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Review

Energy and material recovery potential from municipal solid wastes (MSW) in Nigeria: Challenges and opportunities

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Abstract: Municipal solid waste (MSW) generation is increasing in Nigeria. This poses serious environmental and public health issues because of its poor management. MSW has become a valuable resource which offers opportunities for socio-economic growth, thus the relevance of this review. The study adopted a secondary or desktop research method. The objectives of the study include identifying MSW generation rates in popular Nigerian cities, estimating daily and annual generation rates and the material and economic potential of the generated MSW. The average MSW composition for 22 cities was as follows: organics (56%), plastics (9%), paper (13%), glass and metal (3% each), textiles (2%) and others (14%). The estimated 34 million population living in the cities generates about 20378 tons of MSW each day (7.4 million tons per year). Valorization of the MSW finds applications in different—energy (power, transport, household), agriculture, construction and manufacturing. The energy potential of the generated organic, paper, plastic and textile wastes is about 947981358 kWh/ year, with a revenue potential of $131769409. This represents about 2.6% of the energy generated in Nigeria in the year 2020. The estimated revenue potential of trading the waste materials (plastic, metal, waste paper, textile and glass) for recycling ranges from $493.3 million to $16.4 billion. Converting wastes to raw materials will reduce the amount going to landfills/dumpsites and reduce the fiscal burden of waste management on municipalities. It will also create employment. Among others, the challenges facing MSW valorization in Nigeria include poor waste management, non-recognition of the informal waste sector, financial incapacity, etc. Thus, it is important to have adequate and effective policy and decision making.

Keywords: municipal solid waste; waste generation; waste characterization; recycling; waste-to-energy; valorization; sustainability; Nigeria

1. Introduction

The global economy largely operates on a linear model, which is take-make-use-dispose. This leads to huge waste generation, which ends up in dumpsites or landfills, or indiscriminately dumping in the environment (in developing countries). Disposal of these wastes represents huge economic and natural resources losses. The products-turn-waste represents value-addition, starting from natural resource extraction, production and distribution. These processes have intrinsic costs in terms of monetary, environmental and natural resources depletion [1,2]. From a socio-economic and ecological perspective, it is critical and sustainable to use suitable technology to convert these wastes to beneficial materials or products [3]. The conversion is part of the circular economy (CE) framework, which encompasses redesigning production-consumption so as to do away with waste and pollution, and support regenerative or restorative economy. CE aims to decouple economic growth from resource utilization and waste generation [2].

Waste valorization support Sustainable Development Goals (SDGs). Waste recovery reduces water pollution and improves environmental quality, associated with SDG 6 "clean water and sanitation." It also supports renewable energy production—SDG Goal 7 (access to affordable, reliable and modern energy). MSW valorization creates jobs and prosperity: SDG 8 "decent work and economic growth" and SDG Goal 12 "sustainable consumption and production patterns." Circularity also aids in reducing greenhouse emissions: SDG Goal 13 "urgent action to combat climate change and its impact" so as to limit temperature increase to 1.5 °C above pre-industrial levels. Proper waste management is also associated with SDG 11 (sustainable cities and communities). Recycling offers huge ecological advantages—conservation of natural resources and environment and pollution abatement. [4]. Recycling can be coupled to Nigeria's pursuit of reducing greenhouse emissions under the Paris Climate Accords [2,5]. However, adequate and suitable waste management starting from collection, transport, etc. is important to achieve this [2,6,7].

Available data indicate that cities account for about 1.8% (17196 km^2) of the total area of Nigeria [8]. Yet, they contain 52% of the population. This is because they are the seats of economic, political, technological, legal, healthcare and social development. They offer better economic opportunities and standards of living. For example, 83% of the urban Nigerian population is non-poor, in contrast to the 51% of the rural population that is poor [9]. City dwellers have more purchasing power and accordingly higher levels of waste generation [6]. Waste disposal methods in developing countries such as Nigeria comprise mostly indiscriminate dumping in the environment—empty plots, water bodies, drainages and open-burning. The waste constitutes environmental pollution, posing public health risks [10]. The indiscriminate disposal leads to chemical pollution and biological contamination of surface and groundwater [6]; the burning releases emissions (pollutants) such as dioxins and furans, particulate matters (PM), NMVOCs, etc. The ubiquitous practice of dumping MSW in drainages leads to flooding, especially during the rainy season [10].

Studies have been done on waste generation levels in different cities across Nigeria [11–20] and recycling and/or uses of different waste streams, such as plastic, metal, organic, etc. However, our study synergizes these different aspects of research, to determine the levels of waste generated in some major Nigerian cities for the recent year (2021), the potential applications of the different waste types and potential revenue generation. The identified MSW generation rates were used to estimate recent levels of generation for each of the identified cities. The estimation is important to numerically represent the levels of waste generation and their potentials. The potential applications of the MSW were synthesized from different studies across different fields. The applications are energetic and material. The monetary or economic values of the MSW applications were also quantified. This is important, considering economic benefits (apart from environmental and social benefits) are a serious factor in MSW valorization. This is important to policy and decision making. Fiscal consideration often weighs heavily in any agenda or programs, especially developing countries such as Nigeria, where governments have limited financial resources. The economic benefits also demonstrate that MSW valorization can help alleviate poverty and unemployment issues, while generating revenues for the cities and also funding of proper waste management. Also, proper waste management will help address many public health issues in Nigeria. Other opportunities and challenges facing MSW valorization in Nigeria were also identified from various literature sources and discussed. The research objectives include (i) identifying waste generation rates (kg/day) of some major cities in Nigeria, (ii) estimating the amount of MSW generated for the year 2021, (iii) quantifying the amounts of different waste fractions generated from the MSW, (iv) discussing the practical applications the MSW fractions can be recycled to and (v) discussing the opportunities and challenges facing recycling in Nigeria.

2. Methods

The study adopted the secondary or desktop research method. The reason for adopting the method is to synthesize data from different sources to yield an average waste generation and characterization for different urban areas in Nigeria and build on the practical value of waste as a resource. The data necessary for the study were collected through these sources: (i) academic peer-reviewed journals; (ii) grey publications such as policy briefs, government publications; technical reports and (iii) companies' websites, newspaper articles or interviews of those involved in recycling (such as entrepreneurs and founders of recycling firms). Waste generation rates and characterizations in some of the major cities in Nigeria were identified. The study applied both quantitative and qualitative methods to synthesize data and discuss the waste generation in some cities in Nigeria, the potential applications for these wastes to support economic and environmental objectives. The 2006 population (last conducted national census) of the identified cities were obtained from Federal Republic of Nigeria Official Gazette [21]. This is more than fifteen years ago. However, the census forms the basis for any population projection in Nigeria. Equation 1 shows the formula for population projection.

$$P_n = P_o\ (1\ +\ r/100)^n \tag{1}$$

where P_n is the population in year 2021, P_o is the base population from which the future years were projected, and it is based on NPC 2006 data, where r is the average city population growth per annum, and n is the projection period (15 years). The World Bank [22] shows Nigeria's population grew by an average of 2.62% from 2006 to 2021. The growth rate was assumed equal for the whole set of cities.

