning and implementation of other disposal methods like composting, digestion, and recycling. Almost a decade later, waste management officials cite (1) community awareness, (2) effective collection systems, (3) limited disposal capacity, and (4) unplanned nature as ongoing challenges. Figure 6 discusses an investigation of Accra's urban planning, waste management and climate change plans and strategies to ascertain consideration for MRFs as an adaptation tool.

In the far East, containers are placed in common places each Kebele, close to main roads where waste trucks can access. Pushcarts are used to collect waste from each household at a fee. Those who cannot afford the fees carry their own waste to the container. Services are provided by Kebele workers and street sweepers (Cheru 2016). In 2017, the Reppie Waste-to-Energy Facility was commissioned, producing 25 MW of

Plans and Strategies - Accra

Accra Spatial Development Framework (2017) recognizes the various challenges presented by poor waste collection and disposal propelled by insufficient infrastructure and urbanization. It proposes that AMA 'explores job creation and economic opportunities associated with engineering service delivery, for example decentralize waste collection to locals / individuals. Furthermore, preparation and implementation of sanitation action plans for all leading urban centers, including related statutory regulations and by-laws ensuring effective collection, disposal and treatment of solid, liquid and toxic waste. The ASDF also proposes New Solid Waste Management Schemes and Environmental and Land-Use Policies but is not explicit about disposal methods, location determination or MRFs. Although it states that district level climate change mitigation and adaption strategies must be developed in order to plan for and implement requirements for climate change, additional details are not provided. However, detailed consideration is given in the Ghana National Climate Policy (2013). The policy recognizes the opportunities presented by beneficiating waste, problems with land acquisition for waste disposal as well as the need to increase recycling activities as means to reduce carbon emissions. It is reported that in April 2020, AMA entered into a public-private partnership (PPP) for Waste Transfer Site and Material Recovery Facility (MRF). Zoomlion currently operates a 200-tonne recycling plant in Accra. No reference of MRFs in Integrated Urban Environmental Sanitation Master Plan (IUESMP), Metropolitan Land Use and Transport Plan for Greater Accra Region, Emergency Solid Waste Management Improvement Programme 13 (E-SWMIP), the Accra Climate Strategy and Integrated Urban Environmental Sanitation Strategy and Master Plan.

Fig. 6 Investigation and discussion of MRF consideration in Accra. (Source: Author's own compilation)

electricity. The facility is located next to Koshe Landfill site and waste has since been diverted for incineration instead, thus reducing emissions. There are traces of recycling activities but on a small scale at disposal sites (Geda et al. 2011). Private sector, community-based organizations, informal waste pickers, and international donor agencies are the main participants promoting some levels of at source separation and income generating activities. IGNIS was a joint project between Ethiopian and German partners. The project started in 2014, with the aim of implementing *income generation and climate protection by valorizing municipal solid waste in a sustainable way in emerging mega cities*. Strategies included creating individual waste recycling projects that could create employment and income opportunities while reducing GHG emissions. The project lasted until 2018 and provided valuable data to waste management agencies, namely composting (Gerji and Ataklet Tera Composting pilots) and biogas (Sidest Kilo and Menelik II preparatory School pilot) (Cheru 2016). Figure 7 also investigates Addis Ababa's urban planning, waste management, and climate change plans and strategies to ascertain consideration for MRFs for adaptation.

Johannesburg has better waste management infrastructure and initiatives. Pikitup is CoJ's waste management agency responsible for collection and disposal across 11 regions. As with many cities on the continent, increasing urbanization trends are causing strain on quality service delivery. CoJ has numerous private-public-partnerships throughout the waste value-chain to reduce the high costs of collection and disposal incurred. Most PPPs fall within waste collection and disposal. Formal urban areas have scheduled collection dates and residents have municipal bins. Some informal areas do have some sort of waste service and others do not. This results in pockets of illegal dumping. There are four landfill sites in different ends of Johannesburg and all four have reached their airspace capacity. Although CoJ has championed waste diversion activities such as recycling, composting, and pilot projects for small scale biogas projects, there is a need to increase these activities. The recycling sector is relatively well established compared to Accra and Addis Ababa. Associations such as South African Plastics Recycling Organization, National Recycling Forum, and the Institute

