

Review Article

Obiora B. Ezeudu*, Jonah C. Agunwamba, Uzochukwu C. Ugochukwu and Tochukwu S. Ezeudu

Temporal assessment of municipal solid waste management in Nigeria: prospects for circular economy adoption

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Abstract: This work reviewed the past and current status of municipal solid waste (MSW) management in Nigeria towards offering a direction for the future. The past status shows that poor policy regimes, inadequate financing mechanisms, absence of waste data, and abysmal institutional arrangement negatively impacted the MSW management outcomes in the country. At present, few improvements recorded like an increase in the number of landfills, and public-private partnerships have been largely undermined by the continuous upsurge in the urban population and lack of corresponding growth in critical capacities in terms of economic resources, technological advancement, and state-of-the-art urban infrastructures. The current waste generated in cities in Nigeria is calculated as 66,828 tonnes per day (TPD) at the total urban population of 106 million, while the projected value for 2040 will be 125,473 TPD at the urban population of 199 million. The current work further discusses prospects and implications for circular economy adoption in solid waste valorization in Nigeria.

Keywords: circular economy; municipal solid waste; Nigeria; urban development; waste management.

Introduction

Urban cities around the world are structured in a way that a large number of people are concentrated in a localized area of land. As such, they often depend on the importation of foodstuffs and other necessities of life from far distances as a supplement for other commodities that come from the countryside [1]. The city's environment already saturated with developmental activities cannot properly absorb, dilute, or disperse the generated waste from the use of these materials. This makes the streets to be constantly flooded with used and discarded items which are known as "urban solid waste" or "municipal solid waste" (MSW). The potential threat posed by this waste on the environment and public health has made it necessary for city authorities to devise means for its management. Goals 6, 11, and 12 of the United Nation's Sustainable Development Agenda 2030 captured an increase in waste recycling and global safe reuse; paying special attention to MSW management, and ensuring sustainable production and consumption patterns respectively [2]. In line with the concept of sustainable development that has also served as a parameter for assessing the sustainability of cities and society, it is often perceived to be that any city or society that cannot properly manage its solid waste cannot also manage other more complex services such as health, transportation, or communication [3]. The increasing global population and the resultant rise in the anthropogenic activities have triggered a surge in man's quest for finished consumer goods and hence the sophisticated dynamics in the variants of waste being generated by communities. In response, perspectives and methods of MSW management have also evolved. This is because societies have responded to these changes through policies, institutions, and methodological approaches in rhythm with developments in science, technology, and globalization [4, 5]. In essence, the extent to which any society can respond to the changes in waste dynamics will largely depend on its characterizing

*Corresponding author: Obiora B. Ezeudu, SHELL Centre for Environmental Management and Control, University of Nigeria, Enugu Campus, 410001, Enugu, Nigeria, Phone: +234 08060828002, E-mail: obiezeudu@yahoo.com

Jonah C. Agunwamba, SHELL Centre for Environmental Management and Control, University of Nigeria, Enugu, Nigeria; and Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria

Uzochukwu C. Ugochukwu, SHELL Centre for Environmental Management and Control, University of Nigeria, Enugu, Nigeria

Tochukwu S. Ezeudu, Institute for Development Studies, University of Nigeria, Enugu, Nigeria

features in terms of economy, social, political, culture, and other critical capacities. High-income countries with higher capacities have acted more proactively compared to low and middle-income countries. This easily explains why waste-to-energy technologies are more in the global north than in the south [6–8].

Waste management involves the minimization, collection, storage, transportation, treatment, recycling, and disposal processes [3, 9]. Based on contextual conditions, societies tend to adopt a combination of these methods in managing their MSW. The waste collection involves the processes of retrieving the discarded materials from the generating sources. The sources could include households, institutions, commercial establishments, markets, etc. To optimize resources, this waste could be stored in designated areas before transportation. Trucks and vehicular equipment are used to transport them to the designated places for onward treatment or recycling. The final process is waste disposal which involves the application of a single or combination of proven scientific methods. The commonly practiced disposal methods include landfilling, incineration, anaerobic digestion, and composting. The procedures, economic and environmental benefits of each method in Nigeria's context have been discussed in [10, 11]. Turning away from the perspective that views solid waste as a problematic material that needs to be properly discarded to avoid harming the human and the environment, circular economy has been adopted and implemented as a promising way for solid waste valorization. In its theory and practice, it has shown evidence of offering more prospects as it proposes a restorative and regenerative approach to waste management [12, 13].

Nigeria is a developing country located on the west coast of Africa with a land area of 924,000 km². Nigeria's population has witnessed outrageous growth in the last few decades. In exact terms, the country's population rose from 45 million in 1960 to 97 million in 1991 and has been approximated at 195 million in 2018 [14]. Consequently, many urban and urbanizing areas are continuously emerging with the rate of population growth and urbanization [15]. The aftermath is the rise in the quantity of MSW disposed of many generating units. In contrast, Nigeria is not growing in critical capacities such as economic resources, social infrastructure, and advanced technology towards positioning itself in solving the emerging waste challenges. For this reason, the country waste managers need to explore other value reclamation measures such as circular economy principles in solving its waste problems.

In this work, therefore, we reviewed the past and present status of MSW management in Nigeria, to understand

how it has been approached, and the contributions of institutions, policies, financing, and other miscellaneous development. We further offer critical discussions on the prospects and challenges for circular economy adoption and implementation. For Nigeria to make any remarkable progress towards managing its urban solid waste, there is a great need to review and analyze the past and present situations. The current work will lend a helping hand to the relevant authorities in charting a new course and finding a sustainable solution for the country's waste management problems.

Material and methods

We searched Google scholar – which is the most comprehensive research database – for academic literature on MSW management in Nigeria. Other relevant grey publications such as policy briefs, project documents of agencies, government and international agency's publications were also searched for. The agencies' documents include World Bank [3, 16], United Nations Environment Program (UNEP) [17, 18], United Nations University, Institute for Advanced Sustainability Study [19], Basel Convention [20, 21], United Nations Human Settlements Programme (UN-Habitat) [22], Nigerian Communications Commission (NCC) [23], National Environmental Standards and Regulations Enforcement Agency (NESREA) [24] and International Solid Waste Association (ISWA) [6, 25]. Further documents included in the review were sourced from the reference lists of these materials. The keywords for the search include “waste management”, “municipal solid waste”, “municipal solid waste management”, “urban solid waste”, “waste minimization”, “waste composition”, “waste generation”, “waste recycling”, “e-waste management”, “waste characterization”, and “waste management policy”. All search terms were conducted with the inclusion of “in Nigeria”.

Retrieved records from the search were exported to Microsoft word and were divided into two periods (in a table), the ones published before 1999 were mainly considered in the context of the past as they are useful in providing insight on the past status of MSW management in Nigeria. While the materials published after 1999 (2000–2019) were analyzed towards understanding the present status. The reason for the temporal division is because Nigeria has been on the military rule until 1999 and the period was characterized by several political and economic instability and sanctions from international communities, which likely undermined the evolution and development of basic policy-making and institution development in the

country [26]. In essence, what seems like consistency in democratic governance and policymaking in Nigeria started in May 1999. Due to these reasons, the content, type, and variant of documents available at these distinctive periods will vary.