To calculate amount of MSW generated in each of the cities in the recent year (2021), the estimated recent population was multiplied by the waste generation rate obtained from literature. The composition fractions of MSW generated in the year 2021 were calculated by multiplying the total MSW generated in each city by the respective percentage compositions obtained from the literature. Equation 2 calculated the amount of MSW generated for the year, while Eq 3 calculates for MSW fractions.

$$M_g = P_n * MSWg \tag{2}$$

$$M_f = M_g * X \tag{3}$$

where M_g is the total MSW generated (kg/cap/day); *MSWg* is the waste generation rate (kg/cap/day) in each city for the present year; M_f is the calculated MSW fraction (organics, plastics, paper, textile, metal, glass and others), and *X* is the MSW fraction in percentage.

3. Results and discussion

Table 1 shows waste generation rate (kg/day) and percentage composition of the MSW in the 22 Nigerian cities, while Table 2 shows the estimated 2021 waste generation (kg/day) and composition. From Table 1, the average per capita MSW generation of the set of cities is 0.56 kg/cap/day. The rate falls within the widely accepted range of 0.44 to 0.66 kg/cap/day for Nigeria [11] and closer to World Bank's 0.53 kg/cap/day reported for lower-middle income countries [23] such as Nigeria. Waste generation is dependent on socio-economic, cultural preferences and seasonality (which affects goods such as agricultural produce, etc.) [10,15,23]. As Nigeria's economy, income level and population grows, it is expected that waste generation will increase correspondingly [10,23]. If the MSW are not adequately managed, it will pose more environmental and public health challenges. For example, 66% of MSW generated in Nigeria and other LMICs are openly dumped, while only 18% and 6% are landfilled and recycled, respectively [23].

Table 1. Waste generation rate and characterization of some cities in Nigeria.

Location	Population (2006)	Authors	Waste generation (kg/cap/day)	Organic	Plastics	Paper	Textile	Metal	Glass	Others
Lagos	9113605	[11]	0.63	56	4	14.0	-	4.0	3.0	19.0
Nsukka	309633	[11]	0.44	56	8.4	13.8	3.1	6.8	2.5	9.4
Makurdi	300377	[11]	0.48	52.2	8.2	12.3	2.5	7.1	3.6	14.0
Kano	2958000	[11]	0.56	43.0	4.0	17.0	7.0	5.0	2.0	22.0
Onitsha	263109	[11]	0.53	30.7	9.2	23.1	6.2	6.2	9.2	15.4
Ibadan	2559853	[11]	0.51	76	4.0	6.6	1.4	2.5	0.6	8.9
Maiduguri	540016	[11,12]	0.28	25.8	18.1	7.5	3.9	9.1	4.3	31.3
Enugu	722664	[13]	0.48	39	21	11	5	2	3	19
Abuja	776298	[14]	0.66	54.10	5.13	11.2	1.01	1.65	4.51	22.4
Benin	1156366	[15]	0.43	78	9	4	-	4	3	2
Okigwe	132701	[15]	0.54	77	6	12	-	1	4	0
Minna	348788	[15]	0.51	44.63	5.91	-	-	3.6	1.11	44.75
Ogbomoso	291723	[16]	0.13	56.4	10.4	15.7	2.5	-	1.5	13.5
Uyo	305961	[17]	0.54	65	10	8	3	4	3	7
Abeokuta	449088	[18]	0.60	57.8	8.7	26.2	-	1.6	2.2	3.5
Ado-Ekiti	313690	[18]	0.58	60.4	4.3	21.4	-	0.2	2.2	11.5
Ife	396508	[18]	0.38	77.9	7.3	5.3	-	0.2	1.1	8.2
Ijebu-Ode	157161	[18]	0.44	58.7	14.7	19.6	-	0.5	1.8	4.7
Osogbo	155507	[18]	0.55	58.2	12.1	17.8	-	1.4	0.6	9.9
Oyo	428798	[18]	0.63	62.1	10.6	18.5	-	3.1	1.4	4.3
Port Harcourt	1005904	[19]	1.2	56.2	4	6.2	9.07	6.2	8.2	10.13
Warri	564657	[20]	1.04	77	7	6	1	1	3	5

Table 2. Estimated 2021 waste generation (kg/day) and composition in some Nigeria cities.

Location	Waste generation (kg/day)	Putrescible (kg/day)	Plastics (kg/day)	Paper (kg/day)	Textile (kg/day)	Metal (kg/day)	Glass (kg/day)	Others (kg/day)
Lagos	8462738	4739133	338510	1184783	-	338510	253882	1607920
Nsukka	200808	112452	16868	27711	6225	13655	5020	18876
Makurdi	212514	110932	17426	26139	5313	15089	7651	29965
Kano	2441554	1049868	97662	415064	170909	122078	48831	537142
Onitsha	205538	63100	18910	47479	12743	12743	18910	31653
Ibadan	1924267	1462443	76971	127002	26940	48107	11 546	171260
Maiduguri	222867	57500	40339	16715	8692	20281	9583	69757
Enugu	394764	153958	82901	43424	19738	7895	11843	75005
Abuja	755184	408554	38741	84581	7627	12461	34059	169161
Benin	732899	571661	65961	29316	-	29316	21987	14658
Okigwe	105621	81328	6337	12674	-	1056	4225	-
Minna	262187	117014	15495	-	-	9439	2910	117329
Ogbomoso	55898	31526	5813	8776	1397	-	838	7546
Uyo	243523	158290	24352	19482	7306	9741	7306	17047
Abeokuta	397158	229557	34553	104055	-	6355	8737	13901
Ado-Ekiti	268169	161974	11531	57388	-	536	5900	30839
Ife	222083	173003	16212	11770	-	444	2443	18211
Ijebu-Ode	101924	59830	14983	19977	-	510	1835	4790
Osogbo	126065	73370	15254	22440	-	1765	756	12480
Oyo	398175	247267	42207	73662	-	12343	5574	17122
Port Harcourt	1779173	999895	71167	110309	161371	110309	145892	180230
Warri	865563	666483	60589	51934	8656	8656	25966.8864	43278
Total	20378673	11729141	1112781	2494682	436917	781286	635695	3188170

The estimated 34 million people living in the cities generate about 20.3 million kg (20378 tons) of MSW each day in the year 2021. This represents total waste generation of 7.4 million tons per year (TPY). The per capita waste generation is 281 kg/year or 0.21 tons/year. This amounts to 193.4 kg/cap/year or 0.19 TPY. There is variation in the compositions of household wastes (especially paper and plastic) across the various cities. Figure 1 shows the MSW percentage composition and generation (tons/year).