Plans and Strategies – Addis Ababa

Addis Ababa City Structure Plan (2017-2027) shares strategic plans and land use tools to improve urban development in the city. It recognises waste and climate related challenges as well as the need for improved recycling activities. The CSP states that it is preferable to make use of a mix of centralized and decentralized offsite and onsite liquid waste management systems as well as wastewater treatment technologies that do not consume large tracts of land. Interestingly, the plan proposes that three transfer stations with material recovery facilities (south, east, west) should be developed at each waste transfer station. The Draft Work Plan for Addis Ababa - Climate and Clean Air Coalition, prepared by the U.S. Environmental Protection Agency (2015) addresses the direct relationship between climate change and improved waste management.

The World Bank has a number of urban and climate change related projects underway in Addis Ababa. 'Enhancing Urban resilience Programme' was launched in 2013 to help cities strengthen their ability to prepare for and adapt to changing conditions, and to withstand and recover rapidly from disruptions related to climate change, natural disasters, and other shocks and stresses. The programme serves as an umbrella for delivering the analysis, rationale, and support local governments need to make resilience part of their urban management agendas. The 'Urban Local Government Development Project' (2008-2014) was designed to financially support the Ethiopian government "to support improved performance in the planning, delivery, and sustained provision of priority municipal services and infrastructure by urban local governments", inclusive of waste infrastructure.

Fig. 7 Investigation and discussion of MRF consideration in Addis Ababa. (Source: Author's own compilation)

Plans and Strategies – Johannesburg

Various national policies require municipalities to develop Integrated Waste Management Plans (IWMPs) and Integrated Development Plans (IDPs) every five years. The IWMP recognizes that development planning in the City must also consider waste service provision and therefore early engagement and communication between planners and those involved in waste management is needed. Composting facilities, MRFs and buy back centers are noted as action plans for waste diversion. Similarly, the IDP 2018/19 acknowledges the need to improve waste management infrastructure supportive of waste minimization and recycling as well as climate change. CoJ has Environmental Sustainability Strategy and Action Plan (2019) encourages spatial transformation in cities. This includes applying existing and develop municipal planning instruments to integrate and secure ecological infrastructure into the urban fabric.

Tedcor piloted a materials recovery facility (MRF) in Wadeville, near Germiston in Gauteng, in partnership with local buy-back centers. Droplets for Life – a private waste management company - have their own MRF situated in Wadeville, Gauteng. They receive waste through this facility from clients and from their own waste. The facility processes approximately between 25 to 30 tons of recycling per month and employed 12 people currently from the disadvantage background. Training and up-skilling were provided to them according to their job specification. In 2014 CoJ commissioned a dirty MRF pilot at the Robinson Deep landfill in Turffontein, Johannesburg, Gauteng under the 'Separation at Source Programme'. The facility was processing 4,970 tons per annum of recyclable materials in 2014. MRFs do not tend to go beyond pilot stage due to low rate of recyclable recovery (Simelane, 2016)

Fig. 8 Investigation and discussion of MRF consideration in Johannesburg. (Source: Authors own compilation)

of Waste Management of Southern Africa collaborate with private sector, civil society, and academia to promote greater adoption. As with this Figs. 6, 7, and 8 discusses MRF consideration as an adaptation tool for Johannesburg.

Role of Informal Waste Collectors

Informal waste collectors play an integral role along the waste value chain. Through their activities, waste collectors assist municipalities to collect, separate, and recycle

waste material because they do not have sufficient financial and nonfinancial capacity to provide efficient waste management alone. They operate in similar approaches despite not being recognized or integrated in municipalities' strategies and plans. Due to socio-economic factors, waste collectors continue to operate alongside the municipalities, collecting waste from household to household, designated communal containers and institutions.

