

Christian-Albrechts-Universität zu Kiel
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**Evaluating the Effectiveness of 3R (Reduce, Reuse, and
Recycle) Policies in Sub-Saharan African Cities: A Case
Study of Lagos State, Nigeria**

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DECLARATION

I certify that the conceptualisation and execution of this research titled, “*Evaluating the Effectiveness of 3R (reduce, reuse, and recycle) Policies in sub-Saharan African Cities – a case study of Lagos State, Nigeria*”, was carried out by me under the supervision of Prof. Dr. Hans-Rudolf Bork. I affirm that only the sources referenced here have been used and no part of this dissertation has been submitted in fulfilment of the award of a doctoral degree at any university. Furthermore, I wish to state that I adhered to the rules of good scientific practice of the German Research Foundation while embarking on this research and preparing this dissertation. I equally affirm that none of my previous academic degrees has been withdrawn at any time.

Kiel, 17.06.2025

(Ort, Datum)



(Unterschrift Doktorand)

DEDICATION

To the glory of God, the Creator of heaven and earth, and the service of humanity. To the memory of my late father, Pa Lawrence Sunday Adedara, whom death denied the opportunity of seeing me make this advancement. To my mum, who supported me morally and financially during my undergraduate degree programme in Nigeria.

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ABSTRACT

Global municipal solid waste (MSW) volume currently stands at an estimated 2.1 billion tonnes annually as of 2024. Owing to perennial waste management (WM) challenges in many developing countries, about 27% (540 million tonnes) of the global waste volume is left uncollected yearly. Sub-Saharan Africa (SSA), including Central and South Asia, are two regions with the most uncollected waste, resulting in rampant open burning and indiscriminate dumping. While several studies on MSW management and its associated challenges have been conducted in both developed and developing countries, there is limited empirical evidence in the literature on evaluating the effectiveness of 3R (reduce, reuse, and recycle) policies essential for sustainable WM, in SSA countries. This dissertation aimed to assess the effectiveness of ongoing efforts towards the sustainable management of MSW in SSA by conducting three distinct but related studies using the lens of Lagos, Africa's largest city by population. The research began with a systematic review of the literature, fortified with a meta-analysis on the status of MSW collection in SSA. Sequel to this, the performance of an extant recycling initiative in Lagos, the Lagos Recycle Initiative (LRI), was analysed to understand the effectiveness of one of the Rs, recycling on landfill diversion by calculating the recycling diversion rate (RDR) and applying machine learning algorithms to determine the most important motivation for recycling participation. The research concluded with a review of the Lagos State Environmental Management and Protection Law to get a holistic understanding of the emphasis placed on the 3Rs regarding the efficient management of MSW. Overall results revealed that the MSW collection rate of 10% in Lagos falls far below the regional average of 65% for SSA. Additionally, a low RDR of 0.37% under the LRI implies that the city's target of recovering about 50% of recyclables from the MSW stream remains a mirage. The machine learning analysis revealed that waste collection time is a critical driver of recycling motivation in Lagos. The dissertation concludes that the imbalanced attention given to the 3Rs in the Lagos environmental policy could have accounted for the abysmally low MSW collection rate, significantly impacting the effectiveness of the LRI and impeding the city's progress towards the realisation of a truly circular economy.

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1.0 GENERAL INTRODUCTION

Globally, according to the 2024 report of the United Nations Environment Programme (UNEP), over two billion tonnes of municipal solid waste (MSW) are generated annually [1]. As of 2012, Sub-Saharan Africa (SSA) generated about 65% of the total MSW on the African continent [2]. Unfortunately, most of these wastes end up in uncontrolled landfills in the region [3]. More worrisome is the fact that, according to the most recent report of the United Nations Environment Programme (UNEP), SSA, along with Central and South Asia are the regions of the world with the lowest levels of MSW management [1].

Lagos, the case study selected for this research is Nigeria's commercial capital and one of the largest megacities in Africa [4]. Lagosians generate an estimated 14,000 metric tonnes of MSW per day as confirmed by the Lagos Commissioner for Environment and Water Resources in 2021 [5]. Private sector involvement in the collection of MSW has been ongoing in Lagos since 1997 [6], but despite these efforts, MSW collection and coverage rates fall below 70%, resulting in indiscriminate dumping and open burning of uncollected wastes across the state [7]. The implication of this is that useful waste resources that could have been recovered in their clean state from the waste stream end up in the city's unsanitary landfills [8].

The foregoing problems in SSA call for the urgent action of municipal authorities to develop effective policies with clear implementation plans for the sustainable management of waste in line with best international practices. This doctoral research aims to assess the effectiveness of environmental policies in SSA cities in terms of waste reduction, reuse, and recycling (3Rs) to gain a comprehensive understanding of the importance of a circular economy (CE). The research focused primarily on Lagos with some other sub-Saharan cities also included, where three different but related studies were conducted. The research questions addressed in the individual studies are summarized in the following sections.

In chapter one, a comprehensive review article published in MDPI Waste Journal in 2023 is presented. In answering the research question, "*What is the status of MSW collection in SSA cities?*", this article reviewed the situation in four SSA cities – Accra and Kumasi (Ghana); and Abuja and Lagos (Nigeria). A meta-analysis was conducted to determine the current collection and coverage rates of MSW in the region. This was considered a first step in the research as the collection of municipal waste is a barometric test of the effectiveness of the 3Rs policy. This is so because the collection of MSW in developing countries takes up a large part of the municipalities' budgets and is therefore seen as a critical step in the sustainable management of solid waste [9]. Hence, if priority is not given to the recovery of materials from the MSW stream

through an efficient collection system, resources will not be available for reuse and recycling. In South Korea, for example, an effective waste management (WM) policy has proved to be a deterrent to waste reduction at the source, while it has at the same time simplified the process of collecting clean materials for reuse and recycling [10]. Having understood the situation of waste collection in Lagos in the first article, it became imperative to conduct a field survey to understand efforts being made by the municipal government in Lagos on the collection of recyclable materials for processing in local recycling industries.

Chapter two therefore presents a research paper that addressed the research question, “*What is the impact of the Lagos Recycle Initiative (LRI) on waste diversion from landfills?*” In this article, the performance of one of the 3Rs, recycling, was evaluated to understand its effectiveness on landfill diversion, using the recycling diversion rate (RDR) as a measure. The RDR is one of the known metrics for assessing the effectiveness of city-wide recycling programmes. Additionally, the drivers of recycling motivation among Lagos residents were then predicted using machine learning algorithms. An understanding of what motivates people to recycle helps the municipal authority to know areas where improvements are necessary. The findings from this study then occasioned the need for a review of the Lagos State policy on the environment in the subsequent chapter.

In **chapter three**, the Lagos State Environmental Management and Protection Law 2017 was reviewed. The objective of this policy review was to understand the reasons for the low RDR observed in the second article. Using content analysis, chapter three captured the coverage of the 3Rs in the policy and further examined whether each of the Rs was proportionately represented in the policy. Furthermore, the policy was checked for guidelines on implementation. The proportionate and sufficient representation of the 3Rs in a WM policy gives a vivid picture of the policy’s emphasis on waste reduction, reuse, and recycling. Subsequently, a concise discussion and synthesis of the results from each of the articles is presented. Following this is a general summary of the findings, implications for policymakers, research limitations, as well as a future research outlook for postdoctoral studies.

References

- [1] UNEP, ‘Global Waste Management Outlook 2024 | UNEP - UN Environment Programme’. Accessed: Aug. 19, 2024. [Online]. Available: <https://www.unep.org/resources/global-waste-management-outlook-2024>
- [2] N. Scarlat, V. Motola, J. F. Dallemand, F. Monforti-Ferrario, and L. Mofor, ‘Evaluation of energy potential of Municipal Solid Waste from African urban areas’, *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1269–1286, Oct. 2015, doi: 10.1016/j.rser.2015.05.067.
- [3] UNEP (2018). Africa Waste Management Outlook. United Nations Environment Programme, Nairobi, Kenya.
- [4] World Bank, ‘Lagos Diagnostic Study and Pathway for Transformation’. Accessed: Sep. 21, 2024. [Online]. Available: <https://documents1.worldbank.org/curated/en/099062123034023646/pdf/P1750310c8d0390000afa70e5c583aa3b87.pdf>
- [5] Vanguard Media Limited, ‘Lagos generates 14,000 metric tonnes waste daily — Commissioner’, Apr. 29, 2021. Accessed: Jan. 13, 2025. [Online]. Available: <https://www.vanguardngr.com/2021/04/lagos-generates-14000-metric-tonnes-waste-daily-commissioner/>
- [6] LAWMA, ‘Private Sector Partnership (PSP)’. Accessed: Dec. 31, 2024. [Online]. Available: <https://lawma.gov.ng/psp/>
- [7] M. L. Adedara, R. Taiwo, and H.-R. Bork, ‘Municipal Solid Waste Collection and Coverage Rates in Sub-Saharan African Countries: A Comprehensive Systematic Review and Meta-Analysis’, *Waste*, vol. 1, no. 2, Art. no. 2, Jun. 2023, doi: 10.3390/waste1020024.
- [8] A. O. Aderemi and A. A. Otitoloju, ‘An Assessment of Landfill Fires and Their Potential Health Effects- a Case Study of a Municipal Solid Waste Landfill in Lagos, Nigeria’, *Int. J. Environ. Prot.*, vol. 2, no. 2, p. 5, 2012.
- [9] UN-HABITAT, *Collection of municipal solid waste in developing countries*. United Nations Human Settlements Programme, 2010.
- [10] Jerin, D. T., Sara, H. H., Radia, M. A., Hema, P. S., Hasan, S., Urme, S. A., ... & Quayyum, Z. (2022). An overview of progress towards implementation of solid waste management policies in Dhaka, Bangladesh. *Heliyon*, 8(2).