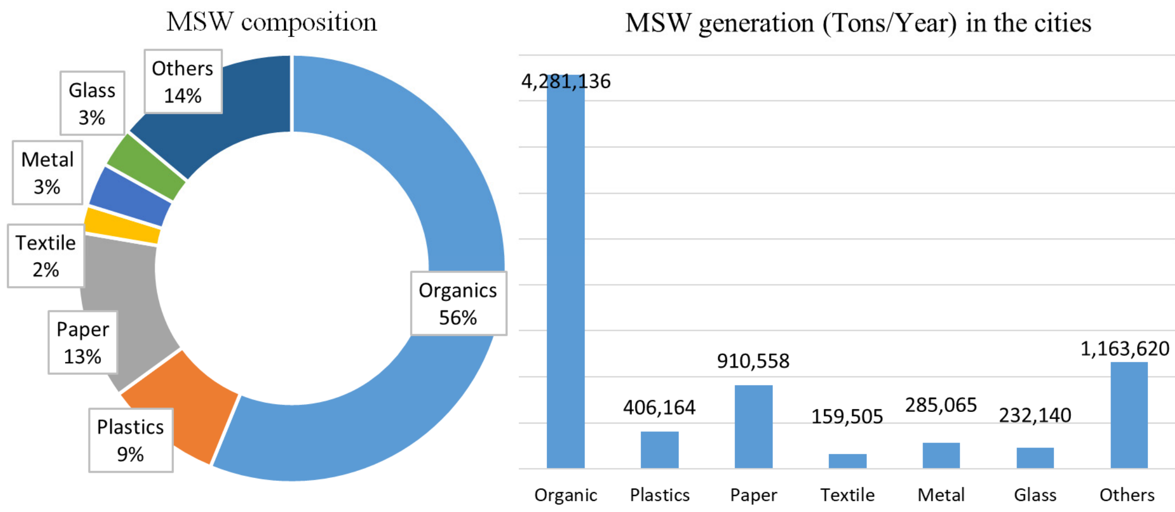

Figure 1. Composition and generation (TPY) of MSW.

Figure 1 shows organics represent the highest MSW composition, followed by paper, plastics and the least, textiles. Nigeria has an average waste collection efficiency of 44% [24]. This indicates 4.4 million TPY of the waste are carelessly disposed to the rivers, drainages, empty plots, open-burning, etc.; meanwhile, 3 million TPY are collected by formal waste managers for onward disposal to landfills or dumpsites. Our estimated organic waste generation in the cities for the entire year 2021 was 7438215645 kg or 7.4 million tons, representing 56%. This is similar to the value obtained in Nnaji [15], which shows organic waste for the entire Nigeria averages at about 50% and is about three times those generated in developed countries. Since the 1950s plastic production and resultant waste generation have increased tremendously. The increase is related to durability, cheapness, light weight, resistance to heat and corrosion. Only 12% of the plastic waste generated in Nigeria is recycled, while 80% ends up in dumpsites or landfills [6]. Our estimated waste paper produced by the cities is 910558 tons per year (TPY), representing per capita paper waste generation of 0.026 TPY or 26 kg/cap/year. It is far below the global average of 55 kg/cap/year and higher than the average for Africa (7 kg/cap/year) [24].

3.1. MSW valorization for different applications

3.1.1. Energy recovery

Energy content of wastes is converted through various technologies. They can feed both grid and off-grid electricity systems, or serve as fuels for industrial and transportation purposes. The energy recovery from MSW can be achieved via thermal or biological treatment. Thermal treatment needs high calorific value (HCV) dry combustible wastes such as organic, plastic, rubber and paper wastes. Wastes with high organic content, such as food waste, garden waste, etc., are suitable for biological treatment [3]. Incineration is the easiest and cheapest thermal recovery option [1,3]. For incineration, the moisture content of the wastes should be less than 50%, or else it will require a pre-drying process. The combustion requires adequate oxygen to oxidize the fuel (waste) in temperature exceeding 850 °C. The resultant products are water, CO_2 and bottom ash. The produced steam can be used to run a turbine to generate electricity [1]. Table 3 shows potential electricity and revenue generation from the generated MSW.

Table 3. Electricity generated from waste incineration.

Waste type	Electricity (kWh) per kg of waste treated [1]	Generated waste (kg/yr)	Calculated energy (kWh)	Estimated revenue ($)*
Organic	0.04	4281136100	171245444	23803117
Paper	0.36	910558200	327800952	45564332
Plastic	0.96	406164700	389918112	54198618
Textiles	0.37	159505000	59016850	8203342
Total	-	5757364000	947981358	131769409

*Averagely, 1 kWh = $0.139 in Nigeria [25].

As shown in Table 3, 947981 MWh (or 948 GWh) of electricity will be generated from the waste per annum in the cities. This is equivalent to 2.6% of all electricity (36397920 MWh, or 36397.92 GWh) generated in the country in the year 2020 [26]. The estimated potential revenue generation from incinerating the wastes is $131.7 million per annum. An estimate shows MSW incineration will produce between 6 to 52% of Nigeria's electricity demand [27]. In Ilorin, Nigeria, 584 tons/day of combustible MSW generated daily has an energy potential of about 3.2 GWh, which can meet the city's 15% daily power demand [28]. Waste generated in Enugu can satisfy 21.6% of their electricity demand [13]. If integrated into the national grid, the WtE system will help solve Nigeria's persistent electricity supply challenges. Currently, fossil fuels account for more than 80% of Nigeria's grid electricity generation [28]. WtE also aid in meeting the Nationally Determined Contributions (NDC) pledge by Nigeria in its climate objectives. A typical example of the viability of incineration is the Istanbul Metropolitan Municipality WtE plant, which incinerates 15% (3000 tons/day) of the city's MSW to generate 90 MW of electricity per day. The power evacuated to the Turkish national grid meets the electricity demand of 1.5 million people in the city. Compared to fossil-fueled electricity generation, the plant saves 1.4 million tons of GHG emissions for equivalent electricity generation [29].

Other energy recovery methods from MSW include landfill gas to energy (LFGTE), anaerobic digestion (AD), gasification, biogasification, etc. [3]. AD is a viable form of energy recovery from organic MSW. It is processed in a closed environment (temperature control) in the absence of oxygen, creating the optimum setting for biogas production. One ton of organic waste treated via AD produces 2 to 4 times more methane in 3 weeks than landfilling will produce in 6 to 7 years [3,12]. Pyrolysis of plastic waste produces fuel oil, which is comparable to crude oil. In the US, it is estimated that waste incineration for energy recovery yields more energy per ton of combusted waste compared to landfill-gas-to energy (LFGTE). One ton of MSW will yield 600 kWh of electricity via incineration compared to around 60 kWh for LFGTE. This is because in the LFGTE scenario, only the biodegradable fraction of the MSW will contribute to landfill gas production. Incineration fares very well for GHGs emissions relative to LFGTE. GHG emissions for LFGTE are about 2.3 $MTCO_2e$ for each MWh generated, while it ranges between 0.4 to 1.5 $MTCO_2e$/MWh for combustion [30]. MSW is increasingly being used for energy recovery (heat, electricity or fuels) across the globe. There are more than 800 thermal waste-to-energy plants in forty countries around the world. These plants use about 11% of the global generated MSW and produce around 430 TWh of power [28]. Nigeria should adopt the model to improve energy production.