In Accra, informal waste collectors continue alongside AMA but are not officially recognized. Known as Kaya Bola, they typically port waste from households or markets for a fee, separate the various material, and sell the recyclables for an income. Not being legitimized by local government induces ill-treatment and hostile social environment that keep them operating in an unorganized/informal manner (Oteng-Ababio et al. 2013). Presently, Kaya Bola collect and sort 25.0% of total waste generated for income but dispose worthless material in open drains and streams. The only sanitary landfill known as Knope has reached its capacity, leaving a few operational dumpsites scattered across the region, namely, Oblogo and Sarbah (Tuani 2008; Baah and Kharlamova 2018). It is located 37.0 km outside Accra which makes collection and transportation fees very high (The World Bank 2017). The distance and nature of road infrastructure from waste producers to Knope or other dumpsites is too far for informal waste pickers, more so for the small transport modes they use, for example, motorkings (Accra Metropolitan Assembly 2019).

Presently, informal waste collectors are not recognized as part of Addis Ababa's integrated waste management system. They are seen more as a potential enemy rather than partner (Cheru 2016). Waste pickers collect and sort for valuable recyclables and take them to sell at the Merkato Market place, the biggest market in Ethiopia. Various buyers are located there, ranging from independent buyers to factories. In Johannesburg, the lack of landfill space is increasing pressure on the municipality to integrate informal waste collectors along the waste value chain. The Wastepickers Empowerment Programme was launched in 2011 with the aim of creating a database of waste collectors in the metropolitan, skills training, assistance to establish cooperatives, provide protective clothing, and assist with fund raising. A pilot program was launched in 2014 and more than 500 waste collectors were registered and benefited from various skills training and personal protective equipment while 55 cooperatives participated in separation at source (Baker et al. 2016). The program can be scaled to other regions in Johannesburg but some lessons from the pilot would need to be considered:

- Consultation with different municipal stakeholders and recycling associations
 - Identifying suitable sites for sorting and storage
 - Establishment of guidelines for waste collectors
- Identification of waste collectors
- Sourcing external funding for training and equipment

There are opportunities to still officially integrate informal waste collectors in the city's strategies and plans. Associations such as the African Reclaimers Organization represent collectors' views in this regard. The Department of Environmental Affairs estimates that there are over 62,000 waste collectors in the country, with 40.6% operating as trolley-pushers (Mathye 2019).

Overall, various proposals and plans drafted by international organizations such as The World Bank and the African Development Bank stress the need to integrate informal waste pickers into waste management and increase waste transfer stations as strategies for climate adaptation. Their involvement in the waste value chain would boost collection rates and income.

Nationally Determined Contributions

The Paris Agreement requires every country to produce Nationally Determined Contributions (NCD). These are climate change policies detailing each country's plans towards adaptation and mitigation. Ethiopia, Ghana, and South Africa developed their NCDs. Ethiopia's plan recognizes carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) as priority gases that need to be mitigated by 2030. Key sectors producing these gases are agriculture, forestry, transport, industry, as well as waste and cities. In its medium to long term actions, drought relief is an action point where the government will "ensure the uninterrupted availability of water services in urban areas to make them comfortably and productively habitable irrespective of droughts through planning and construction of dams or deep wells, deployment of water saving technologies, and wastewater treatment infrastructure." South Africa's NCDs target agriculture, land use, and waste as targeted sectors for GHG reductions. However, energy is the primary focus.

Lastly, Ghana's adaptation and mitigation commitments strongly feature solid waste management in urban areas while ensuring positive socio-economic derivatives. The country committed to adopting alternative urban solid waste management by 2030. As an adaptation policy action, Ghana committed to building standards for urban waste management through city-wide infrastructure planning. Three mitigation action points include:

- Improve effectiveness of urban solid collection from 70.0% to 90.0% by 2030 and dispose all to an engineered landfill for phase-out methane recovery from 40.0% in 2025 to 65.0% by 2030.
- Scale up 200 institutional biogas in senior high schools and prisons nationwide.
- Double the current waste to compost installed capacity of 180,000 ton/annum by 2030.

There is an opportunity for MRFs to feature as adaptation or mitigation actions depending on each country's resources, more so for Ethiopia and South Africa.