CHAPTER ONE

Municipal Solid Waste Collection and Coverage Rates in Sub-Saharan African Countries: A Comprehensive Systematic Review and Meta-Analysis

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Abstract

The annual volume of waste generated in sub-Saharan Africa (SSA) increased from 81 million tonnes to 174 million tonnes per year between 2012 and 2016 and is projected to reach 269 million tonnes in 2030. In 2018, SSA's municipal solid waste (MSW) collection coverage was estimated at 44%. Concerned that the waste generation rate outweighs the collection pace, we conducted a systematic review of studies on MSW collection to examine the current situation in the region concerning the waste collection and coverage rates and to highlight the impediments to rapid progress in waste collection using the lens of four cities. Findings reveal that, despite the involvement of private waste collectors, collection and coverage rates are still below the desired 100% with backlogs of uncollected waste in public spaces, especially in low-income neighbourhoods where coverage remains abysmally low. This study fortifies the systematic discussion on MSW collection and coverage rates by conducting a meta-analysis. The result of the analysis shows that the waste collection and coverage rates are 65% and 67% in SSA, respectively. Aside from the paucity of data on waste generation rate and characterisation, most available data are incongruent. The review further shows that although several studies have been carried out on waste disposal, waste treatment and recycling in SSA studies directly focused on MSW collection are still few, leaving room for more research in this area. The review offers suggestions on how collection and coverage rates can be increased and equally proposes a strategy for reducing scavenging activities in the region's unsanitary landfills, given its concomitant health impacts on the scavengers.

Keywords: municipal solid waste; waste collection rate; waste collection coverage; meta-analysis; source segregation; circular economy

1.0 Introduction

Global waste generation, propelled by continuous urbanization, economic development, and an increase in population was estimated at 2.01 billion tonnes per annum in 2016 [1]. This represents an increase of 54.62% from the generation rate of 1.3 billion tonnes [2] per annum in 2012. Unarguably, the rate of waste generation varies across world regions and individual countries, with the rise in per capita waste generation expected to surge in developing nations during economic growth, coupled with high organic contents in municipal solid waste (MSW) streams compared to that of developed nations [3]. Solid waste in the environment, especially where it is openly burned, buried, or indiscriminately dumped, impacts public health [4,5]. Consequently, the collection of MSW remains the most critical aspect of waste management (WM) [6,7], which strains municipal budgets [8]. While the MSW collection rate is estimated at 96% in high-income nations, most least-developed countries (LDC) have a collection rate of about 39%, with low-middle income (LMI) nations reaching about 51% [1].

Sub-Saharan Africa (SSA) is composed mainly of developing countries. Some critical issues contend with sustainable WM in the region at all levels of government such as the lack of political will, the absence of an effective policy on WM, inadequate funding, the lack of environmental education and awareness, a weak infrastructure, and limited collection coverage, among others [9,10]. To ensure public health safety, waste should not be left uncollected; unfortunately, this remains a persistent public health issue in developing countries [5,11]. In many SSA cities, numerous cases of uncollected waste have been documented. For example, uncollected waste in Cameroon, Central Africa, is commonplace in public spaces [12,13]. In Ethiopia, Tassie et al. [14] also observed incidences of uncollected waste in Addis Ababa. Similarly, in Johannesburg, South Africa, piles of uncollected refuse littering some streets have been blamed on corruption and administrative flaws of the municipal authorities [15]. This collection gap has paved the way for scavenging activities on the region's non-engineered landfill sites [16,17]. While it is acknowledged that scavenging in developing nations contributes to the recovery of materials for local recycling industries, the health problems associated with this activity have also been widely researched [18,19]. These different cases of uncollected waste across cities in the region represent a lost opportunity for providing clean recyclable materials to local recycling industries, and this could be a reason for the proliferation of scavenging in the region.

In SSA, MSW is disposed of primarily in uncontrolled landfills [20]. Since segregation is not carried out at the source, organic waste is lumped with recyclables at the dumpsite [21]. Over time, under anaerobic conditions, the organic waste undergoes decomposition, resulting in the release of landfill gas (LFG) with methane (CH₄) as the highest component [22]. However, under

controlled conditions, CH₄ from the LFG could be harnessed for energy generation to meet the acute energy demand in the region, given the high organic content of about 57% in the waste stream. This possibility has been shown in Malaysia [22] where the organic fraction is 45%, lower than in many SSA countries. CH₄ captured from some sanitary landfills is being converted to electricity to meet part of the country's energy demand, thereby limiting the use of carbon-intensive energy sources given their attendant environmental and health impacts. Similarly, as shown in a study by Aziz et al. [23], to continually explore the potential of waste as a resource, it is imperative for relevant authorities in developing economies to consider investments in waste recycling facilities to address the mounting volume of the non-biodegradable components in MSW while equally seizing the opportunity of the high organic component to set up waste composting facilities.

Despite the reported myriad of challenges with WM in the sub-Sahara, individual cases of improvements in some countries show that these challenges can be overcome with political will and the commitment to developing local solutions. For instance, the small community of Moshi in Tanzania was able to maintain the status of a 'top clean city' through the efficient collection of waste from its informal settlements, owing simply to the city council's commitment and residents' determination towards the success of the project [11]. In reviewing the literature on MSW collection in SSA cities, we observed that the articles seldom addressed the topic of waste collection directly, compared to the literature on waste disposal, waste treatment methods, and recycling. A similar situation has been reported for low- and middle-income countries [8,24]. This study shows that the scant amount of literature on MSW collection leaves room for more research in this area in SSA. Hence, the article highlights the need for more scholarly work on MSW collection as a way of using science to drive rapid progress in MSW collection in the region. The suggestions offered for increasing the collection rate and coverage as well as the strategy proposed for reducing scavenging activities in the interest of public health, if given the necessary attention by concerned authorities, can be translated into policy statements targeted at making a paradigm shift towards a more sustainable WM system in SSA countries.

2.0 Description of Study Areas

Ghana and Nigeria are located in West Africa within the SSA region, which comprises 48 countries. The region has an estimated population of 1.107 billion as of 2019 [25], and 34 of these nations are classified as LDC or low-income countries (LI) [26]. SSA is also the most undeveloped among the developing regions in the world, coupled with high infrastructure inadequacy and a world GDP share of 2.23% as of 2014 [27]. The SSA cities examined in this study are Accra and Kumasi in Ghana and Abuja and Lagos in Nigeria.

2.1. Accra and Kumasi

Accra is the capital of Ghana and the Greater Accra Region. It is Ghana's largest city by population [28]. The Accra Metropolitan Assembly's (AMA) WM department is responsible for environmental protection and the promotion of public health. One of its responsibilities is to ensure the efficient collection of MSW in Accra [29]. Kumasi is the second-largest city in Ghana. Like Accra, WM in Kumasi is coordinated by the city's administrative office, the Kumasi Metropolitan Assembly (KMA).

2.2. Abuja and Lagos

Abuja replaced Lagos as Nigeria's Federal Capital Territory (FCT) in 1991 when the capital was moved from Lagos. Abuja Environmental Development Board (AEDB) coordinates WM in the city. Lagos, Africa's largest city by population had a population of 20 million in 2020 [30]. WM in Lagos is coordinated by the Lagos Waste Management Authority (LAWMA), the city's municipal waste authority.

3.0 Materials and Methods

To access a wide range of literature for this review, the following scientific databases were explored using a combination of some keywords: ScienceDirect, Web of Science, Springer Link and Google Scholar. Apart from government records, publications of international organisations, and references to some unpublished materials with useful information, the bulk of the articles reviewed in this paper were from peer-reviewed journals written in English from 2010 to 2021. The search query, "municipal solid waste collection AND sub-Saharan Africa" entered in the ScienceDirect database returned 632 results after they were refined by year to the period under review. In the titles and abstracts of articles displayed in the results, we looked for the combination of words such as waste collection, municipal solid waste collection, municipal solid waste management, waste bin/receptacles, waste segregation/separation/sorting or recycling. A second search query, "municipal solid waste management AND sub-Saharan Africa" was again entered in the query box and it was noticed that the first five results were the same set of materials as in the first query, while the next 95 materials showed some similarities. Hence, we maintained

the results of the first query, given their proximity to the review discourse. We entered the first query above on the SpringerLink database and retrieved 939 materials within the same review window. Using the advanced search function, the Web of Science database was queried with a combination of Booleans, truncation, and field tags viz, TS = (Africa* AND (waste collection OR waste management)). The search returned 981 results for the study period.