3.2. Material recovery

3.2.1. Plastic

The estimated plastic waste generation of about 404,164 TPY can have various useful applications. Various plastic recycling methods exist. Mechanical recycling is applied to only single polymer plastic, such as PE polystyrene (PS), etc. Chemical recycling converts the plastics to either liquids or gases. It recycles both mixed and homogenous polymers. It involves de-polymerization and consists of the process such as pyrolysis/thermal degradation, liquid gas hydrogenation, steam or catalytic cracking. Another and most common method of recycling plastic is referred to as primary recycling or reuse [31,32]. Emerging R&D is showing the immense applications plastic waste can be used for.

Water sachet has been incorporated in a matrix reinforced by carbonized palm kernel shell (CPKS) and iron filings, to create a composite for automobile application (bumpers). The composite has high impact energy-to-density ratio of between 0.19 to 0.26, which compares favorably with the standard (0.22). The composites can also find applications in other automobiles parts, such as body liner, rear-view mirror cover, dashboard and others [33]. Post-consumer LDPE water sachets and *Parinari* fruits shell have been used to produce a bio-composite which exhibited satisfactory mechanical properties—hardness strength of 4569 N/mm^2, impact of 51.75 kJ/m^2, tensile strength (10.02 N/mm^2) and flexural strength (18.23 N/mm^2). It has good ductility, is biodegradable, has fairly high compressive strengths, which are proper for applications where high compressive strengths are required [34]. A composite (for storage tank production) from variable ratios of *Gmelina arborea* sawdust, water sachet and acrylic plastic waste in the ratio of 4:1:0.5 has been developed. The moisture contents of the composite (14.7%) exceeded slightly 12% specified by ISO. The densities (1.24 g/m^3) also surpassed slightly the ISO minimum value (1 g/m^3) of cement-bonded composites. The water absorption of the samples is comparatively low (<6%), indicating suitability for use as a water storage [35]. These established the possibility of producing practical and lasting water storage tanks from the recycled materials. This is very important as the cost of water storage tanks are relatively expensive, leading many urban households to use many unhygienic means to harvest rainwater.

For construction, recycled plastics are showing immense opportunities. Waste plastic films-recycled products (WPF-RP) has compressive strength (CS) of 38 MPa, which is nearer to that of cement concrete. The CS was about 2.3 times that of tensile strength (TS), indicating its suitability for use as a compression member in construction. The WPF-RF has higher quality than asphalt commonly used for road pavement. Therefore, the mechanical properties of the WPF-RP show its suitability and stability for use in road pavement. It also offers alternative solution to pothole repairs and backfilling structures for pipes laid underground [36]. Recycled plastics can also be blended with asphalt to improve skid and crack resistance of pavements. Recycled comingled plastics can also be used to substitute wood as plastic lumber and traditional blocks or bricks. They are more durable than wood and can be cut, sawn and nailed. The plastic lumber finds applications as benches, plastic walls, railroad ties, door panels, etc. [7]. Plastic wastes are being recycled to produce shoes' soles, boots, generators and motor cycle handles [37].

Polyvinyl chloride (PVC)—a thermoplastic—presents very challenging problems to recycling. This is because many PVC materials comprises different plastic types. They are unstable in the presence of light and heat, and therefore cannot be mechanically recycled. Pyrolysis offers the way out. Dechlorination method improves pyrolysis process. In pyrolysis, waste plastic is heated in oxygen-deficient settings, until it decomposes into gases and oils. Other processes include incineration, gasification, hydrogenation and others, including a combined mechanical-chemical recycling process [31,32].

3.2.2. Organics

The organic fraction of MSW (OFMSW) finds useful material applications as organic fertilizer or composts. Considering the environmental and health impacts of synthetic or inorganic fertilizers, utilization of organic fertilizers from OFMSW is growing [38]. It is also supporting the organic-based agricultural production evolving across the globe, contributing to the organic matter content of the soil [39]. Organic fertilizer can be produced via aerobic (composting) [38], anaerobic (biofertilizer) process [39] and other methods such as microwave assisted extractions (MAE), conventional solvent extraction for organo-mineral and organic liquid fertilizer or solid/liquid extraction [40]. The growth of agro-produce treated with inorganic NPK fertilizers and those of organo-mineral fertilizers did not show significant differences. Both were higher than the control leaves (untreated soil). Both the NPK and organo-mineral also improved the average fruit weight and yield of the watermelon [41]. Organo-mineral fertilizers and composts release nutrients slower than inorganic fertilizers and are available for a longer time in the soil [38,41]. Compost and organo-mineral fertilizers have high nutrient content, suitable to a wide range of crops, they biodegrade easily and are safe. Insufficient and high cost of inorganic fertilizers in Nigeria affects the country's food security [39]. Therefore, development of organo-fertilizers or composts is important to the Nigerian agriculture sector, which employs 36% of the country's total workforce and is the highest contributor (24.2%) to the country's GDP [42]. In our estimate, the 22 cities generate 4.2 million tons of organic wastes, which can be composted to help improve agriculture in Nigeria.

Composting is the controlled conversion (aerobic) of biodegradable waste and materials into organic and inorganic byproducts products with the help of microbes. Some of the advantages of composts are bioremediation of heavy metal-polluted soils, degradation of chlorinated and non-chlorinated hydrocarbons in soils, improved soil water holding capacity, soil structure and aggregate stability and erosion mitigation [38]. In south-West Nigeria, it is estimated that the OFMSW generated will produce about 1648690 m^3 of compost per year. This will add about 1991 Mg of Nitrogen and 174900 Mg of carbon to the soil. The compost production will save about 2523654 metric tons of carbon dioxide equivalent per year ($MTCO_2$-e/year) [43]. Roughly 30 tons of compost fertilizer are produced from 46 tons of OFMSW [44]. Technical capacity on production of compost from OFMSW exists in the country. Organic fertilizer production machinery, which comprises a shredder, mixer, pelletizer and a conveyor system with an efficiency of 76%, a carbon-to-nitrogen ratio of 30, and a pH value of 7 has been designed [39]. Organo-fertilizer is very suitable as it is not acidic nor basic, and it is rich in nutrients. An example of a Nigerian company turning organic wastes into compost and organic fertilizer is EarthCare Nigeria Limited, located in Lagos State. At full capacity, their plant can produce 200000 tons of organic fertilizer (branded Compost^{PLUS}) every year [45].

Environmental and public health effects of organic fertilizers include the possibility of infectious agents (bacterial, viral and parasitic origins) and toxic compounds such as antibiotics being introduced into the food chain. The presence of pathogens (microbial contamination) may be present in the compost. Others are the issues of offensive odor, hydrogen sulfide (H_2S) by-products. Application of unstable compost may hinder germination and reduce plant growth via competition for oxygen or lead to phyto-toxicity of plants [46]. Improvement is taking place in the field to tackle the issues. For example, aeration in compost piles via oxygen feedback control will address the issue of odor; airbag reactors can entrap and recover the ammonia, thus increasing the nitrate content of the compost [38].