Two of the authors participated in the screening/selection of material while the two other authors independently examined the screening process to resolve areas of disagreements and to ensure consistency. We first expunged duplicate records and irrelevant materials. At the second stage of the record screening, we excluded materials based on the following criteria (i) Those that do not report an outcome of interest in any of the components of the MSW management system which include waste minimization, waste generation, waste composition, waste disposal, e-waste management, waste recycling, waste resource recovery, waste characterization, and waste management policy. (ii) We excluded articles from journals not indexed in SCOPUS, Web of Science, and/or Pubmed to avoid including predatory journals. Only materials published in English were considered. The process of the literature selection/review and number of records considered at each stage is further shown in the PRISMA flow chart (Figure 1), while the complete list of materials considered/included in the study is available as supplementary material.

The selected materials were reviewed, analyzed, and categorized to answer the following questions:

- (i) What is the global status of MSW management?
- (ii) What is the status of MSW in Nigeria before the last two decades?
- (iii) What is the present state of MSW in Nigeria?
- (iv) What are the institutional and policy landscapes concerning solid waste management in Nigeria?
- (v) What is the financing mechanism for MSW in Nigeria?
- (vi) What are the future challenges and implications of circular economy adoption in solid waste valorization in Nigeria?

Because MSW management is interdisciplinary in scope that covers many fields of study such as engineering, development studies, management, and social sciences, the range of materials collected include both qualitative and quantitative literature. We adopted a mixed studies review as recommended by [27].

Results

Global status of solid waste management: an overview

Exponential growth in the global population and the parallel rapid industrialization has caused people to migrate from rural to urban cities in search of greener pastures, which lead to generating a high amount of MSW [28, 29]. Solid waste is inextricably linked to urbanization, and economic development [3, 8]. The explanation is that growth in urbanization leads to growth in economic wealth and as standards of living and disposable income increase, consumption of goods and services increases which results in a corresponding increase in the quantity of waste generated [30]. Solid waste is associated more with the urban areas since waste generation is always lower in rural areas. This is not difficult to understand, since rural dwellers are poorer in the average, purchase fewer finished consumer products, and have more waste pickers who recover and recycle wastes at generating points, collection, and disposal sites. MSW, in general, includes degradable and non-degradable waste streams such as paper, food leftover, plastics, textiles, e-waste, ceramics, walled yard waste, etc. The city waste managers are continuously faced with an enormous task of collecting and finding appropriate destinations for final disposal of these wastes in a manner that the environment and public health will not be compromised.

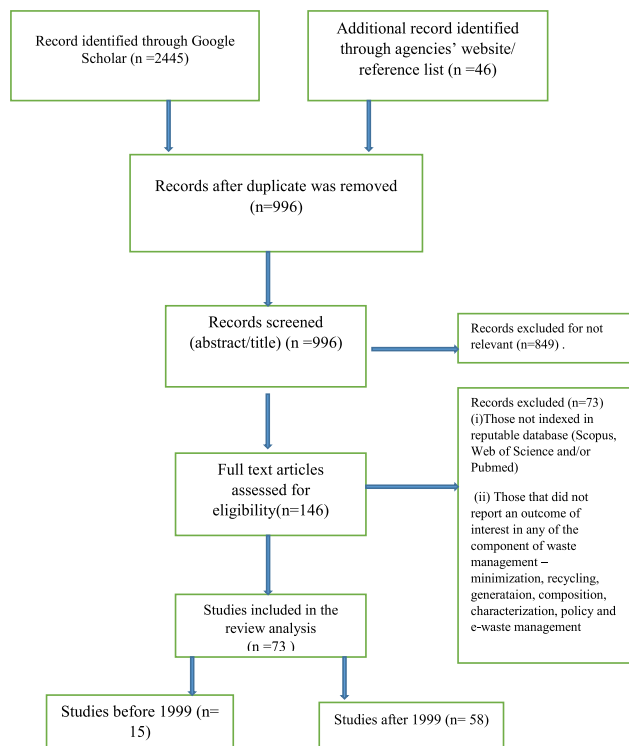


Figure 1: PRISMA Flow chart for the literature selection.

Today, more people are living in urban cities around the globe, generating about 1.3 billion tonnes of waste per annum at the rate of 1.2 kg/capita/day. Projections have it that by 2025, about 4.3 billion people will be residing in the world's urban areas generating 2.2 billion tons of solid waste per annum. The global costs of managing this waste will also rise from the current annual figure of \$205.4 billion to \$374.5 billion by 2025 [3]. In low and middle-income countries, the cost of waste collection is about 80–90% of the municipality's waste management annual budgets, yet the services are far from being efficient and often limited to visibility areas. While less than 10% is spent in high-income countries with more efficient service delivery [8, 18, 22]. Global state-of-the-art solid waste management includes the following methods; source reduction (minimization), collection, recycling, composting, incineration, and landfilling/dumping. Waste reduction from the generation sources is usually achieved through (i) organized education programs that emphasize, reduce, reuse, and recycle (ii) implementation of extended producer responsibility, and (iii) increased attention on cleaner production. These practices are found more in high-income countries than in low and middle-income countries.

In the high-income countries, waste collection rates are generally higher at about 90%, with enhanced technology such as compactor trucks, highly mechanized vehicles, and transfer stations [3]. They have an efficient recycling system, recyclable material collection services, high technology sorting, waste processing facilities, formal regulations, and long-term recycling planning. Waste composting is a more popular practice both at the household level and large-scale facilities. The generated waste streams contain lesser compostable, odor control is a critical consideration while anaerobic digestion is increasingly more common. Incineration of waste is largely regulated, prohibited in areas with high land costs, and low availability of lands (e.g., Japan). Incinerators are constructed with environmentally controlled considerations and energy retrieval systems, with the generated emissions regulated and monitored by laws. The highest grade of landfills is available in the form of sanitary/engineered landfills, built with a combination of liners, leak detection devices, leachate collection systems, biogas collection, and treatment technologies. Landfill sites are reused after closure for golf courses and parks [31]. Above all, there is a decline in waste landfilling in high-income countries induced by advanced regulations that encourage waste reduction and recycling.

However, in low and middle-income countries, the degree of waste separation from the source is poor. Waste is

not segregated or sorted before disposal, except a few materials that are removed by the informal waste pickers. Collections schemes are not differentiated by the type of waste generators as more attention is placed in households than commercial places and institutions. Albeit, the dominant recycling practices are through unorganized informal waste pickers, the rate of recycling seems quite high due to the local market and industries that make demands on recyclables [32, 33]. Recycling markets are grossly unregulated, replete with price fluctuations, and long chains of middlemen [34]. Lack of markets and poor knowledge hinders adoptions of composting as waste handling techniques even in the face of the fact that the waste streams are more of compostable contents [35]. Incineration technologies which are about three times the cost of landfilling per tonne of waste are not common in these areas. Poor technical knowledge, high moisture content waste, and a huge percentage of inerts further make incineration not feasibly common in the regions [8, 10, 18]. Landfills are constructed as low-technology sites, unregulated, pollutes the underground water sources, nearby surface water bodies, and human settlements [25, 31]. Landfill-disposed wastes often contain hazardous substances and are regularly burnt without precaution. As a result of the unmitigated increase in waste generation, an increase in landfilling is expected in the short term in low and middle-income countries [8]. The environmental health implication of inefficient solid waste management schemes in low and middle-income countries is summarized as (i) health hazards from uncollected waste (ii) health hazards from collected but poorly disposed of waste and (iii) the economic/environmental burden of waste disposal on towns and cities [36].