To eliminate chances of missing relevant materials, we typed in the query “municipal solid waste collection AND African cities” on Google Scholar, which returned 19,300 results from various scientific databases after refining the results to the period under review. Since most of the results from Google Scholar combined records from the other three above, we mainly selected those considered relevant to our review. It is pertinent to note that we consistently looked for the keywords listed above in all the databases. Then, we read through the abstracts and conclusions to manually select pertinent and non-pertinent materials. Our guiding keywords formed the basis of all articles selected for this review. Additionally, while writing, we made references to all the databases when searching for specific titles. Some pertinent materials which could not be accessed due to the paywall barrier were magnanimously sent by their authors via the “request article” button on ResearchGate—although some did not revert. Cumulatively, 100 peer-reviewed articles published in English from 2010 to 2021 (Figure 1) were cited in this publication.

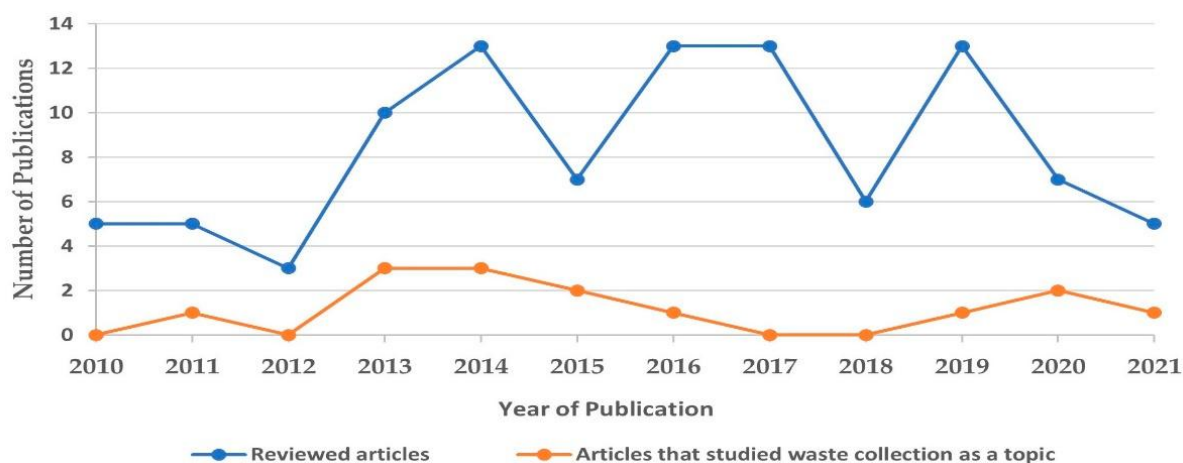


Figure 1. Analysis of peer-reviewed articles and the number of articles that studied waste collection as a topic. The articles that studied waste collection as a topic exclude articles that briefly discussed waste collection under other titles and non-peer-reviewed articles that studied waste collection as a topic.

3.1. Methodology for Meta-Analysis

Meta-analysis is a rigorous review usually employed to aggregate data from various studies to obtain a reliable estimate of findings in previous studies [31,32]. In a metaanalysis, the individual studies are usually assigned a weight, which is a function of the sample size considered in such a study [33]. In this study, the population of the region under investigation at the time of the data collection is used as the sample size. The objective of the meta-analysis conducted in this study is to estimate waste collection and coverage rates in selected SSA countries.

3.2. Selection Criteria for Included Studies in the Meta-Analysis

One important procedure in meta-analysis is defining appropriate inclusion and exclusion criteria for the studies to be included in the analysis. This procedure helps to ensure that only studies that are relevant to the analysis' objective are included. The defined inclusion criteria include (1) studies that present waste collection and coverage rates; (2) studies that highlight the location (i.e., city or country) associated with the data; and (3) studies that focus on SSA countries. Similarly, the exclusion criteria entail (1) studies that do not present quantitative data related to waste collection and coverage rates, (2) studies with no full-text availability, and (3) studies written in other languages apart from English. After this procedure, 12 studies out of the retrieved articles met these criteria.

3.3. Data Extraction for Meta-Analysis

After the selection of the relevant articles, the papers were carefully read to extract the necessary data for the analysis. From each shortlisted article, data relating to (1) the names of the authors, (2) waste collection rate, (3) waste collection coverage rate, (4) year of data collection, (5) region under investigation (i.e., city/country), (6) population of the region at the time of the investigation, and (7) variability measures where available (i.e., standard deviation and error). In a case where the variability measure is not reported in a study, the standard error is estimated based on the guidelines provided by Borenstein et al. [34]. Tables 1 and 2 show the extracted data for waste collection and coverage rates, respectively. While the data used for the collection rate are associated with the four SSA cities (i.e., Accra, Kumasi, Lagos, and Abuja), the data used for the coverage rate are related to SSA countries in general. This disparity is due to the unavailability of sufficient data in the four SSA cities. This generally suggests that there is a low level of research related to waste collection coverage rate in SSA cities.

Table 1. Extracted data for waste collection rate meta-analysis.

References	Collection Rate	Standard Error	Year of Data Collection	City	Population of City at the Time of Data Collection	Country
35,36]	0.384	0.03303	2013	Abuja	2,168,000	Nigeria
[1,37]	0.1	0.0085	2015	Lagos	12,239,000	Nigeria
[37,38]	0.277	0.0129	2014	Lagos	11,856,000	Nigeria
[1,39]	0.83	0.0248	2015	Accra	2,290,000	Ghana
[39,40]	0.93	0.185	2006	Accra	1,893,000	Ghana
[40,41]	0.91	0.08	2006	Kumasi	1,628,000	Ghana
[42]	0.799	0.0286	2005	Accra	1,960,797	Ghana
[42]	0.799	0.0263	2010	Accra	2,317,583	Ghana

Table 2. Extracted data for waste coverage rate meta-analysis.

References	Collection Coverage	Standard Error	Year of Data Collection	City	Population of City at the Time of Data Collection	Country
[43,44]	0.4	0.0256	2009	Dar es Salam	3,659,000	Tanzania
[36,45]	0.42	0.0315	2016	Abuja	2,442,000	Nigeria
[43,46]	0.57	0.0366	2009	Bamako	1,825,000	Mali
[43,47]	0.63	0.0376	2009	Lusaka	1,643,000	Zambia
[37,48]	0.63	0.0131	2018	Lagos	13,463,000	Nigeria
[49]	0.7	0.0401	2007	Kumasi	1,300,000	Ghana
[43,50]	0.82	0.0366	2012	Maputo	1,098,000	Mali
[39,51]	0.9	0.0992	2018	Accra	2,439,000	Ghana
[3]	0.95	0.0065	2012	Lagos	11,127,000	Ghana

3.4. Effect Size and Summary Effect

In a meta-analysis, the effect size is the parameter of interest, which indicates each study's outcome or finding [52,53]. In this research, waste collection and coverage rates are the effect sizes. The summary effect is a single estimate that combines the effect size of multiple studies to provide an overall effect. If the included studies are equally precise, the summary effect can be estimated as the weighted average of the effect sizes [33]. However, the studies are not usually consistent due to the variability in the sample size and method of data collection. Hence, weights are assigned to the studies based on their variability measures and sample sizes. The weights of the studies and the summary effect at a specified confidence interval (CI) were computed using a meta-analysis software known as Review Manager 5.4 [54].

3.5. Heterogeneity and Sub-Group Analysis

Heterogeneity refers to the degree of variability between the studies included in the meta-analysis. It may arise due to differences in the sample size, method of data collection and analysis, and other factors that may affect the effect size [34]. Usually, the I² statistic is used to measure the level of heterogeneity in a meta-analysis. An I² value of 25% or less indicates that the heterogeneity level is low, while a value between 25–75% is considered moderate. The heterogeneity is considered high when I² is greater than 75% [55]. A possible cause of heterogeneity should be investigated when the I² is high. One of the ways of investigating the cause is to conduct a sub-group analysis, which involves dividing the studies included in the meta-analysis into different groups based on a criterion that may affect the effect size. Careful attention needs to be paid to how the studies are divided into groups, as inappropriate criteria may lead to misleading interpretations [33]. In this study, the country where the effect size is estimated is used as a criterion for dividing the studies into groups. This is in agreement with previous studies with similar contexts [33,56,57].