3.2.3. Paper

Waste papers include discarded or unsold newspapers, off-cuts from printed or colored papers, paper packaging materials, carton and cardboards. The prices range from \$0.2/kg for sorted waste paper, \$0.8/kg (cardboard wastes) to \$17.6/kg for calibrated cardboard sheets [47]. About twenty-four (24) trees are cut down to produce 1 ton of standard office paper. Globally, between 80000 to 160000 trees are cut down every day, representing between 29.2–58.4 million trees per annum. Recycling 1 ton of paper saves 17 trees from being cut down. Paper can be recycled about 5 to 7 times [48]. Nigeria is highly a paper-run economy. Economic growth and population increase indicates waste paper generation will continue to increase. This has serious environmental and climate impact since paper is obtained from trees (wood), which is a major sink for CO_2. Hence, there is a need for digitalization in all the sectors in Nigeria. Untill full digitization and other business models, recycling of generated wastes is the solution.

Waste papers (fibers) are increasingly being utilized to strengthen plastics, cement and other hydrophobic polymers. Waste paper has been incorporated with cement (ratio of 1:1) and reinforced with kenaf fibers to produce a composite which is durable and have good mechanical properties (modulus of elasticity, modulus of rupture and internal bonding). The applications for the composite include wall claddings, non-load bearing structures as well as ceilings [49]. Recycled paper pulp filled natural rubber composites for structural applications in low-cost buildings has been developed [50]. Paperboards have been produced from waste paper blended with cement and kaolin [51]. Fuel briquettes which are smokeless are produced from waste paper blended with coconut husk admixtures [52]; promoting good health, especially in rural Nigeria. The use of waste paper for briquette production and reinforced composites will reduce over-exploitation of trees for construction, fuelwood and other purposes.

The demand for poultry and eggs are increasing in the country. Waste paper is a huge raw material for egg cartons/tray production. A closed egg crate containing six eggs made of recycled papers weighs between 15 to 22 g. Recycling of 1.1 ton of waste paper will produce 50000 egg crates, while it is 0.75 tons for polystyrene [53]. Paper egg tray is strong, biodegradable and offers optimum shield for eggs against destruction during transport and storage. A locally fabricated egg tray machine using recycled paper with a design capacity of 12 egg trays per hour is estimated to cost about $200 in Nigeria [54]. A typical bundle (100) pieces of paper egg tray in Nigeria costs about ₦4100 ($9.6) [55]. Utilization of waste paper for packaging production offers the solution, considering the serious environmental impact associated with single-use plastic bag. Recycled waste paper for paper production is unsuitable because of the decrease in the length and strength of fibers during degradation [49].

3.2.4. Metals

3% (285065 tons/year) of the MSW generated in the cities are metals, and they have valuable applications. There is a readily available and thriving market for recycled metals. 75% of household appliances, from furnishings to beds to dinning sets, cooking pots, etc., contain steel [56]. Household items are in much demand in Nigeria because of the huge population increase and urbanization taking place in the country. Scrap metal is a major material for high quality steel production via electric arc furnace. This is very pertinent to Nigeria where inadequate building material supply is a major challenge. Copper scrap is relevant for blast furnace, reverberator furnace or electric arc furnace. Recovered metal can effectively serve as feedstock for the different steel making companies in Nigeria such as Ajaokuta Steel Company, Delta Steel Company, Jos Steel Rolling Mill, Osogbo Steel Rolling mill, etc [57].

Metal ores may be regarded a diminishing resource, whose production is confined to the area where it is found. This indicates the need to recycle wholly or re-integrate recovered metals in virgin production. Recycling of one ton of steel leads to saving of about 1115 kg of iron ore, 53 kg of limestone and 625 kg of coal [57]. It is estimated that the global iron and steel scrap recycling market size is around $380.7 billion in 2021, and is projected to grow at a cumulative annual growth rate (CAGR) of 82%. By 2027, it will be $610.7. In 2020, the global market for steel scrap is about 574.5 million tons. The market is supported by increase in demand for recycled metal scrap in automotive and other manufacturing industries such as packaging, building and construction, industrial machinery, shipbuilding, etc. However, the unorganized nature of waste collection and poor recycling technologies in developing countries such as Nigeria are posing serious limitation to efficient utilization of this valuable resource—scrap metals [56]. Because of this limitation, many collected scrap metals are often shipped to China even though it is illegal in Nigeria. The illegal exportation affects the viability of local recycling companies [57]. In 2018, Nigeria exported about $100 million of scrap metal, including iron and steel. On the other hand, the country imported metal to the amount of $1.1 billion in the same year. The exported products are re-processed to materials and then imported into the country [58]. The huge deficit between the exported scrap metal and importation of recycled metals drains Nigerian foreign exchange reserve, further undermining the economy and local steel industries. Thus, the need to establish and support viable metal recycling economy inside the country to drive economic growth.

3.2.5. Textile

The paper estimated that about 159475 tons per year of textile waste are generated in the 22 cities, accounting for 2% of the entire generated MSW. Many Nigerians depend on imported used clothing, popularly referred to as "*Okirika or Ok*" which is relatively cheaper than new ones (natives or foreign). Globalization and its associated fashion trend are additional factors supporting the importation, most of which are from countries such as China and the western countries [59]. Textile recycling method or application depends on the material composition—synthetic or natural fibers. There are three methods of textile recycling—thermal, mechanical and chemical. Thermal recycling involves incineration of waste textile to recover heat energy (energetic recovery). Chemical recycling involves breaking down of textile polymers into monomers. The monomers are then treated to reach the quality of the primary monomers [60].

Both types of textile waste (natural or synthetic) can be mechanically recycled to produce fibers for filling materials such as insulation or lagging; soundproofing pad for acoustic purposes; flocking for production of filling used in mattresses, furniture and pillows; production of shoes and carpets; blankets and knitted products; filters for pollution control. Native fabrics such as "*Ankara*" cut-offs can be used to produce rugs and sandals [59,60]. The different automobile assemblers and manufacturers in Nigeria such as Innoson Vehicle Manufacturing (IVM) can find useful the huge waste textiles generated annually in the country.

3.2.6. Glass

The estimation shows about 232140 tons p.a. of waste glass is generated in the cities. Glass is non-biodegradable. Thus, waste glass constitutes a nuisance to the environment. Flint or clear glass, green and brown bottle, beverage (soft drinks), wine, beer, glass jars, sauce bottles and others are recyclable [61]. The process involves crushing of the glass into various sizes (known as cullet), which range from coarse granulates to very fine powder [62], with the glass cullet recycled for general applications such as abrasives, fluxes/additives, fiberglass insulation and foam insulation production. It is also increasingly being used for construction applications such as cement substitution, aggregate replacement in concrete, road beds, pavement, trench fill, drainage medium, etc. [63]. Production of one ton of fiberglass from recycled glass saves about \$3 to \$8, compared to virgin production [62]. This is because glass cullet is a low-melting substance and needs relatively lower energy to melt than virgin raw material used for the manufacture of new glass material. Fiber glass reinforcing bars solves the corrosion problem commonly seen with steel reinforcement, especially in tropical climate like Nigeria. Fiber glass use for reinforcement showed extended lifespan for concrete structures [63].