The past and current approaches to MSW management in Nigeria

Before 1999

There has been an effort towards urban environmental management in Nigeria even at the onset of British rule in the 1900s through colonial bye-laws [37]. These efforts also suffixed stronger in the 1979 constitution that emphasized clearance of refuge, management of liquid and solid waste in abattoirs, residential homes, and streets [38]. The major landmark in environmental effort in Nigeria happened in 1988 with the establishment of the Federal Environmental Protection Agency (FEPA) on December 30th 1988 through military decree. This event has been the center of major

discussions on environmental management in Nigeria based on the available literature before 1999. FEPA's establishment heralded the formation of the maiden national policy on the environment [39]. The key objectives of this policy instrument were summarized by FEPA [24] as (i) to secure for all Nigerians an environmental quality adequate for their health and well-being (ii) to raise public awareness towards promoting understanding of the essential linkages between the environment and development (iii) to encourage individual and community participation in environmental protection and improvement efforts. The section on solid waste management stipulated specific actions which include; collection and disposal of solid waste in an environmentally sustainable manner, setting up waste laws, regulation and standards, and their enforcement, encouraging public participation, environmental monitoring, and imposing penalties on offenders to deter defaulting [24].

However, the FEPA solid waste guideline was hugely faulty as it did not articulately view waste management as a complex issue that requires careful considerations of the waste life cycle by integrating waste collection, transportation, treatment, recycle, and disposal. Rather because of the overzealousness of the then Nigerian-led military government that wanted only to enforce the street cleanliness, greater emphasis was laid more on the waste collection and disposal at all costs [37, 39]. There were no clearly laid down modalities on how other parts of the waste management system such as treatment, recycling, and resource recovery should be handled. This city cleanliness-induced zeal further prompted the government to institute the National Sanitation day that holds on every last Saturday of the month. On this day, beginning from 7 to 10 am, residents are mandated by law to stay at home and clean up their premises. To further incentivize this law, there was an introduction of a cash reward of one million naira to the cleanest state by the federal government.

Nevertheless, the width and breadth of other essential elements that are associated with the solid waste handling and management such as waste characterization, data collection on generation, quantity documentation of streams of waste generated, disposal modalities, social and economics of waste management, landfill management and specification for landfill construction were never captured in the solid waste management policy. The waste management disposal practices commonly reported during the period under review include open dumping, burning of waste at the dumpsites, dumping of waste at the erosion sites (as erosion control measures), and even water bodies [40–42]. The open dumping/burning of waste is discredited as a waste disposal technique because it results

in uneconomical use of available space, allows uncontrolled access to waste pickers, animals, and flies and most times unpleasant and hazardous smoke emanate from slow-burning fires [43]. Open waste dump serves as a breeding hood for dangerous disease-causing vectors in addition to the release of hazardous substances in the air and soil. While the open burning of waste leads to the uncontrolled discharge of dangerous gases to the atmospheric environment such as oxides of sulfur (SO_x), oxides of nitrogen (NO_x), and particulate matter which all poses a public health risk. A survey conducted by the federal office of statistics in 1978 shows that about 52% of urban dwellers have no known access to an authorized dumping ground [41]. Consequently, indiscriminate dumping of wastes by the roadsides, gutters, beneath the bridges, and at the unauthorized sites were reported in the locations across the country [44, 45]. Only two known sanitary landfills were reported in the country during this period [39].

Because of the poor availability of funds, at the state levels, the responsible agencies did not have enough trucks/vehicles, and equipment for waste transportation [16, 46]. The few available ones had the problem of unavailable spare parts and were poorly maintained [45]. On an ad-hoc basis, private truck owners were contracted without any documented formal contracts and monitoring mechanisms [46]. It was even reported that sometimes during the National Sanitation Day, the sanitation law offenders were forced to transport waste with their vehicles as punishment [47]. Waste was therefore not collected on time, city waste bins were overfilled and sometimes obstructs traffics. Piling up of solid waste leads to the proliferation of disease-carrying vectors which increases the risk of diseases [43]. As there was an absence of guidelines on waste stream characteristics, certain classes of waste that are not qualified as MSW usually find their way in the mix of collected waste [48]. For instance, the waste mix usually contains human excreta because of lack of sanitation facilities in many households [43], hazardous waste from industries were also a regular component in the waste mix due to the absence of streamlined modalities for industrial waste monitoring and disposal techniques. Waste minimization did not also reflect on the national solid waste management policy, therefore manufacturers and importers of goods never considered means of waste minimization in their processes, thus products were never designed/imported to reduce environmental impacts. Neither was there adequate environmental awareness on the need for households and institutions to engage in practices that would ensure generation of less waste, or the masses to patronize environmentally friendly products [39]. The most cogent explanation for these anomalies

seems to be that economic growth had been mainly emphasized in the country's national development plan than environmental protection [37].

Informal waste pickers had been in operation in Nigeria as of the period but were not properly organized or supported by the government or any institution. This is opposed to what was obtainable in other low and middle-income countries of the globe at this period. In the early 1990s, it was already reported that in Latin America, informal waste recycling were been promoted through the formation of small enterprises, or cooperatives [43]. For example, in Ciudad Juarez, Mexico, Landfill waste pickers as at this time, were organized into a recycling cooperative that obtained a concession arrangement to operate on city landfills. Also in Medellin, Colombia, they were organized into small firms for collecting commercial waste and for door-to-door purchasing of recyclables. In both cases mentioned, the municipalities were instrumental in the creation of the firms and providing necessary logistics such as finance and training [43]. The need to regulate the activities of informal waste recyclers is crucial due to the associated environmental health risk. Informal e-waste recycling, for instance, though plays a significant role in job and income creation in low and middle-income countries, it also involves the application of some rudimentary practices prone to human health risk exposures. Burning cables and plastic coating to recover valuable copper causes the release of harmful polyvinyl chloride, dioxins, furans, brominated flame retardants, and polycyclic aromatic hydrocarbons to the environment [49]. Using acid baths to recover precious metals without protective clothing exposes the recycler to the risk of chemical injury. Contamination from e-waste is believed to be a significant contributor to adverse health impacts in the communities where informal recycling takes place and the most vulnerable are women and children [50]. Moreover, the class of people that participate in the informal waste picking being dominated by the poor and low-income population is most likely to have lesser access to health care facilities and improved hygienic conditions [51].

Further, more attention was paid to the waste collection than disposal, as there were no policies on specific modes of waste disposal. There were no incinerators, anaerobic digestion methods were never practiced or adopted, recycling and resource recovery were voluntarily practiced by households usually induced by poverty without any form of incentives [16, 45]. Poverty and quest to make a living, as a motivating factor for urban waste picking simply signifies that the larger public perception of recycling was based on economic means and not based on waste management and environmental quality promotion.

Of course, this was the dominant notion across most low and middle-income countries at the period under review [43, 52].