4. Results and Discussion

4.1. MSW Generation, Composition, and Collection in SSA

Some studies in SSA have published data on waste generation and collection in selected countries, either from municipal records or generated through field studies. For example, Miezah et al. [58] generated field data on Ghana's waste composition and generation rate. However, there appears to be a paucity of current and regularly updated data on the aggregate collection coverage of MSW in the entire region, leaving a noticeable gap open. However, after extensive research on the global waste situation, Kaza et al. [1] reported an average collection coverage of 44% for the region. This figure could be higher than 50% in middle- to high-income areas owing to good access roads, high-income level, and willingness to pay. Since collection coverage refers to the

number of households (expressed as a percentage) with access to MSW collection service [11], the collection coverage average of 44% implies that waste from 56% of households in SSA could have been lost to the waste stream through indiscriminate dumping, which could accumulate in water bodies and cause blockage to drainage systems [10,59]. This raises concerns about public health [60].

In 2012, waste generation in SSA was estimated at an aggregate of 81 million tonnes per year (Figure 2) by cumulating data obtained from SSA countries [61]. This figure more than doubled to 174 million tonnes per year in 2016 compared to 2012 [1], which means that per capita waste generation has been rising. Of the total waste volume generated in 2012 in SSA from the data provided by Scarlat et al. [61], it can be deduced that a collection rate of 44.3% was achieved for that year. The waste collection rate is the proportion of waste collected for disposal from the volume of waste generated [40]. It is essential to note that although Scarlat et al. [61] estimated that SSA MSW generation would rise to an estimated 172.47 million tonnes per year in 2025, interestingly, this figure had already risen to 174 million tonnes as of 2016 as reported by Kaza et al. [1]. This indicates that estimates of the MSW generation rate might exceed projections for SSA countries, thus calling for urgency on the part of authorities to adopt sustainable WM strategies without further delay. The reported collection coverage of 44% in 2018 (Figure 3) raises a red flag on the region's need to improve the coverage of collection services, as this is still a far cry from the ideal figure of 100% [11]. The MSW in SSA is composed mainly of organics at an average of 57%, comparable to 50% of organics in South Asia [2]. The high organic fraction in the municipal waste stream could be utilized as a waste-to-energy (WTE) option when subjected to further biological treatment [62]. The organics could cushion the region's energy demand or, if co-digested with poultry waste, be used for producing clean energy [63]. The anaerobic digestion of the organic content can contribute to a significant reduction in global warming, as shown in a study on China [64] (something considered desirable for the environment). One challenge with AD, however, is ensuring that the organic fraction is properly separated before being fed into the digester to avoid interference with the biological process in the digester [22]. Hence, a good MSW separation scheme should be in place to separately collect organic waste to maximize the opportunity of this environmentally friendly WTE technology. Unfortunately, the current co-mingling of organic waste with other fractions in SSA impedes these possibilities. Bearing in mind that 2030 is less than a decade away, it has become imperative for SSA countries to take decisive steps towards achieving a sustainable solid WM system.

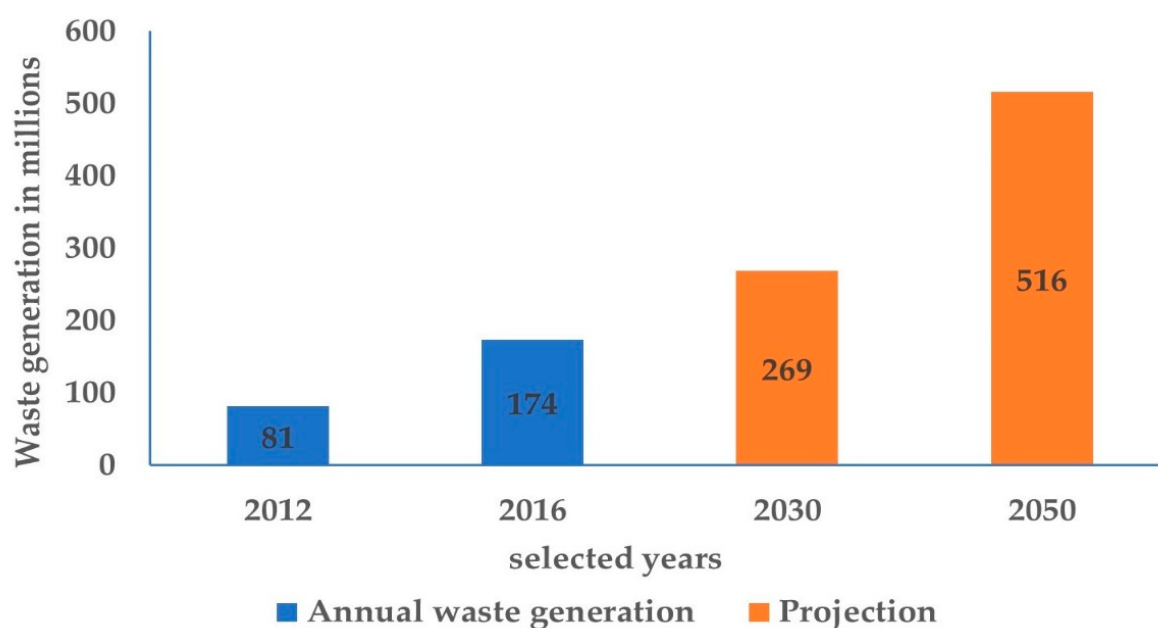


Figure 2. Waste generation in SSA [1,61]. This figure was developed from data published by the cited authors.

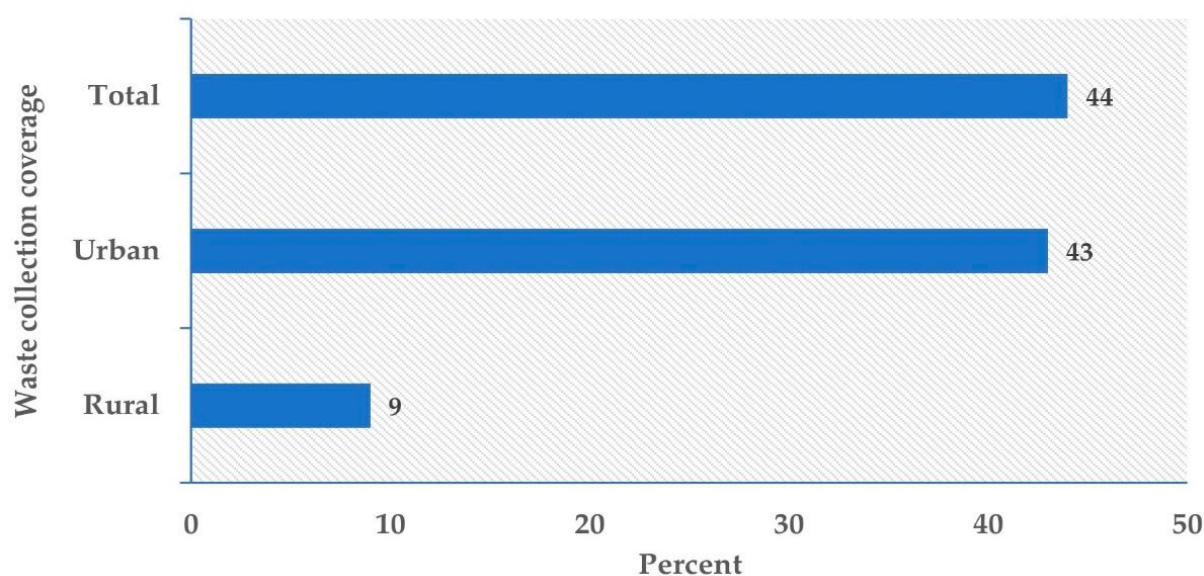


Figure 3. SSA waste collection coverage [1]. Permission to use this figure is granted under the Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO). Reference is cited in the bibliography as advised under the ‘Attribution’ condition

4.2. Generation, Composition, and Collection of MSW in Accra and Kumasi, Ghana

Ghana’s average waste generation rate is 0.51 kg/capita per day [1]. Based on a field study carried out by Miezah et al. [58] in 2015, the waste generation rate in Ghana was estimated at 0.47 kg/capita per day. The annual volume of waste collected in Ghana in 2012 was estimated at 377,000 tonnes of the 444,000 tonnes generated for that year [61]. This translates to an 85%

collection rate in 2012. In 2013, Oduro-Kwarteng and Van Dijk [40] had earlier reported a range between 0.35 and 0.75 kg/capita per day as the national household waste generation rate. Though the data from 2013 show some variation compared to the 2015 figure above, the lower value of 0.35 kg/capita per day shows that per capita waste generation in Ghana has been on the rise compared to the situation in 2015. As is typical of developing countries, the organic content of the MSW generated in Ghana comprises 61% organic components, followed by 14% plastics [21]. The data on waste generation rates and their corresponding characteristics are limited and not regularly updated [42,65], as is commonly reported about many least-developed countries. As of the time of writing this review, recent research articles did not report the status of the aggregate collection rate in Ghana; hence, we could not compare the above figures with the situation from 2019 to 2021.