3.3. Challenges and advantages of MSW valorization in Nigeria

3.3.1. Challenges facing waste valorization

Recycling offers huge benefits such as employment, etc. More than 25000 persons are involved in the informal sector in Abuja. Globally, the sector supports 15 million people [64]. There is an existing informal private sector in Nigerian cities, including waste pickers or scavengers or itinerant buyers, collection entities, scrap dealers and recyclers. However, their method has intrinsic public health risks and inefficiency. Scavenging at dumpsites or landfills leads to contact with harmful or toxic substances. Another great challenge facing waste management and recycling, particularly in Nigeria, is poor sorting of MSW at source. Without proper and adequate sorting, it is difficult or becomes more expensive to recycle wastes [6]. Different waste types require specific pre-treatment and recycling processes [7,27]. Poor MSW collection related to poor road networks, refusal of households to pay collection levies, techno-economic and managerial incapacity on the part of waste management authorities [15]. Poor and inconsistent data is another reason for the poor collection [23,27]. For example, in one city, two different studies recorded a waste generation rate of 0.31 kg/cap/day and 0.86 kg/cap/cay [15]. This is caused by poor research design and methodologies [15,27]. Quality waste generation and characterization data is required for effective planning and allocation of resources to manage MSW. Table 4 presents the challenges facing waste valorization in Nigeria. Table 4 shows the challenges facing MSW valorization.

Table 4. Challenges facing MSW valorization in Nigeria.

Factors	Issues	Authors
Finance	Poor public and private investment. Some recycling involves advanced technology which is costly.	[7]
	Poor funding of waste management crucial for improved collection.	[4]
Attitudes	Poor awareness of waste's usefulness	[7]
	Indiscriminate disposal methods	[2,6,10,11]
	Cultural apathy and fear (taboo) of the use of recycled products such as textiles, etc.	[59]
Poor waste management	Non-sorting of wastes.	[27]
	Poor waste collection efficiency.	[2,6,10,11,15,20,27]
	Insufficient policies and infrastructure.	[2,6,7,17]
	Inadequate and inconsistent waste generation and characterization data to support recycling investments.	[4,15,27]
Technology	Lack of proper and relatively inexpensive automated sorting and recycling technologies.	[39]
	Inadequate experience in blending recovered materials (for example textile with virgin fibers).	[59,60]
Regulatory framework	Non-recognition of informal sector in waste management.	[2,4,11,64]
	Absence of CE frameworks such as EPR, reverse vending, take-back schemes.	[2]
	Exorbitant levies and permits on the recycling operators.	[5]
	Inconsistent and uncoordinated government policies (for example, ban on export of scrap metals and inadequate recycling outfits).	[5,17,37,64,65]
Infrastructure	Slum development and lack of amenities hinders accessibility and efficient scaled collection.	[11,23]
	Poor transportation network.	[15,10]
	Unreliable grid-power supply and the exorbitant cost of alternative (fossil-fueled self-generation).	[4,57]
Health, safety and environment considerations	Lack of protection (PPE) for workers.	[4,11,64,]
	Unfriendly re-manufacturing or recovery processes.	[4,66]
	Release of untreated effluents, discharges, residues from recycling processes to the environment.	[32,66]
	Polluted environment from the recycling impacts public health.	[66]
End-products	Heterogeneous composition of materials used in making the EOL product (e.g. textile) creates difficulty for recycling.	[3,31,32,49]
	Recycled products are perceived to be of poor quality and pose health and safety issues.	[49,59,60]
	Recycling sometimes leads to down-cycling.	[49,59]
	Poor demand and non-viable market of some recycled products.	[59]
	Stiff price competition between some recycled products and their virgin production.	[2,60]

Non-recognition of informal sector in waste management in Nigeria has made them operate without city and planning permits. Out of the eleven recycling operators in Ota, only three have business names [4]. The workers involved in scavenging are exposed to unsafe and oppressive environments [4]. They work without proper protective clothing. Though many studies have highlighted the employment opportunities informal recycling provides in Nigeria, they are mostly low-paid wages, below the national minimum wage. Further, the perception of the waste pickers, scavengers or collectors as menacing, dirty and troubling persons is very strong among Nigerians. Their activities are not socially accepted [4,11,65]. Un-regulation also leads to indiscriminate release of toxic or harmful by-products to the environment from the recycling processes; causing air, soil and water pollution. For example, metal recycling plants were shown to pollute soil around the plant with heavy metals such as lead, zinc, copper, nickel, cadmium and chromium. It also contaminates the air quality with particulate matter [66]. Accordingly, there is a need for registration and regulation of the sector so as to offer meaningful wages and ensure protection for the workers, environmentally safe processes and social acceptance.

Perception of the quality of recycled products or materials is one of the factors affecting their market viability. Strong culture or tradition affects negatively the people's perception of donating or using recycled products (especially textiles). For example, there is widespread belief among the people that buying of "*Okirika*" or their donated used clothing may be used for rituals, witchcraft or occultic practices, thus the preference to burn them [59]. Environmental and health impact of recycling is also a challenge. Plastic contains petroleum-based resins and additives like plasticizers, heat stabilizers and anti-oxidants including during its manufacturing. The recycling process and use of the recycled materials may release these compounds to the environment if not tackled, impacting the environmental quality and human health. Similarly, recycled post-consumer plastics that is not proper for food-contact may be blended into food-contact packaging [32].

3.3.2. Advantages offered by MSW valorization

Huge MSW generation and emerging recycling technologies create a huge potential for businesses and entrepreneurs to create socio-economic value. Waste recycling industry in the US employs more than 137000 people, generates revenue of about $90 billion and $24 billion in export sales each year [57,67]. Benefits of MSW valorization are illustrated in Figure 2.