1999 to date

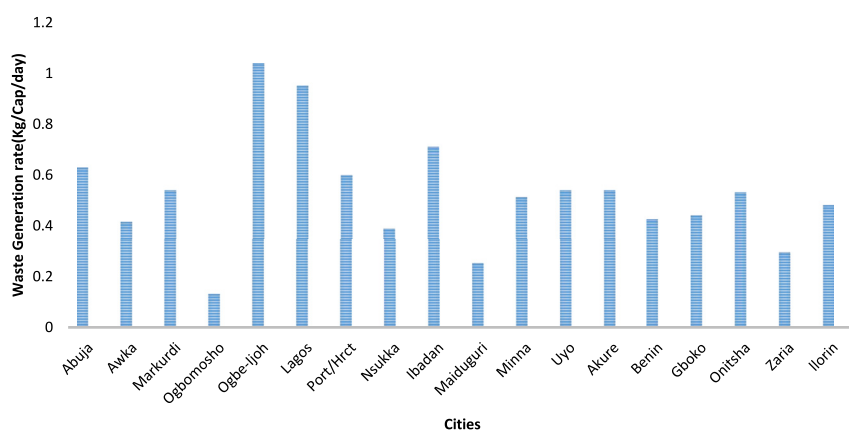
Nigeria returned to civil rule on May, 29th 1999 following the transfer of political power from military to civilian. The transition in government has somehow fostered economic growth such that, the country has been consistently rated among the largest economy in Africa since 2004 [26]. This economic growth as expected triggered growth in urbanization and corresponding growth in the general and urban populations. The country's total population grew from 88 million in 1991 to 140 million in 2006, was approximately quoted at 195 million people in 2018, and projected to hit 441 million by 2050 [14]. While the urban areas have also recorded an extraordinary high annual growth rate of 5–10% [15]. Specifically speaking, as at 1995, there were only 78 cities in Nigeria with a population of over 100,000 people compared to currently that, seven cities are now with a population of over one million, 80 cities have a population between 100, 000 and one million while another 248 cities have 10,000–100,000 people [53].

The increase in the urban population has resulted in a rise in the quantity of solid waste that is being generated and disposed of across Nigeria. The country's perceived economic growth at the period under review has been largely undermined by the upsurge in population, hence there was no significant improvement in the country's critical infrastructure, resources, and technology towards tackling the problems of the increasing amount of solid waste. To date, there is still no government's nationally documented data on solid waste management in Nigeria. However, there is a significant number of case study research on cities, states, and in a few occasions' institutions on solid waste management in Nigeria [11, 30, 54–57]. Only a few academic reports have done a national-scale analysis of the status of solid waste management in Nigeria [9, 58–61]. The key elements of the findings on the status of MSW management in Nigeria within this period are summarized in what follows:

Waste generation and composition – Several factors influence the waste generation and quantities such as income, population, culture, geographical location, social behavior, industrial production, markets for waste materials, and climatic conditions [56, 59]. Waste compositions and quantities generated in Nigeria locations vary according to these factors as shown in Table 1, But the common pattern identified is that organic component is usually high and varies from 15 to 79.1% and the generation rate

Table 1: Waste characteristics and component in Nigeria.

Reference	City	Land area, Km ²	Population	Waste fraction, %						
				Organic	Paper	Plastic	Metal	Glass	Textile	Recyclable
[56]	Abuja	250	776,298	63.6	9.7	8.7	3.7	2.6	1.6	–
[64]	Makurdi	820	300,377	25–73.4	2.10–10.9	5.9–10.2	0.7–3.4	0.1–6.9	0.3–6.10	–
[54]	Unilag	5.61	87,000	15	15	9	3	2	7	
[62]	Ogbomosho	235	245,000	79.1	15.7	10.4	1.5		2.5	
[55]	Awka	522	301,655	73.24		7.98				20.3
[65]	Uyo	187	305,961	73.7		12.9	4.3	4.2	4.3	
[66]	Lagos	1171	9,113,605	22	14	29			14	
[63]	Ogbe-Ijoh			77						14
[67]	Akure	991	484,798	25	17.3	1.6	0.1	0.8	3.6	
[68]	Port-Harcourt	2700	1,005,904	38.6			10.8	23	64	
[58]	Nsukka	17.5	309,633	47	6	4	4	4	3	
[58]	Onitsha	52	261,604	49	8.1	17.9	8.7	4.5	10.1	
[69]	Benin	1204	1,086,882	78	4	9	4	3	–	–
[70]	Zaria	563	408,198	45.2	17.8	8	7	7.2		
[71]	Maiduguri	132	540,016	25.8	7.5	18.1	9.1	43	3.9	

**Figure 2:** Waste generation rates in Nigerian cities

was higher in urban areas than in the semi-urban area, which aligns with the assertion that increase in socio-economic status/income instigates an increase in waste generation rate [3]. Figure 2 shows that the waste generation rate in Nigeria varies from 0.13 kg/Capita/day in Ogbomosho in 2007 [62] to 1.04 kg/Capita/day in Ogbe-Ijoh, Delta state in 2015 [63].

Waste management data – Accurate and comprehensive data mining and documentation on specific waste stream characteristics is a critical step towards proffering sustainable solutions to solid waste management [18, 72]. It aids optimal MSW planning and allocation of resources. There is no available data on the quantity or generation rate of solid waste in Nigeria documented for the use by waste management authorities in the federal, state, or local governments. But in the period under review, several academic research efforts have been done on waste characterization on several locations of Nigeria including

institutions [54–57]. Table 1 is the list of works in Nigeria's location and the documented waste stream characteristics. The absence of the officially collected data has resulted in the quantity of waste generated surpassing the ability of the agencies to collect for disposal. Hence untimely waste evacuation, overfilled city waste collection bin, and indiscriminate dumping of waste are still common in Nigeria [54, 73].

Waste collection – Waste collection means the collection of waste from the point of generation (household, institutions, and commercial areas) for onward movement to disposal and treatment sites. Because of the absence of nationally collected waste data in Nigeria, the waste collection rate cannot be reliably ascertained. World Bank report of 2012 on the review of global solid waste management suggested that the waste collection rate in the African low-income countries (including Nigeria) is 41–46% [3]. The commonly identified method of solid waste collection

in municipalities include: house-to-house, community bins, curbside pick-up, self-delivered, and delegated or contracted service [58, 74]. House-to house waste collection has been reported in some high-income areas in Nigerian major cities [30, 75, 76], but what is prevalently practiced in Nigeria, is a self-delivered to community bins method [74, 76]. Collection services do not get to some unplanned areas of the urban cities such as slums, shanties, and ghettos due to poor street networks that make it difficult to access [71, 76, 78]. In a place like Kano, a major Nigeria city, 20% waste service coverage was reported [30]. While multiple collection methods have been reported in Lagos, the most commercialized city of Nigeria [79]

Waste minimization – To date, waste minimization has not been extensively adopted in Nigeria. Conceptual planning to generate less waste by harmonizing city development planning and management with waste generation is yet to be extensively embraced throughout the country's waste management landscape [80, 81]. The practice exists only in Abuja, Nigeria's capital city, where the Abuja Environmental Protection Board Act on solid waste control/Environmental monitoring of 2005, stipulates that all proponent of major projects within the capital city's territory must submit to the Abuja Environmental Protection Board (AEPB), a detailed proposal containing the nature and scope of the project together with the location and address [81]. The proponent is also expected to submit the details of the activities to be carried on and other relevant information. The board subjects the proposal to scrutiny factoring the anticipated waste stream to be generated before making a decision [82]. The statutory practice has helped the city authorities to know where, how much and type of waste being generated for optimally allocation of resources, assessment of relevant technologies, and also to decide on the best waste management approach.