4.2.1. Accra Metropolis

Accra's data on waste generation rates are discordant because waste audit reports were unavailable for more than two decades [42]. Following an extensive literature search, the most recent data on waste generation rate from the waste department in Accra found in the peer-reviewed literature is that reported by Sarfo-Mensah et al. [66]. The report states that the environmental protection agency in Accra documented 2800 tonnes per day in 2014 with 2200 tonnes being collected. This implies a collection rate of about 79% (this is in close range with the collection rate of 85% calculated from the 2012 waste collection data provided by Scarlat et al. [61]), although this study also noted that about 30% to 50% are never collected. This casts doubt on the correctness of the figures reported by the environmental agency. Kaza et al. [1] reported an 83% collection rate for Accra while Oduro-Kwarteng and Van Dijk [40] arrived at a much higher collection rate estimate of 93%. A different survey in 2015 [58] showed a value of 1552 tonnes per day and noted that the generation rate was higher in high-class income areas and lowest in low-class income areas. Two studies [42,67] published five years apart seem to agree on waste composition data in Accra. These studies reported 60% for organics while another study [58] published 63%. Interestingly, the figure of 48.8% for organics published in 2017 [68] differs widely. This could mean that waste data are not periodically updated. There are interesting statistics on waste collection coverage for Accra. For example, Frazier [69] reported a collection coverage of 70%; Wilson et al. [43] published a collection coverage of 67%; UNEP [3] documented 80% coverage for Accra. It is pertinent to add that MSW collection coverage improved owing to the engagement of public-private partnerships (PPP), which became necessary because of the increase in waste volume resulting from Accra's population growth.

4.2.2. Kumasi Metropolis

Owusu-Sekyere et al. [70], relying on data from the KMA forecasted waste generation in Accra for 2013 as 591,016 tonnes (we summed up figures from January to December 2013) using monthly waste volume values from 2005 to 2010. Since the waste generation per capita per day is derived by dividing the waste generated per year by the population of the reference year [71], we determined the per capita value for 2013 as 0.32 kg/capita per day using the official population figure of Kumasi metropolis in 2013, which was 1,827,014 according to Ghana Statistical Service [72]. This is in proximity with Ghana's waste generation estimates of 0.35 to 0.75 kg/capita per day as reported by one study [40]. The subsequent year, 2014 showed an increase to an average of 0.75 kg/capita per day [58]. Waste characterisation studies carried out in Kumasi show that the organic component for low- and middle-income communities, respectively, is 59.15% and 65.68% [73]. These figures are not too distant from the organic waste composition of 61% reported earlier for Ghana as a whole.

4.3. Generation, Composition, and Collection of MSW in Abuja and Lagos, Nigeria

Estimates of MSW generation rates in Nigeria have been reported by various authors [60,74], but based on our literature review the most current data on Nigeria's MSW generation rate appears to be that reported by Kaza et al. [1] as 0.51 kg/capita per day adjusted to the 2016 population level. Nnaji [75] published data of 0.49 kg/capita per day in 2015, while Oyeboode [60] reported a generation rate of 0.43 kg/capita per day in 2018. One would have thought that the national per capita waste generation should be higher in 2018 compared to 2015 since, as noted by Vij [76], urbanization has a direct impact on per capita waste generation, which must have occurred between 2015 and 2018—but again, this could reflect the incongruency in data records. Considering this likely influence, the value of 0.51 kg accurately depicts Nigeria's current waste generation rate. Some authors of articles that reported generation rates before 2010 consistently referred to a particular author's data for over a decade. This again highlights that waste data in the sub-Saharan are not regularly updated to reflect current realities, a trend similar to Ghana, as shown earlier. The composition of MSW in Nigeria is mainly organic, between 60% to 80% [60]. The high organic content in Nigeria is consistent with data reported earlier for SSA. The records of the MSW collection in Nigeria are disparate. It is estimated that only 20–30% of the over 32 million tonnes of annually generated waste are collected [77], while another study [78] reported a collection of 20% to 80%. An older record by Ogwueleka published in 2009 as cited in [75] documented uncollected waste of 30% to 60% before the period under review.

4.3.1. Abuja

In 2010, the waste generation rate in Abuja was estimated at 67,000 tonnes per year [79]. As of 2011, it had increased to 70,000 tonnes per year [80]. The figures for waste generation in Abuja show some disparities. One study [35] reported a generation rate of 0.67 kg/capita per day, while data published in 2015 showed 0.57 kg/capita per day [75]. Two years later, Kadafa [45] documented a range of 0.5 to 1.5 kg/capita per day. There could be reasons for Kadafa's range of figures including the season of the year, the research technique adopted, or the time of data collection [75]. Like other cities in SSA or the urban areas of other developing countries, the per capita waste generation increases with urbanization compared to the rates in rural areas [71]. That effect will increase, with urbanization rates in Africa and Asia projected to reach 64% by 2050 [81]. The composition of MSW in Abuja falls within the range for other cities considered in this review, which is between 52% to 60% organic, followed by plastics at 6.2% (Abuja Environmental Protection Board (AEPB), 2012 as cited in [82]), a trend also observed in the two Ghanaian cities. The MSW collection coverage in Abuja is reported to be insufficient relative to the city's population [83]. In the same vein, the collection rate is low. For example, according to Anyaegbunam [35], the AEPB can potentially collect up to 5000 metric tonnes of waste daily in an ideal situation, but only 1918 metric tonnes (38.4%) are collected, leaving 61.6% uncollected.

4.3.2. Lagos

The MSW waste generation in Africa's most populous city [84] has been rising. The generation rate was reported as 9000 tonnes per day (0.5 kg/capita per day) in 2014 [78,80]. In the same year, a study [85] published a different value of 0.95 kg/capita per day which lies outside the estimated range of 0.5 to 0.8 kg/capita per day for SSA countries [82]. Data published in 2018 estimated 12,000 metric tonnes per day (0.72 kg/capita per day) with a projection to 20,000 metric tonnes per day in 2020 using the estimated population of 30.2 million (LAWMA, 2012 as cited in [48]). Comparing the waste generation per day in 2014 and 2018 shows a 33.3% increase within four years compared to a projected 66.7% surge in the two years from 2018 to 2020. The waste generation rate in Lagos has assumed an alarming scale and calls for increased attention from the municipal authorities. As expected, the organic component of waste generated in Lagos is much higher than other components at 56% [86], although two other studies [48,87] published slightly varied data at 53%. Plastics usually trail behind, as shown in previous figures for other cities, except as reported by Oladepo and Rafiu [86] where the paper fraction came next at 12% with plastics at 10%. However, usually the trend for Ghana and Nigeria shows plastics as the second highest component of MSW. Only a few authors have reported on collection coverage for Lagos within the period under review. We found an article that published 63% collection

coverage, mainly in the medium- to high-income areas with better road access, leaving the hinterland poorly serviced [48], a common trend in the sub-Saharan.

A low collection rate has also been reported for Lagos. For example, between 2007 and 2013 an estimated 77.76 million tonnes of waste was generated with only 27.7% collected, leaving 72.3% uncollected across the metropolis (LAWMA, 2014 cited in [38]). Like Abuja's values, this figure falls below the estimated collection rate of 44.3% for SSA cities [61]. A similar situation is reported for Nigeria where Adeniran et al. [77] noted that from the over 32 million tonnes of MSW generated nationally, only a meagre 20% to 30% is collected. Notably, the collection rate reported for Lagos in 2018 was 10% [1], which is the lowest we found in the literature. It should be added that, in 2018, Lagos residents feared an epidemic outbreak owing to mounting heaps of uncollected MSW across the city. This was due to the lack of capacity by Visionscape (a foreign waste management company contracted by the Lagos state government) to collect waste across the city, resulting in backlogs over a long period in various parts of the city [88] (Figure 4).



Figure 4. Uncollected waste lining a road median in Lagos. Retrieved from[88]. Used with permission.

4.4. Methods of MSW Collection in Ghana and Nigeria

The literature shows that the common methods of waste collection employed in the examined cities are house-to-house (or door-to-door) and communal (or central) waste collection systems [48,51,80]. These authors also highlighted some of the challenges with these methods in the study areas. The door-to-door waste collection entails the pickup of MSW fractions (sorted waste) at

access points from individual dwellings in a locality [89]. In Italy, a study shows, that with more public awareness, door-to-door collection can spur the motivation for waste separation at the source. Thus, the chances of collecting more recyclables are increased [90]. This environmentally friendly approach is captured in the EU waste framework directive (Directive 2008/98/EC). However, the question arises whether this best practice forms part of the ideology of door-to-door collection in SSA. In the communal or central collection system, an area is chosen within a neighbourhood for the placement of waste collection bins. The people from that locality drop their waste for routine pickup by a waste collection company [91,92]. This method is also called the drop-off system. The communal collection is used in a broad sense. The system in Germany (Figure 5) is one variation of the communal method where waste bins are placed at a designated collection point close to apartment buildings [93]. This can also be seen in Maputo, Mozambique, Africa and Bahrain, in the Middle East [43]. It provides a higher service level than the use of communal bins (Figure 6) in the informal settlements of Ghana [43]. The following sections will examine the application of these collection methods and their associated challenges in the SSA focus areas.