Proposed Recommendations and Conclusion

It is evident from current strategies and plans in all three cities that there are opportunities for improved MRF adoption as well as consideration. Urban planners are responsible for designing and developing land, specializing in spatial and land use planning traditionally. Their involvement was seen in activities, decisions,

strategies, and plans for infrastructure development and service provision which are prepared at local government, as seen in Accra's Spatial Development Framework, City of Johannesburg's Integrated Waste Management, and Addis Ababa's Urban Renewal Initiative. As part of the planning process, waste management and/or climate change officials could be included in the process. This was evident in the case of Kenya.

It was also evident that there is a need for the planning process to evolve with the profession and embrace the global push for sustainability and climate change by being more cognizant about waste management and climate change. A central point where all three disciplines converge is land: access to suitable land for disposal, proximity of land to citizens, and possibilities of land inducing negative or positive climate change impacts. In addition, knowledge and implementation of MRFs is generally unknown, with the exception of South Africa, where the Department of Environmental Affairs have taken interest. Climate change adaptation already

Table 2 MRFs as a climate adaptation strategy

Challenge	Recommendation	Adaptation strategy
Local governments spend at least 50% of total waste budget on waste collection and disposal	Consider exploring small-scale decentralized MRFs to address waste collection, transportation, logistics as well as improve data collection and beneficiation opportunities – climate adaptation strategy	Include more waste management and climate change matters in urban plans Integrate informal waste pickers in city waste management plans to create job in the informal sector
Waste generation and quantities are exacerbated by urbanization and population growth, straining local governments' ability to provide services	Using plans and strategies, planners identify land closer to waste producers and socio-economic activities driving waste generation	Use Green Technology such as GIS and IT to map generation hot spots, determine material flows and data
	Decentralize MRFs on a smaller scale to improve access. Closer to informal communities, shorter distance to travel and potentially more material recovery	Design MRFs guided by technical and social dynamics around identified site
Informal waste pickers are not recognized by local governments despite positive impact in the waste sector	Decentralized small MRFs can assist to streamline waste pickers involvement Create associations or cooperatives for informal waste pickers	Provide training and technologies to women and people in informal communities to enable recycling of waste into other marketable products (e.g., paper briquettes, etc.)
		Develop zones in cities, suburbs and settlements to streamline the collection of waste by informal waste pickers

<p>In Africa, where most countries are classified as low- and lower-middle income, there are many parameters to consider when selecting AWT technologies, including:</p> <ul style="list-style-type: none"> • sensitivity to the quantity and quality of waste; • capital investment costs • operation and maintenance (O&M) costs • cost recovery potential • efficiency of the technology • end-product utility • environmental impacts of operation • land, energy and water requirements • availability of local competences to properly manage the system • inclusion of both formal and informal actors in the system <p>Guidance note: Lessons learned</p> <ul style="list-style-type: none"> • An appropriate technology should not be considered in isolation; it must be placed within an integrated waste management strategy. • Both formal and informal actors must be considered to insure the efficiency of the waste management 	<p>strategy (high level of waste collection, improvement of recycling and/or reuse, high material and energy recovery, social inclusion and income generation for the poorest people).</p> <ul style="list-style-type: none"> • The choice of the appropriate technology should consider the following: <ul style="list-style-type: none"> – The technology should be proven based on effective operating experience in African/low-income country contexts. – The technology should be economically viable in the context of low-income countries. – Technical issues related to the implementation of the technology should be easy to fix: the presence of qualified human resources for management and maintenance must be considered. – Low cost technologies are preferred as waste treatment solutions. – The technology should be an opportunity for social innovation (job creation, social inclusion, income generation).
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Fig. 9 Measures to determine appropriate waste technologies (UNEP 2018)

involves plans and strategies, thus once again there is an opportunity to improve adoption and implementation of MRFs as a land-use and adaptation strategy, and urban planners can aid to drive that inclusion. Table 2 below suggests how including MRFs can be considered as a climate change adaptation measure for the three cities and beyond:

For MRF Facility Design: it is important to determine and measure the appropriateness of waste technologies for the continent because of varying drivers, pressures, and parameters (Fig. 9).

Although Africa contributes 4.0% of the world's GHG emissions, with these proposed adaptation strategies, many cities can reduce future emissions and leapfrog into full sustainability despite the current urban and waste related challenges.

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