E-waste – There is a heightening understanding that electronic waste embodies new and complex hazardous materials that are harmful to the environment and human health [18]. The high rate of production and disposal of electronic devices are exasperated by their limited life-spans which mount pressure for an increase in the production and resultant increase in the volume of e-waste generated [83]. The telecommunication industrial revolution in Nigeria started in 2001 after the licensing of four digital mobiles operators through auction by the federal government. By 2006, Nigeria was already rated among the fastest growing telecommunication industry in the world [84]. This may have triggered the e-waste problem in Nigeria as well [13, 85]. Over 219,000 tons of e-waste was reportedly generated in Nigeria, in 2014 [19]. A huge

proportion of this waste was recycled and/or usually processed by informal industries under the most rudimentary processes [20, 21]. So to say, Nigeria has a viable informal recycling sector for e-waste which in overall, may have been employed more than 100,000 people [17]. They collect and disassemble e-waste by hand to retrieve the saleable parts. The other parts with no economic value are normally dumped along with the MSW or burnt [17]. One major factor that emerged in the period under review is that the development in telecommunication in Nigeria to a reasonable extent depends on refurbished or what is called “second-hand” electrical and electronic equipment [85]. In Lagos, for instance, there are approximately 5,500 small enterprises that specialize in refurbishing and marketing used electrical and electronics products [21]. The electronics refurbishing sector in Lagos is also hinted to have transformed into a regional hub that does not only serve Nigeria with second-hand products but also the neighboring West and East African countries [21]. 75% of the second-hand/refurbished electronics imported into the country are either toxic, non-reparable, or obsolete and are moved straight to dumpsites, landfills, and/or dismantling outfits [17, 85]. The apparent potential health and environmental hazard posed by indiscriminate disposal of e-waste in the country prompted the NCC, a statutory government agency charged with the responsibility of overseeing the industry to issue a Nigerian Communication Industry E-waste regulation in 2018 [23]. This policy instrument is the first attempt at specifying the responsibility of each player in the e-waste generation, collection, and disposal across the country, which include manufacturers, importers, consumers, recyclers, vendors, bulk consumers, etc. [13, 23]

Waste disposal – Dumping of waste indiscriminately at the erosion sites, drainages, and other unauthorized areas have continued to date. The current waste disposal status was succinctly captured by [59] as;

‘The need to dispose of waste is so pressing that people dump their waste anywhere as long as they can get away with it. Sections of roads cordoned off by waste, railways entirely overtaken by heaps of waste, drainage channels completely obliterated by waste, and water bodies rendered useless by decades of waste dumping are common features of most Nigerian cities’

Waste incineration was reported in Nigeria for healthcare waste, though it was adopted by only a few health facilities [58, 86]. Composting is practiced only at the backyards, while open dumping of refuse is the most dominantly practiced across the country.

Recycling and resource recovery – Waste recycling and resource recovery doubles as a waste handling techniques and as an acceptable means for retrieving a value from

waste. In the low and middle-income countries' context, it is an activity mostly practiced by the urban poor and often tagged informal activities or the 'informal waste management sector'. Informal waste picking and sorting by scavengers have been tipped as a prime contributor to the urban informal economy and play important roles in the management of urban solid waste [32, 33]. Unlike in the past when it was grossly associated with stigma, it is currently a major element considered in circular economy proposals for most low and middle-income countries [12, 13]. These uncontrolled practices represent a risk for the health of the workers and the population living in neighboring of the sites. Their inclusion in a sound circular economy needs the implementation of actions to create safe recycling operations and to minimize the emissions of contaminants in the environment. In Nigeria, there are clear indications that the formal recycling of MSW does not still exist and prior attempts by the government to establish recycling programs on solid waste have been unsuccessful [87]. However, the informal waste recycling is still neither organized nor regulated in Nigeria and was not recognized in the policy guideline of the federal government released in 2005. It is therefore entirely a voluntary practice in Nigeria. In the period under review, the operating system has improved with reports on a reduced influence of middlemen. Middlemen in the waste picking value chain are businessmen that bulk-purchase the picked recyclables from the waste pickers. Because they have the resources to mop-up the recyclables in a quantity that the industry can purchase, they wield more influence in the recyclable waste market and often fix prices and set transaction conditions that are detrimental to the interest of the poor waste pickers.

The waste operators have organized themselves into small associations and unions in Abuja, while in Lagos, they have come together to register cooperatives to have better bargains and minimize the exploitation from middlemen. But the notable associations are the ones that deal mainly in metal, plastic, and electronic waste. No known union or association currently exists for other variants of waste recyclables such as paper [81].

Private-public partnership – Private-public partnership (PPP) is a variant of policy system that brings together both private and public entities to synergize resources, manpower, and ideas towards solving societal problems. It was first introduced in waste management in Nigeria by the Lagos state government in 1997 [88, 89]. By the millennium, the policy model has been adopted in some other cities in Nigeria and elsewhere in the low and middle-income locations [89]. The commonly identified media for financing the PPP projects in Nigeria include multilateral

agencies, stock exchange market bonds, bank loans, and external donors. It was reported that in Lagos, private service providers collect waste from households for disposal at a fee. The services were adjudged better in areas of consistency, flexibility, affordability, coverage, and accessibility while at the other Nigerian locations, unwillingness to pay for the services and poor performance of the program was reported [90, 91]

Landfilling – Landfill remains a common and one of the cheapest methods acceptable for municipal waste management in most parts of the world [25, 28]. It is a critical component of MSW management since all other means of waste treatment eventually produce residues that must be disposed of through landfilling [3]. The number of landfills in Nigeria has increased over time though they are still only available in major cities such as Lagos, Abuja, Onitsha, etc. The vast majority of urban areas does not still have a landfill and hence practice open dumping of refuse [30, 58, 77]. However, analyses on landfill standards conducted recently have shown that most of the landfills in Nigeria are far from meeting the basic requirements towards delivering environmental, economic, and other social benefits [31]. Studies have classified landfills according to various parameters such as waste deposit types, types of liners used, the design and construction protocols, and the landfill operation and practices [31, 92]. Evaluating Nigeria's landfill experience on the foregoing criteria shows that out of 10 landfill sites identified, eight are categorized at the lowest levels.

Solid waste management policies and institutional landscape in Nigeria – past, and present

Nigeria's earliest effort towards MSW management by way of policies and institutions were mainly motivated by the need to protect the environment. As a result of this, waste management laws were made with a focus on safeguarding public health and environmental components of water, land, and air. The public health Act of 1917 (which was amended as the Public health Act of 1958) is one of the earliest formative policies on environmental health protection in Nigeria [38]. It contained laws on the regulation of abattoir hygiene, slaughtering of animals, night soil handling, noise and odor control, and general waste management [37].

The major loophole in these formative policies is that they were mainly created as qualitative edits on which its enforcement was dependent. The laws were devoid of clear scientific standards and criteria. For example, general

cleanliness of the urban environments was emphasized through adequate waste collection and disposal without a stipulated guideline on landfill construction and operation.