Figure 5. A central collection point, near apartments, Berlin, Germany. Author's field photo.



Figure 6. Overfilled communal bin, Accra, Ghana. Retrieved from [94]. Used with permission.

4.4.1. Ghana

Accra and Kumasi's collection methods described above are fraught with some challenges. For example, Boateng et al. [95] reported a low-cost recovery from the communal collection system, which led to the introduction of a 'pay-as-you-dump' (PAYD) cost recovery mechanism, which was successful in the collection system. Unfortunately, as his report indicated, those who could not afford either of the collection services took to illegal dumping, a common trend in the sub-Saharan. However, the study further noted that some community members were willing to pay for either of the methods provided collection is regular, timely, and the appropriate waste collection bins are provided for waste storage. Another issue with communal collection points is the recurring spillover of waste from the skip containers arising from a delayed pickup, usually blamed on faulty collection vehicles [66,96,97]. To substantiate this, we extracted the picture of a skip container in Accra with overflowing waste (Figure 6). In consonance with the findings of Boateng et al. [95] about people's willingness to pay for either PAYD or door-to-door collection, Owusu et al. [98] showed in a Kumasi survey that a higher percentage of the respondents preferred door-to-door collection, followed by PAYD, which, according to him may be due to the timely collection by the waste collection company or the fact that they can afford collection and dumping fees under the PAYD system. In a similar survey, residents were willing to pay a higher collection fee provided collection is consistent and efficient [99].

4.4.2. Nigeria

Ghana and Nigeria have similar challenges with the two prevalent waste collection methods. In Lagos, an article [48] affirmed that the door-to-door collection by the assigned agent is insufficient in coverage, with hinterland Lagos sparsely covered for well-known reasons,

including a poor road network to some areas and low-cost recovery from people in such locations, among others. Opoko and Oluwatayo [100] and Ojolowo and Wahaba [38] highlighted the issues with irregular door-to-door collection in separate field surveys as the non-provision of communal skip bins in some highly populated low-income areas, as well as demands for waste collection payments when services were not rendered. These inefficiencies push some residents to illegal dumping and open waste burning to rid their homes of accumulated waste, which can potentially harm their health. Chidiebere et al. [101] pointed out another problem as the insufficient capacity of the waste collection agencies to cope with the rising waste volume, which consistently results in a backlog of uncollected waste, especially in the low-income areas of Lagos. This situation is corroborated by Adedara [102] in a study carried out in Lagos where it was noted that Alimosho, the largest local government in Lagos by population, had heaps of refuse in street corners, drains, road medians, and some public spaces—a clear indication that the problem persists. In Abuja, cases of irregular collection, inadequate provision of receptacles for communal or door-to-door collection, and insufficient coverage, among others, have also been reported [83,103,104]. In a field survey, Kadafa [45] noted that non-gated communities outside the Abuja metropolis had neighbourhood open waste dumps as communal collection points. In contrast, the municipal waste collection agency provided gated communities with communal waste bins. This social stratification speaks volumes about the waste authority's attitude to sustainable solid WM. Similar to Ghana, the collection of waste in Lagos and Abuja via the two methods are not in separate fractions that would allow the recovery of recyclable materials. Kadafa [45] also discovered that in Abuja the municipal waste authority initially collected healthcare waste in separate containers but at the dumpsite, they lumped them together with biodegradable and non-biodegradable waste materials, which can constitute a threat to public health, as already established in this article. Moreso, this defeats the environmental benefits of waste segregation at the source. Unfortunately, a similar scenario occurred in Accra where domestic waste was mixed with healthcare waste at the disposal site [105]. This practice, no doubt, portends hazards of injury or disease to scavengers as they scout the site for recyclables, not knowing that such waste materials require special handling [106].

4.5. Private Sector Involvement in MSW Collection—Ghana and Nigeria

Both countries, from the cities examined, engaged the services of the private sector in MSW collection as the municipal waste collection authorities/departments became overwhelmed with escalating waste volume. In Kumasi and Accra, MSW is collected mainly by private companies engaged in a PPP arrangement with the municipal government [107,108]. The waste department only takes care of street sweeping and the collection of bulk wastes [109]. A field study in Kumasi

carried out by Awunyo-Vitor et al. [110] concluded that, despite PPP arrangements being in force, piles of refuse were still a common sight in Kumasi. However, according to Oteng-Ababio [111] and Oduro-Kwarteng and Dijk [40], since the introduction of the PPP franchise in Accra and Kumasi, there has been a significant increase in collection coverage (which is higher than the estimated average for SSA countries as shown in Figure 7). On the contrary, Oduro-Appiah et al. [112] are concerned that a collection coverage of 75% in Accra is still a far cry from the desired 100% after the involvement of the PPP arrangement in MSW collection for over 20 years. In Lagos, the private sector participation (PSP) operators and LAWMA share waste collection responsibilities. As in Ghana, the municipal waste collection authority attends to cleaning and waste collection from common city areas, such as highways, major roads, and the like. The PSP operators are assigned to non-public areas, mainly residential premises [48]. In Abuja, the city's environmental board, AEDP, is the main collector of MSW [35,80] with additional services by PSP operators [83,113]. In Lagos and Abuja, waste is collected either once or twice a week, and sometimes twice monthly [114–116]. According to a publication [99], waste from communal waste bins in Accra could be collected up to eight times a day, depending on when they are full. In Lagos, PSP operators do a weekly collection. Irrespective of improvements in collection coverage in Ghana following the involvement of the private sector, there are still complaints of poor service while cases of illegal dumping continue. The waste collection in Lagos by the private waste collectors suffered a setback in 2018 when the government of Lagos state terminated the contracts of PSP operators and replaced them with a foreign waste collection company—the company was overwhelmed by the city's waste volume, which resulted in backlogs of uncollected waste under their watch, as reported earlier in this article. In the case of Abuja, we found that, in addition to complaints of poor service delivery, the city appears to be struggling to meet the average collection coverage for SSA, despite the intervention of private waste collectors.

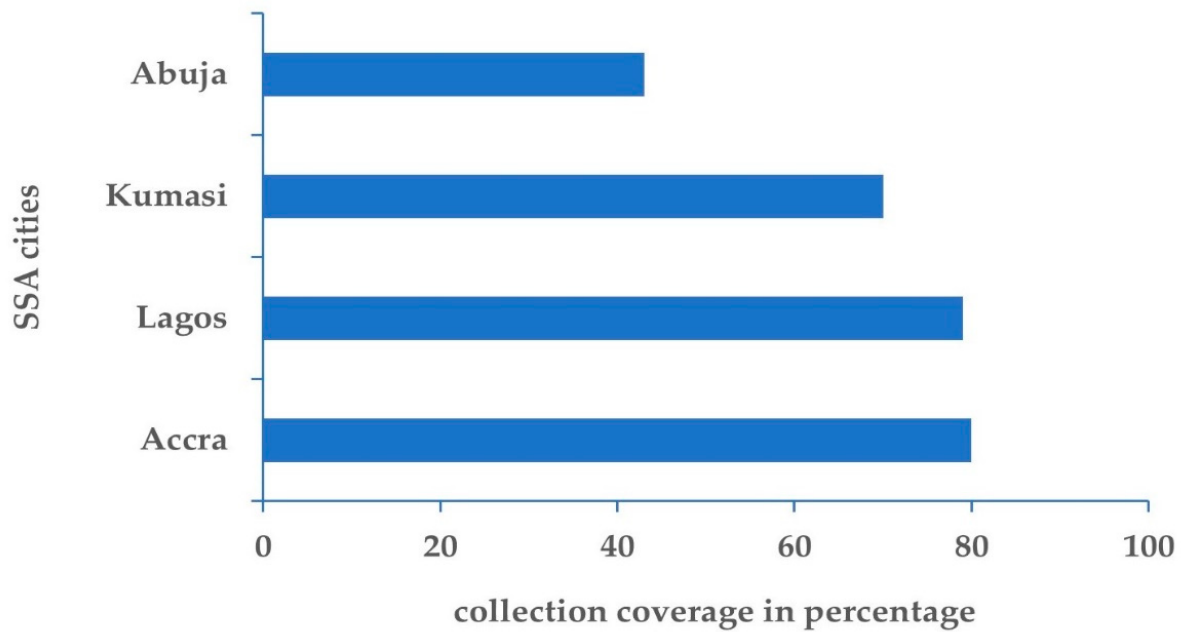


Figure 7. Collection coverage estimates in the four SSA cities [3,45,48,49]. The estimate for Lagos was derived by calculating the average of figures published by [3,48] given their wide disparity and the fact that they were published in the same year.