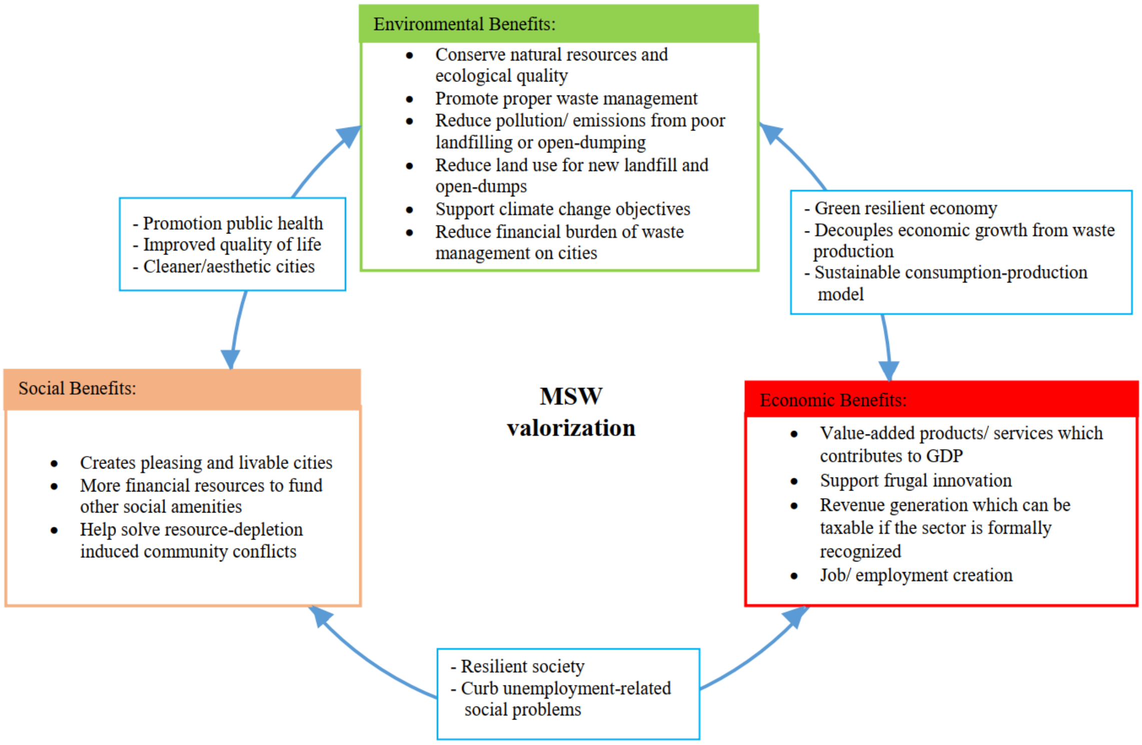

Figure 2. Benefits of MSW valorization.

These massive socio-economic and environmental potential should be strongly developed in Nigeria. Table 5 shows the monetary value of trading the scrap to recyclers.

Table 5. Potential revenues from trading the generated MSW.

Waste type	Tons per year	Cost ($/ton)	Authors	Revenue potential ($)
Organic	4281136.1	-	-	-
Plastics	406164.7	555.55	[64]	225644799
Metal	285169.4	81.66–93.32+	[68]	23286933–26583491
Waste paper	910558.2	200–17600	[47]	182111640–16025824320
Textile	159505	99.86–998.66 ++	[59]	15928169–159291263
Glass/cullet	232140	200	[69]	46428000
Total	-	-	-	493399541–16483771873

+Converted from Naira to USD (USD1 = ₦428.61); ++ Converted from EUR to USD (USD1 = EUR 1.001349) (September 2022).

As shown in Table 5, the estimated revenue potential of trading the plastic, metal, waste paper, textile and glass wastes for recycling ranges from $493.3 million to $16.4 billion. Current price of buying plastic waste is $555 per ton [64]. This is substantially higher than $110 which it sold for in 2014 [4], indicating the growing importance of waste as a resource. Thorough waste characterization data provides comprehensive and useful assessment of waste valorization opportunities. A typical example is the characterization of "metals" to represents different ferrous and non-ferrous metal such as aluminum, copper, etc. Inadequate characterization limits techno-economic assessment of waste recycling in Nigeria [6,7,27]. For instance, while the assessed cost of 1 ton of scrap metal ranges from $81 to $93; for aluminum, it is between ₦150000–₦250000 ($350–$583) per ton [68]; one ton of scrap copper goes for ₦1.5 million ($3500); while for brass, it ranges from ₦800000 to ₦1 million per ton ($1866–$2333) [37]. Quantity, composition, transportation route and demand by itinerant buyers are factors that determines prices "wastes" are sold [4,69]. Table 6 summarizes different applications for MSW.

Table 6. Different applications of the waste materials.

Waste type	Applications
Organic	Energy recovery (biofuels, heat, electricity production, etc.)
	Bio-fertilizer and composts
	Soil bioremediation and anaerobic degradation of chlorinated and non-chlorinated soil hydrocarbons
Plastics	Reinforced composites for automobile application (bumpers, rear-view mirrors, etc.), water storage tank.
	Blending with asphalt for road construction
	Replacement of wood, conventional blocks or bricks in construction
	Production of equipment parts, shoe soles, etc.
	Energy production
Textile	Monomer recovery for primary production of synthetic fibers
	Insulation and/or lagging materials
	Acoustic (soundproofing) materials
	Mattresses, upholstery, etc.
	Pollution control filters
	Automotive applications
	Rug and carpet production
	Energy recovery via incineration
Paper	Reinforcement for plastics, cements, etc.
	Composites for wall padding and non-load supporting structures.
	Waste-paper reinforced natural rubber composite for structural functions in low-cost housing
	Paperboard production
	Non-food packaging materials
	Production of egg crates
	Briquettes for home heating
Metal	Household items (furnishing, beds, dinning sets, cooking pots, etc)
	Packaging, building and construction, industrial machinery and automotive industry
	Feedstock for the different steel making companies in Nigeria
Glass	Production of abrasives, fluxes and additives
	Fiber glass production for insulation and concrete reinforcement
	Aggregates for construction
	Geoengineering purposes

As shown in Table 6, these value-added materials, products and services can be obtained from MSW, providing some solutions to some needs. This spans from energy production to construction, agriculture and chemicals. This calls for minimum and suitable investments and appropriate policy initiatives which will support entrepreneurship in the waste management sector. Entrepreneurship establishes new ventures which are drivers of socio-economic growth, and it also creates innovation. The innovation takes existing opportunities in a local area, commercializing them via production of goods or services. One of such is frugal innovation (FI). Frugal innovation (FI) is "*a design innovation process in which the needs and contexts of citizens in the developing world are put first in order to develop appropriate, adaptable, affordable, and accessible services and products for emerging markets*". FI, alternatively referred to as resource-constrained product development (RCPD), provides more material value (less resource demanding goods) at less costs, and decreases material utilization in production and post-consumer goods [70]. This is pertinent considering that production factors such as fairly cheaper labor, lower per capita GDP, lack of advanced amenities/facilities and poor investment in Nigeria entail the need for frugality in recycling of waste materials [2]. Hence, waste plastics for example can be deployed to road construction since the country has a very bad road network; suitable organic wastes for compost and organo-mineral fertilizer to support agriculture, waste paper used for production of toilet tissue, egg crate and others. The advantages which integration of FI and recycling offers are relatively lower cost of materials; value addition, reduced waste management spending; reduced energy cost, lower transportation cost and others [7].