However, the literature suggests that the creation of FEPA was the government's reactive actions to secret dumping of toxic waste in Koko Port (Bendel State) now Delta state in May 1988 by foreign parties [93]. The advent of FEPA, therefore, came with the immediate establishment of national guidelines on environment and health quality such as effluent discharge limit, toxic waste criminal act, facility, and premises' inspections, and waste management policy. FEPA Act of 1988 equally empowered the state and local governments to establish their environmental protection agencies to oversee the affairs of environmental protection, including waste management at the state levels. This development has often been regarded as the foremost government's attempt to give coherence and visibility to environmental issues in Nigeria. However, the federal ministry of environment was created in 1999 by merging FEPA and other key environmental agencies and institutions. The newly created ministry assumed the responsibility of administering environmental issues in Nigeria including solid waste management, but with distinctive functions in setting policy guidelines on how key environmental issues are to be approached in Nigeria. But the implementation of the policies is the responsibility of state governments through various state ministries of environment, states independent waste management authorities, and local government councils. The first guideline on solid waste management in Nigeria was released in 2005. This policy document has little improvement from the previous FEPA policy guideline. It is still made up of qualitative laws. In 2007, however, the NESREA was created as a parastatal under the federal environment ministry through the act of parliament. The NESREA was established to concentrate on setting up national environmental quality guidelines, monitoring procedures, and enforcement. This role largely conflicts the already existing institutional protocols that empowered the state government over environmental matters in their respective state. Further conflicts also suffixed with the recent creation of parallel industrial e-waste guidelines by NCC in 2018, as mentioned in the foregoing section.

The state governments through their various house of assemblies make laws on solid waste management. These laws on occasion aim at downplaying the role of municipal councils or at creating a particular area of jurisdiction that derogates the powers of local government [94]. In principle, the local governments (municipal councils) are responsible for solid waste management in the municipalities, but

because, in Nigeria, local governments are not fully autonomous and such lack financial and political independence to perform this function, solid waste management in Nigeria is, therefore, implemented by the state governments.

Financing mechanism for solid waste management in Nigeria –past, and present

The foremost institutional framework in Nigeria has largely classified solid waste management more as an environmental issue than as a health and social problem. The past waste management activities in the country were, therefore, mainly categorized and handled under environmental protection programs. Reviewed past government's environmental budgetary allocation shows that from 1981 to 1985, about \$2.5 million was allocated to environmental protection and planning. This is roughly about 0.001% of the total annual budget of the federation, as against 4–5% that was being allocated in other high-income countries at that time [37]. After the creation of FEPA in 1988, the then federal military government budgeted and appropriated more funds to FEPA, but as an ecological fund that is specifically tagged for national emergencies and disaster management such as flood, drought, erosion control, and other human hazards [26]. From 1990 to 1992, total funds budgeted by the federal government under the National Rolling Plan for community development, town and country planning, environmental development, sewage management, development of water supply, housing development, mapping, etc. were aggregated at \$29.6 million, from which \$4 million was earmarked for environmental protection. Other key economic sectors like agriculture, defense, energy, transport, and commerce consumed about 53% of the total appropriated funds [95]. This could be cogently explained by the government's onset effort on emphasizing and prioritizing economic growth over environmental protection as mentioned in the foregoing section [96]. Another contributing reason for this could be the poor economic and political agenda that characterize the then military rule. A typical example is that from 1981 to 1985, 10% of the country's national budget was assigned to the defense which was unreasonably high compared to the 0.001% meant for environmental protection alone. The high fund allocation for defense in the budget is unjustifiable on the fact that Nigeria was not at war with any country at the period under review [37]

At present, the three tiers of government – federal, state, and local have shared roles in the financing of developmental projects in Nigeria. There is the

constitutional provision that mandates the federal government to distribute funds to state and local governments which are known as ‘statutory monthly allocation’. The state governments and local governments are also expected to raise funds individually from internally generated revenues towards meeting up with their recurrent and capital expenditures. Amongst these internally generated revenues are the waste management levies and dues imposed on households, institutions, and commercial outfits. Certainly, there is no documented data on the amounts of funds generated specifically from waste management fees by various states in Nigeria in the current era. The reason is mostly connected to how these levies are collected in most states. Because of costs and logistics challenges involved in the collections of levies on the Nigerian urban areas such as improper housing structure, lack of staff, and corrupt practices, the government often outsourced the function to private consultants on contracting bids that are hugely underpriced, which probably shortchanges the government [58]. Apart from Lagos, other state governments have not shown aggressive interest in optimizing waste levy collection in most cities in Nigeria. Perhaps, this might be linked to the fact that in low and middle-income countries, waste management services are majorly perceived as an essential service to the public that needed to be subsidized or undertaken without expected returns on investment [8].

On the other hand, ascertaining the level of funds allocated for waste management services in the various state governments in the current time is difficult, since waste management activities are often jumbled with other environmental issues such as water and sanitation, at the state level. The persistent poor status of waste management services in Nigeria is a reflection that the waste authorities are still largely underfunded as was reported in studies before 1999 [39, 46]. The lack of funding mirrored the poor quality of waste services, inadequate manpower, poor vehicle maintenance, absence of waste collection trucks, and waste storage containers, and poor waste disposal methods [9, 91, 92].

Discussion

In this section, we discuss the future of MSW management in Nigeria. In the first part, the theoretical quantities of urban solid waste to be generated in Nigeria in the future were calculated and discussed, while in the second part we discuss the prospects for circular economy adoption.

Future projections of solid waste generation and collection rates in Nigeria

Many socio-economic parameters influence the quantity of waste generation in cities. But the most accepted general factors sensitive to making projections are; the city’s population, population growth index, and per capita waste generation [64]. Nigeria’s total population P_{20XY} , (current and future year) is calculated with the model given as:

$$P_{20XY} = P_{2006} (1 + r/100)^{20XY-2006} \quad (1)$$

where $P_{2006} = 140,431,790$ (2006 population census figure); $r=3.2$ (annual population growth index, which is a national value) [55],

The urban population for the current/future year is calculated with the model:

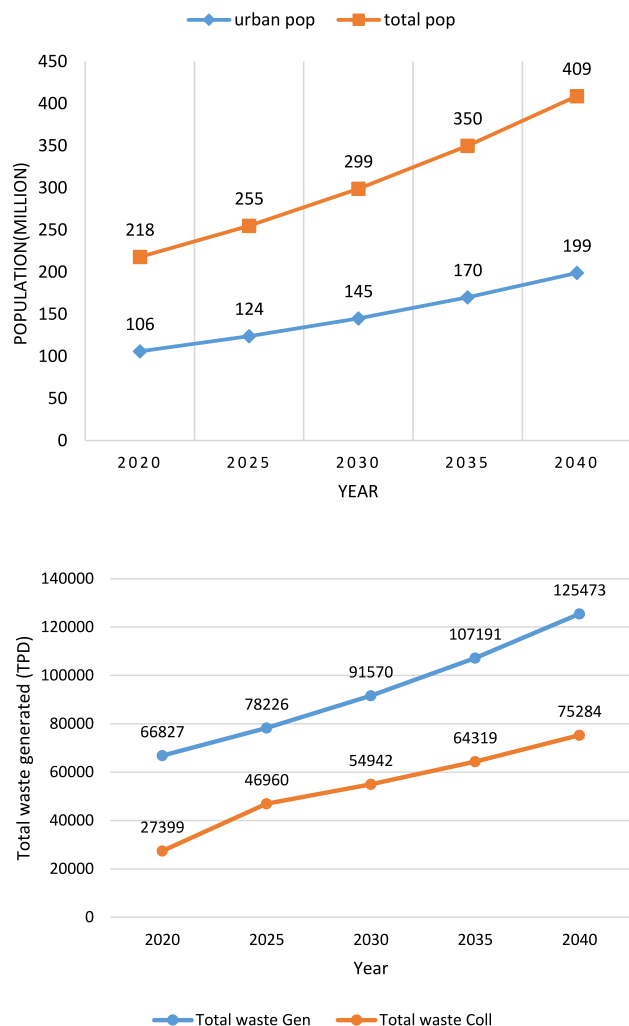


Figure 3: (A) Projected growth in the urban and total population in Nigeria from 2020 to 2040. (B) Current and Projected quantities of solid waste generated/collected in Nigeria.

$$P_{20XY \text{ (Urban)}} = 0.486 P_{20XY} \quad (2)$$

where 0.486 (48.6%) = current urban population which is assumed to remained constant [97]. The growth in the total and urban population in Nigeria for 2020, 2025, 2030, 2035, and 2040 is shown in Figure 3A.