4.5.1. MSW Storage Receptacles—Ghana and Nigeria

The source separation of solid waste, in line with best practices targeted at environmental protection, including the recovery of quality recyclables, segregation of organics, and reduction of MSW is imperative [117–119]. Therefore, waste storage receptacles at the point of generation should enable the collection of MSW in separate fractions. In Ghana, polythene bags, wheeled plastic bins, baskets, paper boxes, metal containers, old plastic buckets, sacks, and others are commonly used for MSW storage before collection [94,120,121]. Sometimes PPP operators in Ghana give free plastic bins to customers during door-to-door collection [95]. This could be to encourage more sorting towards their next pickup. In other cases, for example in Kumasi, the PPP operators distribute 120-litre plastic bins to households for a fee [109]. Similar types of receptacles are used in Lagos [115] and Abuja [45,80], but in Lagos the wheeled bins are only given to property owners who pay the state’s land use charge [122]. The land use charge is a levy imposed on landed property owners in the city [123]. People residing in properties whose landlords are either non-resident in the property they live in or do not pay the levy resort to self-help, which in many cases results in indiscriminate dumping. In addition to the non-separation widely reported for door-to-door collection, wastes were also co-mingled at the skip bins in Ghana [21]. Common problems in all four cities examined are the non-segregation of waste fractions either at the door-to-door collection points or at the communal bins, and the persistent spillover of refuse around the collection bins due to delayed pickup. The co-mingling of waste

fractions is not beneficial to the environment and will not facilitate the shift to a circular economy [119].

4.5.2. MSW Waste Collection Vehicles in Ghana and Nigeria

When municipal authorities and private waste collectors choose their waste collection vehicles, they should consider waste density. It varies depending on location, the season of the year, or the type of storage receptacle [8]. We found that a common type of vehicle utilized for door-to-door collection of MSW across the four cities is the compactor truck, in addition to others such as tipping trucks, roll-on-roll-off trucks, rear loaders, and tricycles, among others [48]. During our review, we did not find an article that discussed the technical requirements for the selection of collection vehicles. Instead, issues such as inadequate vehicle fleet or foul odour from obviously decaying biodegradable waste were dominant in papers [38,116,124]. An additional grave concern is the incessant breakdown of collection vehicles due to overloading and sometimes due to poorly surfaced or dilapidated roads [125]. Overloading occurs when the mass of the transported waste is greater than the truck's maximal payload [8]. Vehicle breakdowns remain a daunting challenge coupled with the appalling state of the roads. The engagement of PPP/PSP operators in the cities examined has, no doubt, alleviated the burden of the municipal authorities in waste collection. Nevertheless, the cities are still faced with lingering collection challenges.

4.6. Waste Collection in the Context of a Circular Economy (CE)

According to the Ellen MacArthur Foundation [126], the circular economy (CE), driven by design, promotes the transition from the current linear model of take–make–dispose towards keeping materials in use for as long as possible to reduce the pressure on virgin raw materials, eliminating waste and pollution, and regenerating nature. As developed economies move more intently in the direction of a circular economy (CE), it is imperative for SSA countries to also make a shift in this direction. In this section, we examine how a better understanding of the CE concept can help waste management authorities/departments in SSA countries improve their waste collection systems by taking a cue from the CE drive in Europe and adapting the approaches to local situations. In 2015, the EU presented its policy statement on transitioning to a CE with a review of its waste legislation. It focused on improving the separate collection of waste from households in its bid to increase reuse and recycling among member states while reducing the pressure on finite virgin materials. A critical statement from the document reads, “there will be no circular economy without good waste separation”. In the document, the EU expressly emphasized the critical need to separate organic waste from other fractions to ensure a clean collection of recyclables so that recycling industries do not incur increased costs in their operations. It summarised that waste separation could be adapted to local situations in big and

small cities [119]. By implication, this could mean that small cities do not need to copy what big cities do directly, but it is necessary to look for ways to improve separate collections within the limits of their size and financial capacity. In the same vein, cities in SSA would have to practice the separate collection of waste in ways locally possible to begin the shift to a CE so that they can increase landfill diversion rate and keep secondary raw materials in circulation. Among other benefits, the regular separate collection of recyclable fractions at the point of generation helps to ensure that local recycling industries have a continuous supply of clean secondary raw materials for their operations, while at the same time reducing the volume of waste disposed of in landfills as shown in a study by Bashir et al. [127]. If this is backed up with an effective waste policy as in the EU, it would no doubt contribute to stemming the tide of indiscriminate dumping in SSA. Non-recyclable waste fractions could be converted to energy with some materials also recovered using incineration as a WTE technology [128]. Although a major issue with incineration is the potential to cause air pollution [76,129], this does not eliminate its potential benefits in energy generation. For example, an empirical study in Palestine [130] showed that incineration generated the highest amount of electricity compared to other WTE technologies. The study further suggested that the combination of AD with incineration will produce more energy with the least damage to the environment. Some other potential benefits of using MSW as a feedstock for energy generation and biofertilizer production, and how these processes contribute to the achievement of some of the sustainable development goals (SDGs) have been thoroughly discussed by Yong et al. [131]. It is essential to add that the state of MSW management in SSA provides a plethora of opportunities for investments in WTE technologies since the raw materials are readily available. These options should therefore be explored by concerned authorities in the region in the shift towards a CE. However, as presented in a study by Yong et al. [22] and Cudjoe [64] in Malaysia and China, respectively, it is essential to carry out an appraisal of the economic viability and environmental implications of various WTE options to decide on which is most viable within a locality as this would guide investors in making an investment choice. As earlier noted, in SSA, organics are co-mingled with other fractions. This is not desirable if the target is high-quality recycling, and it will not attract recycling companies for business since it will increase their operations costs. We reported earlier that there were instances in Ghana and Nigeria where healthcare wastes initially separated at source were co-mingled at the disposal site. This does not align with the CE concept, hence, according to Seyring et al. [90] the separate collection of recyclables at the point of generation is desired. Our take-home observation in the EU document is the commitment of the member states demonstrated through political will, national enforcement, and public

awareness. For example, in 2015 Germany made the separate collection of organics a national obligation, although implementation has not been rapid [118]. Policymakers in SSA countries can take a cue from this and enact locally appropriate waste policies targeted at capturing waste resources from the source rather than losing them to the waste stream as it is now. A strong political will and an effective implementation mechanism should follow this. Central and Eastern Europe were assumed to be behind in waste collection, but a field survey established that some cities in those areas emerged as excellent in the separate collection of MSW [90]. Hence, with political will, policies are formulated based on EU guidelines, while public cooperation is sought through public awareness. In SSA, past field studies in Lagos and Accra have established that people are willing to segregate their waste at home and in the office if they are taught how [102,132]. Increased awareness and public education will foster participation in waste separation, even in informal markets [21]. Based on the findings of Gyimah et al. [133], some people indicated a readiness to participate in waste segregation but were demotivated owing to the unavailability of recycling plants to process the waste. This brings another challenge to the fore in SSA: what to do with segregated recyclables when the volume becomes high in the face of an insufficient supply of waste processing companies. There is a need to open the market for local and foreign waste materials processing investments. Given the willingness to be involved in waste separation, as established in this article, the drive towards a CE, in addition to the points raised earlier, can also be achieved via the encouragement of active participation through continuous public awareness. However, caution should be taken to ensure that strategies adopted are tailored towards what is locally possible rather than the direct importation of systems used abroad.

Informal Efforts towards a Circular Economy—Ghana and Nigeria

Proponents of the circular economy (CE) model view waste as an essential resource that powers economic development. Hence, as an important material for the production process, it should be exploited in preference to the extraction of virgin materials [134]. Waste pickers in landfills in SSA are driven by survival [135] but are also informally engaged in re-circulating discarded waste resources for supply to local recycling industries [136]. The scavengers take advantage of the collection gap created through the inefficient collection of MSW by municipal governments that rely mainly on non-engineered landfill disposals. In Ghana and Nigeria, scavenging is common at many dumpsites [49,137]. Some articles [138–140] have reported on the public health hazards associated with scavenging in West African cities, but equally highlighted the contribution of the pickers to the recovery of materials for reuse as well as the supply of materials to local recycling industries, which is in favour of the CE model. In both countries, there are

active repair markets for imported E-waste—mostly from the EU—such as mobile phones, TVs, old fridges, and car waste sold as spare parts, among others. Although there is a thriving market for shipped functioning equipment, some materials are damaged beyond repair. These constitute another source of waste and amplify the waste burden in SSA. Especially problematic is the content of hazardous materials in some of these products [141,142]. Even though some E-waste products are damaged beyond repair, useful parts are recovered for the repair of other devices; this contributes to the circulation of secondary raw materials and promotes CE. The quest for survival and the scarcity of jobs mainly drive some unskilled people in developing countries to scavenge at dumpsites [18]. However, it is important to note that these activities indicate that SSA may be well-positioned to begin the shift to a circular economy while it improves on efforts to close the gap in MSW collection, especially in low-income neighbourhoods.

4.7. Result of the Meta-Analysis

This section presents the result of the meta-analysis conducted in this study. As highlighted earlier, the meta-analysis was conducted to obtain an overall assessment of waste collection and coverage rates in sub-Saharan African countries. The subsequent sections discuss the results of the analysis.