Using locally-produced parts and materials is another benefit of FI in MSW valorization. Many studies have demonstrated viability of such low-cost technology in Nigeria. They include an organic fertilizer machine with a 76% efficiency [39], a low-cost plastic recycling machine with a recyclability efficiency of 97% and an output of around 265 kg/hr [71] and a manually operated closed-end piston press for briquette production with production capacity of 30 briquettes (35 grams per) per batch [52]. These designs are anchored on FI. All these will solve immediate local needs and foster quality environment, economic benefits and technology advancement. Entrepreneurship innovation is also important as it involves the efficient organization of complex operating activities to solve common problems and as well make profits [72,73]. Coupling FI, with long-term economic and environmental policies will advance the country's development. For example, adopting the locally designed egg tray machine which costs $200 [54], recycling waste paper will produce 100 egg trays each day (for 8-hour workday). It is equivalent to $9.6/ day assuming the cost of Afrimash paper egg tray [55]. This will produce a monthly value of about $212, which exceeds the national minimum wage of $69 (₦30000).

Private sector involvement in waste management or at best private-public partnership (PPP) will reposition waste management as a value-added chain. Government organizations are run as a social welfare and are usually not profit-oriented, hindering performance-based approach. Fortunately, many innovative entrepreneurs and entities are venturing into waste recycling in Nigeria. They include companies such as Wecyclers, RecyclePoints, Chanja Datti, Vicfold Recyclers and others. One distinctive feature is that they are all based in Lagos, the most developed and populated urban area in Nigeria. As at 2019, WeCyclers has enrolled 20000 households into their business model and it is expected to reach 500000 by 2023. One of their service models is offering credits to parents for wards' primary school fees based on the level of plastic waste they donate to the company. The company collects, sorts, compresses and sells all the waste to local companies who recycles them into finished items [74]. Chanja Datti Limited sources their wastes (between 300 to 350 tons per month) from organizations generating huge level of waste. They sell the collected waste papers to paper mills; beverage cans to local smelters who creates items such as kitchen utensils (pots, pans, forks), and farming implements. Low-density polyethylene (LDPE) and high-density polyethylene (HDPE) are recycled into resins and pellets which they sell to manufacturers. The PET is sold to manufacturers who convert it to synthetic fiber for mattress stuffing, pillows, toys and cushions. In their service offering called "Cash for Trash", Chanja Datti partners with a local bank, where waste suppliers (individual or entities) can open savings account and receive the assessed monetary value of the wastes they present [73]. Similarly, RecyclePoint have developed an accumulated "point-based" incentive model for registered post-consumers, targeting specifically collection of water sachets, PET bottles, used beverage cans, glass bottles, disused newspapers and cartons. The points are assigned based on a set "Points Earning Chart" where the amounts of items are linked to the amounts of points made.

The existing recycling model by the aforementioned companies relied heavily on this incentives—credit system, point-based, cash for trash, etc. Hence, the need for incentives approach to scale sorting and collection of waste is critical in Nigeria. This is pertinent because many Nigerians live below the poverty level. There is also a positive association between households' perception of financial incentives for recycling and motivation or willingness to sort and donate MSW to collection or designated points [5]. The financial incentives also stimulate knowledge pursuit for waste recycling; induces behavioral changes and supports best recycling practice. Other mechanisms to increase waste recovery for recycling includes extended producer responsibility, take-back scheme and others [2].

4. Recommendations and conclusions

4.1. Recommendations

To access the vast opportunities recycling offers and surmount the inherent challenges facing it, there is need for reform, starting with policies and institutions. From primary to higher education (both sciences and art fields), the educational curriculum should include the concepts of waste management hierarchy, waste characterization, sorting and recycling; and more importantly the relevance of circular economy framework to socioeconomic and environment sustainability. Economics of waste management and recycling is also critical; while for engineering and technology fields, the importance of frugal innovation in machine and process design for recycling and re-manufacturing should be developed. Policies should be synergized and not on a piece-meal or ad-hoc basis, which tends to conflict or cancel each other.

Policy makers and governments (federal, state and local) in Nigeria should incorporate recycling in her natural resources development agenda. It should include fiscal policies and enabling environment critical for recycling entrepreneurs to harness the gains. This comprises of subsidies for firms involved in waste valorization, in the form of tax breaks, subsidies and other green financial facility. Strong and indigenous R&D is required to support the innovation. Nigerian universities, polytechnics and research organization such as National Agency for Science and Engineering Infrastructure (NASENI) and its various institutes, Raw Materials Research and Development Council (RMRDC), etc., have a role to play towards low-cost and low-technology designs and equipment to geared towards FI and waste valorization.

4.2. Conclusions

Waste generation rates in some major cities in Nigeria were identified. The generation for the year 2021 was then estimated. The average generation rate for the 22 cities is 0.56 kg/cap/day, which falls within the widely accepted rate for Nigeria. About 20378 tons of MSW each day (or 7.4 million tons per year) are generated in the cities. Organics accounts for 56%, followed by paper (13%), plastics (9%), glass and metal (3% each), textiles (2%) and others (14%). The benefits of recycling include environmental, social and economic benefits Valorization of the MSW finds application in various sectors—energy (power, transport), agriculture, construction and manufacturing. Energetic valorization of the combustibles—organic, paper, plastic and textile (5757363 tons) will produce energy potential of about 947981.3 MWh, with monetary value of $131.7 million. Trading of the generated plastic, metal, waste paper, textile and glass (1993432 tons) will produce a revenue of between $493.3 million and $16.4 billion. There are challenges to be surmounted for the cities (and Nigeria) to take advantage of waste valorization. They are poor waste management (such as non-segregation and poor collection efficiency), finance, technology, attitudes and perception towards recycled products, absence of regulatory framework, infrastructure and management of end-products of recycling processes. Deployment of frugal innovation and entrepreneurship in the waste sector can help solve some of these problems; while governments put in place policies such as subsidies, tax breaks, regulatory structure and enabling environment.

5. Limitation and future studies

The study has some limitations. The potential energy generation relies on secondary data obtained for developing countries. However, variations in ultimate and proximate analysis of MSW determine their energy content and thus energy recovery potential. Further, the potential revenue generation from the different MSW constituents varies. Our study assumes generic prices for each of the MSW constituents (for example, metals) in Nigeria. However, there are different types, compositions and price ranges for each of the sub-types for materials such as metals (aluminum, steel, etc.), glass, etc. Another limitation of the study relates to the use of Nigeria Population Commission census, which was last conducted in 2006, (sixteen years ago) to estimate current populations of the set of cities. Seasonality has been shown to affect MSW generation, especially for biogenic MSW.

There is need for extensive generation and characterization of MSW across cites in Nigeria. The characterization should include sub-categories of the different MSW constituents. The studies across the cities should adopt robust methodology and should include seasonality. It also should include ultimate and proximate analysis of the MSW obtained in each of the cities. This will aid in assessing in detail the material, energetic and economic (revenue) potential of MSW valorization in Nigeria. Finally, recent and detailed national population census is highly urgent, to enable planning, management (including waste management) and others.

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Conflict of interest

All the authors declare no conflicts of interest.

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