The total urban solid waste generated in Nigeria in tonnes per day (TPD) for the current and future year was calculated with:

$$Q_{20XY} = 0.00063 \text{ tonnes/day} \times P_{20XY \text{ (Urban)}} \quad (3)$$

where 0.63 kg/day = 0.00063 tonnes/day = is the rate of waste generation assumed to remain constant for Nigeria [56]. The total waste collected for the current and future year is calculated with:

$$Q_{20XY \text{ (Collected)}} = 0.41 \times Q_{20XY} \quad (4)$$

The waste collection rate of 41% was also assumed as an average value for low-income countries [3]. The calculated values of quantities of waste generated and collected for the present year, 2020, and projected values for the future years; 2025, 2030, 2035, and 2040 are shown in Figure 3B.

Sustainable development in its intrinsic meaning implies a type of development that encompasses the sensitive areas of human development which are economic, social, and environmental protection. Nigeria like most low and middle-income countries is in the dilemma of achieving these facets of development simultaneously. Urbanization which is an outcome of socio-economic development often results in an unmitigated growth rate of population and rapid industrialization which is the major driver of MSW generation. Nigeria's current urban population which is calculated at 106 million, has been projected to hit 199 million people by 2040 (Figure 3A) and will generate a total solid waste of 125,473 TPD as against 66,828 TPD that is being generated currently as shown in Figure 3B. Also, global case history rightly points out that when the urban population of a nation exceeds 25% of the general population, the urbanization accelerates [98]. These factors are all precursors that the MSW management and the general urban infrastructure in Nigeria, will receive greater pressure in the nearest future. It, therefore, calls for a proactive and integrated measure in demographic, environmental, health, and social planning in preparation ahead of the challenges.

Opportunities and prospect for circular economy adoption in solid waste valorization in Nigeria

Environmentally sound waste management practices will significantly reduce the degradation of environmental

components of water, air, and land. By extension will improve the quality of life and public health. The circular economy is currently being regarded as one promising means of achieving a high waste recycling rate, economic prosperity, job creation while diminishing the adverse effects of waste on society. One demonstrable example of the positive impact of the circular economy is in the European Union (EU). EU has introduced many directives on waste management improvement modalities. Horizon 2020 initiative, which is one of the biggest EU's research programs with over 80 Billion Dollars of funding spanning seven years period was introduced to this effect [12]. It is aimed at improving the waste management situation in the region by adopting circular economy principles. A lot of signs of progress has been made in EU waste management in recent time. For instance, the recycling rates for MSW has improved by 16% from 2004 to 2017, packaging waste recycling rate increased by 13% from 2005 to 2016; of the total MSW generated by EU-28, Iceland, Switzerland, and Norway in 2017, about 46% was recycled, while 67% of packaging waste generated in 2016 was recovered [99]. The EU's revised legislative framework on waste for 2018 proposed a 65% target on MSW recycling by 2035 and 70% target on packaging waste recycling by 2030 [100]. The circular economy has also been integrated into socio-economy planning at the other high-income countries of the world such as Japan, and few low and middle-income countries such as China [101]. Many factors have been identified as impediments to the adoption of circular economy in low and middle-income countries which include low financial resources, poor technological development, and informal waste recycling schemes [102]. Recent scholarships have, however, recognized that the implementation of the circular economy should be context-specific since cities and societies vary in terms of environment, social, financial, political, demographic, and cultural factors [12, 13]. It is based on this perspective that we discuss opportunities, and prospects for circular economy adoption in solid waste valorization in what follows;

- (i) First is that the foregoing review has shown that at the past and present, waste management policies in Nigeria have mostly followed a top-down structural process, where qualitative laws are formally set and enforced. The reason is that the policymakers have focused on environmental protection without considering business and economic possibilities of waste management. The green economy approach has not been extensively explored since both the policymakers and the general Nigerian public have not viewed waste as a means of wealth creation but as all rubbish needed to be discarded. Although evidence of good waste

management delivered by public institutions exists in several countries, Nigeria's current waste management institutional arrangement is not properly situated to offer more prospects for circular economy adoption and implementation [103]. Efforts are required at supporting market-oriented institutions that will regard households, institutions, and commercial places that generate solid waste as customers. This market-based model of waste management has been exemplified by 'Wecyclers', a Lagos-based waste recycling outfit established in 2012. The company uses a modified tricycle to access and collect waste from inaccessible areas. They will sort the collected waste and sends text messages back to the households notifying them of how many points they have earned for trading their household waste. The earned points are converted as a gift for the households in the form of food items, cleaning products, and mobile phone airtime. By 2015, Wecyclers was reported to have collected over 500 tonnes of waste, and have employed over 80 people [104]. The circular economy incentivize scheme created by Wecyclers has attracted partnerships from Lagos state government and other meaningful organizations such as banks, multinational companies, IT firms, etc., and grant from foreign universities [105]. This service is only available in Lagos at the moment, we believe that it can be created in other states of the federation through appropriate incentive legislatures.

- (ii) Informal waste picking is an important element of MSW management in most low and middle-income economies. A study conducted by [32, 33] had carefully identified that the informal waste recycling system in Nigeria, has a well-organized value chain that comprises of waste pickers, scrap dealers, itinerant waste buyers, cart-pushers, middlemen, and micro and small enterprises (Figure 4).

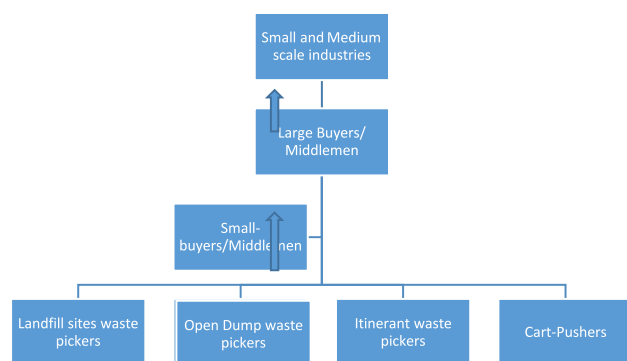


Figure 4: The value chain for informal waste recycling in Lagos, Nigeria

The structured waste recycling system has offered a critical opportunity for a circular economy introduction. The elements that are needed to make the value chain a circular economy model include; the proclamation of formal policies and institutions, the implementation of safety procedures, and environmental health regulations. The policies will establish standards, incentives, health regulations for waste pickers, pension schemes, and safety equipment. While the institutions will enforce, regulate, and also protect the interests of all parties. Moreover, the public institution would also control the implementation of the correct procedures. Wecyclers's experience (mentioned earlier) has shown that organized waste recycling schemes can easily attract partnerships and good funding from credible quarters.

- (iii) According to [106], corporate governance tools could be embedded in the informal waste picking system to improve the economic efficiency of the system. This is hinged on the perspective that regarding waste picking as a business and not as welfare policy, allows proffering management solutions that will help in optimizing the operating activities [106]. And will in the long run minimize the assistance policy of the government as the informal waste system becomes financially independent. Based on this, we also believe that the environmental, social, and health challenges associated with informal waste recycling need to be considered in the business policy. Hence, for proper inclusion of the informal waste picking activities in a circular economy model in Nigeria, we propose the following interventions (i) The environmental challenges can be addressed by incorporating a policy framework on the minimum operational guidelines to be adopted by any private venture (like Wecyclers) that is opting for participation and recruitment of waste pickers. (ii) The social challenges of informal waste picking such as stigmatization can be addressed by formalizing their operation and by them being referred to as "environmental operator" rather than 'waste picker' in the official policy documents. (iii) To minimize the associated health risk, the policy documents could also provide health insurance benefits by integrating the waste pickers in the already existing National Health Insurance scheme in Nigeria, provide free and adequate health education, free protective clothing, and sanitary equipment. These three listed conditions could be set as a prerequisite for issuing an operating license to prospective private waste recycling outfits such as Wecyclers.

- (iv) The activities of the vast majority of industries in Nigeria are regulated by independent government agencies. For example, the National Agency for Food and Drug Administration and Control (NAFDAC) oversees the activities of food and water packaging industries in Nigeria, from the time of registration to operation. But the only problem is that the agency does not regulate the waste generated by the sector. The circular economy opportunity here is that NAFDAC, for instance, may have the database (name, address, and location) of all the food and water processing companies in the country and therefore when a circular economy framework such as extended producer responsibility is introduced by the regulatory body, enforcement, and monitoring of compliance will not be difficult to implement. The NCC has already towed this line to issue an e-waste management guideline for the telecommunication industry as mentioned in the previous section.
- (v) A previous study has also shown that there is an existence of interdependency among the Nigerian industries demonstrated by the case of water packaging industries and the plastic industry [13]. The packaging nylon and plastic bottles used by water packaging factories are mostly outsourced to plastic producers. It simply means that the last user in the reverse logistic supply chain of water packaging material (bottles and nylon) is the plastic industry. This is another critical opportunity for meso-level (inter-industry) circular economy model creation in the country.
- (vi) Various waste components generated in the country's municipal cities have proven to be marketable and reusable. The high organic waste component, for instance, has been reported in many cities, which is an avenue for the development of bio-energy clean technology mechanism for a waste-energy generation. Although there are many sources of biomass for bioenergy production, MSW seems more promising because it is being generated daily and inconsequential volume too. This is an opportunity, in the long term which Nigeria should consider in solving its energy problem through bioenergy technology. One way to achieve this is by integrating energy policymaking in Nigeria with the MSW policy in the meso-level circular economy framework. The renewable energy policy drafted by the Energy Commission of Nigeria in 2014 stated that 'the nation shall incorporate waste-to-energy strategy in its overall waste management framework' [107]. But the policy document also recognized that the high upfront cost of this technology is a key challenge to its deployment [107]. Our opinion is that since waste-to-energy technology is of interest to both the energy sector and waste management authorities, the burden of the so-called upfront capital cost could be shared between the two governmental agencies and spread out in the long term annual budgetary provisions of the agencies. Another way to achieve this policy synergy is that the reverse logistics in the supply chain of the biomass component of the MSW can be collaboratively designed by the two agencies for the optimal yield of the biomass that would serve as a feedstock for the waste-to-energy plants.
- (vii) In the theoretical circular economy model proposed for low and middle-income countries by [12], the introduction of waste recovery shops in the cities was suggested, where a waste picker could be stationed to collect waste recyclables from citizens. The highlighted advantages of waste recovery shops include fostering familiarity between city inhabitants and waste pickers, job creation, enhancing the ease of monitoring, and data collection on recyclables by the municipal authorities. Urban markets in Nigeria provide a subtle opportunity for the establishment of these shops. Being an essential component of urban profile in Nigeria, urban markets act as a great arena for the interaction of buyers, sellers, and producers of commodities. Establishment of waste shops in the urban market will increase public awareness of recycling while ensuring high recycling rates. Furthermore, unlike high-income countries where urban residents can easily source foodstuffs and other necessities of life from supermarkets and shopping malls, most urban dwellers in Nigeria depend on urban markets for their household items due to the perception that cheap commodities can easily be assessed. Therefore, based on the high dependency of Nigeria's urban dwellers on urban markets as the major source of their household items, household solid waste generated in the Nigerian cities can largely be linked to these urban markets. This is another opportunity for implementing extended producer responsibility since the vast majority of commodities sold in the markets can be traced to either local or foreign producers. To achieve good results would require collaboration between the existing organized trade unions in the markets, the producers, and the governments at all levels. This type of collaboration has been pointed out as a major enabler to circular economy adoption in low and middle-income countries [108].

(viii) Efficient and sustainable waste treatment techniques are equally essential in the circular economy schemes. High capital, maintenance, and operation cost of novel waste treatment facilities such as incinerators, and biochemical waste conversion equipment have hindered the large scale application of this technology in most countries of Africa (including Nigeria) [8]. However, a cost-effective mechanical biological treatment technology for pre-treatment of waste before final disposal has been suggested for low and middle-income countries like Nigeria [12]. It ensures organic waste stabilization and production of waste-derived fuels as it converts waste to energy as fuel. It also addresses the issue of energy demand and solid waste management in a circular economy manner [109]. Simultaneously, it guarantees other socio-economic and environmental health benefits such as the reduction of landfill gas production, leachate releases, and unpleasant odor [110]. While the life span of the disposal site can be prolonged. We believe that with effective collaborations between waste management authorities and indigenous research institutes in Nigeria, this technology variant can be locally produced for effective waste treatment through frugal innovation.

Recommendations and conclusion

MSW management is a pervasive urban development challenge in Nigeria [91]. Unmitigated growth in the urban population which has been predicted to persist into the future is a factor that would worsen the problem. A review of the past and present status of the waste handling approaches have revealed many areas for future improvements. Based on this, we make other recommendations for this work. Nigeria has collated national data on demographics and health indicators through the Demographic and Health Survey (DHS) since 1990 at a periodic interval of five years. Surprisingly the waste generation information is not included in these statistics. Since the general purpose of the nationally collected DHS data is to inform national development planning and allocation of economic resources. It is our opinion that future household surveys should integrate waste management survey.

Many urban cities are spreading out in Nigeria without planning or guideline which has often lead to improper community structure and proliferation of urban slums and ghettos. The previous government's approach to tackling this problem is by constant demolition of irregular urban areas. However, in most places in Africa, there is increasing

awareness that cities should be conceived as a complex system with a dynamic informal economy which plays an increasing role in urban solid waste management. Informality is receiving recognition as the new mode of urbanism. Considering the rate of poverty in Nigeria, and the government's lack of capacity in providing adequate employment, we recommend that urban policymakers in Nigeria should explore this new urban policy mechanism that by implementing actions to create a proper and safe waste recycling operation, the current urban informal economy that depends more on waste picking could be legalized. They should be included in social and economic policy planning.

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