4.7.1. Waste Collection Rate

Figure 8 shows the forest plot of waste collection rate in the sub-Sahara African countries generated using the meta-analysis software. A forest plot is often used to denote the result of a meta-analysis graphically. The plot consists of two parts. The first part denotes the included studies, their effect sizes (i.e., collection rate), standard errors, standardized weights given to each study, and their corresponding values at a 95% confidence interval. The other part graphically shows each study's weight, which is represented by the red square. The horizontal line at the centre of the column shows the confidence interval of the weight assigned to each study. For instance, the effect size of the first study in Figure 8 is 0.384, with an upper and lower value of 0.32 and 0.45, respectively, at a 95% confidence interval. The standard error (SE) and the weight of the study are 0.03303 and 10.2%, respectively. The summary effect is represented by the centre of the black diamond, and its 95% confidence interval is denoted by the widths. Quantitatively, the summary effect of waste collection rate in the selected sub-Saharan African countries is 0.65 (i.e., 65%) with a confidence interval of 0.43–0.87. This implies that the waste collection rate in SSA countries is low and less than the desired 100%. The summary effect suggests that there is a significant need for improvement in waste collection practices and policies to reduce the negative environmental and health impacts of uncollected waste.

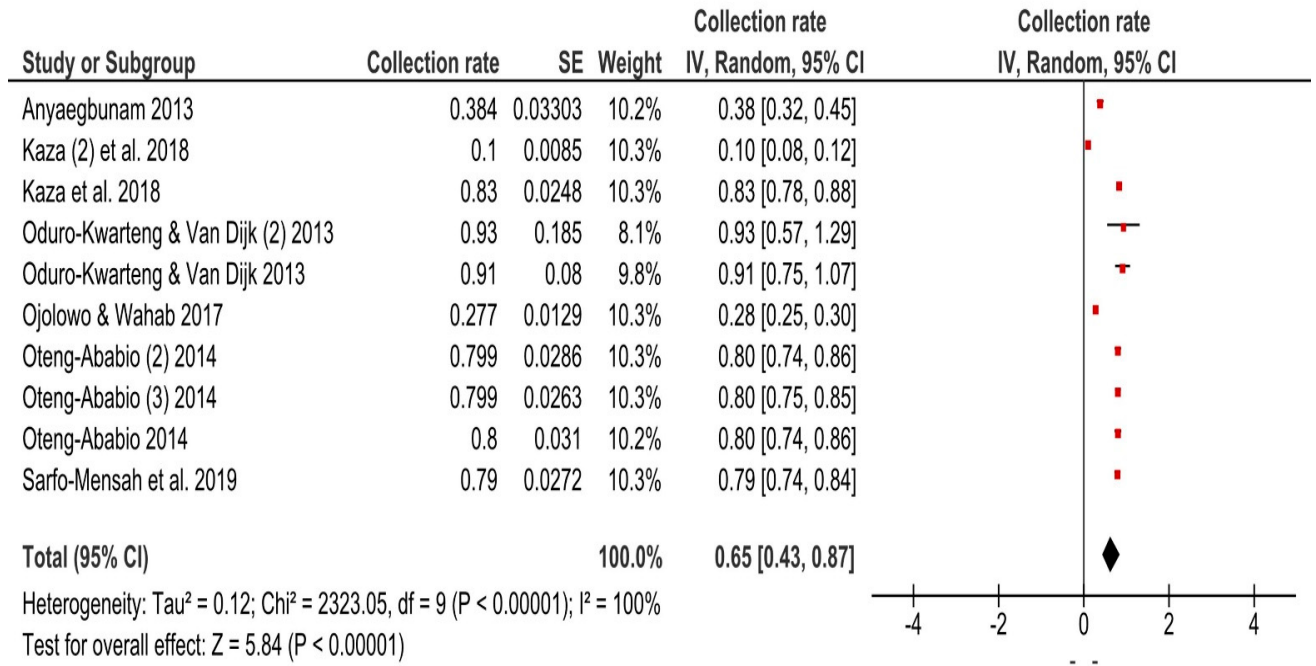


Figure 8. Forest plot of waste collection rate in the selected SSA countries [1,35,38,40,42,66].

Furthermore, the I^2 (100%) shows that there is high heterogeneity in the effect sizes of the included studies. Although the random effect model, which caters for variability among the studies, was used for the analysis, a sub-group analysis using the data collection region was conducted to further investigate the heterogeneity. As shown in Figure 9, the summary effect of waste collection in Nigeria is 0.25 (i.e., 25%), while that of Ghana is 0.81 (81%). This shows that the criterion (location of data collection) used for the sub-group analysis is significant for determining the source of heterogeneity, as confirmed by the I^2 (98%) of the test for the sub-group difference.

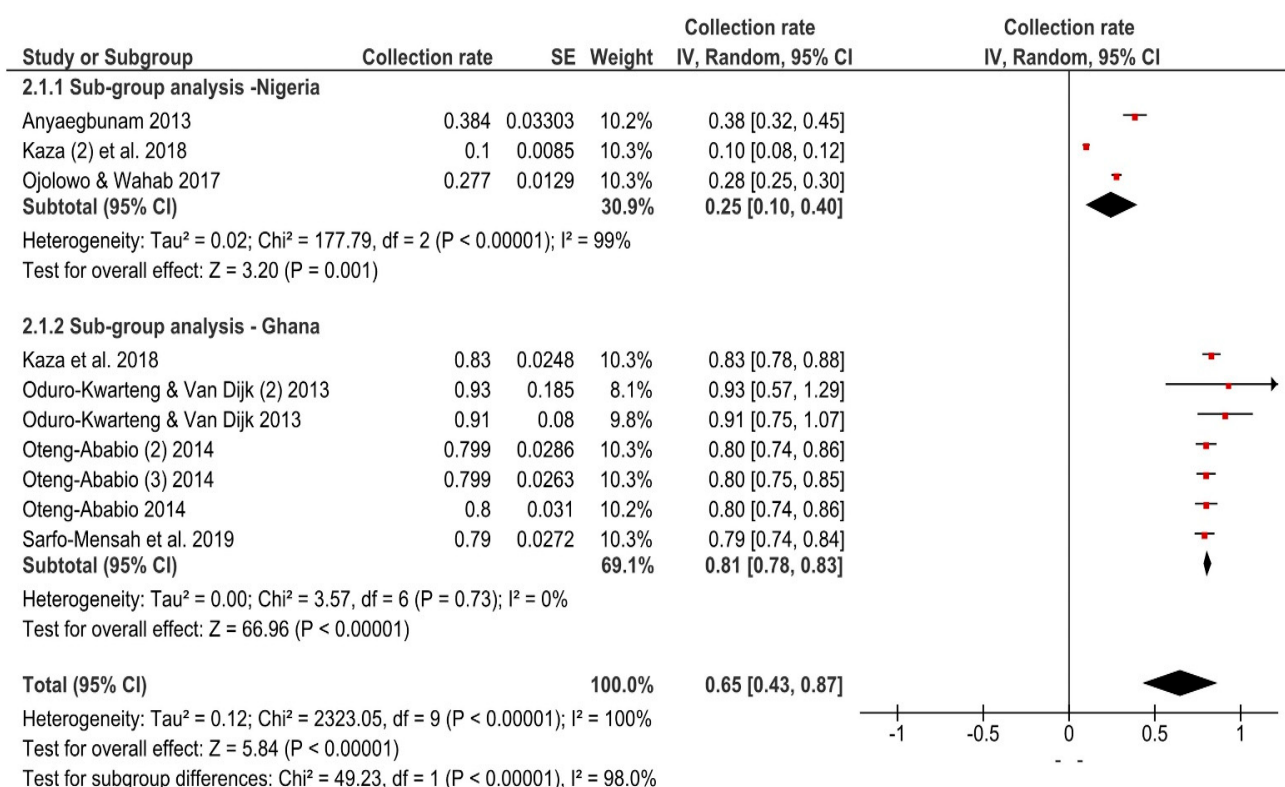


Figure 9. Forest plot of sub-group analysis of waste collection rate based on country [1,35,38,40,42,66].

4.7.2. Waste Collection Coverage Rate

The result of the waste collection coverage rate in SSA countries is represented in **Figure 10**. The Figure shows the studies included in the meta-analysis, their effect sizes (i.e., coverage rate), standard errors, 95% confidence interval of the effect sizes, and the assigned weights to the studies both numerically and graphically. For instance, the effect size reported in the last study [3] shown in **Figure 10** was 0.95, and its 95% confidence interval was found to be 0.94–0.96. Its standard error and assigned weights are 0.0065 and 11.4%. As revealed by the black diamond in **Figure 10**, the summary effect is 0.67 (i.e., 67%) with a 95% confidence interval of 0.50–0.83. This means that the meta-analysis of previous studies estimated the waste coverage rate in SSA countries to be 67%. The 95% confidence interval of the summary effect shows that the true value of the waste coverage rate in SSA countries is likely to fall within 50–83%.

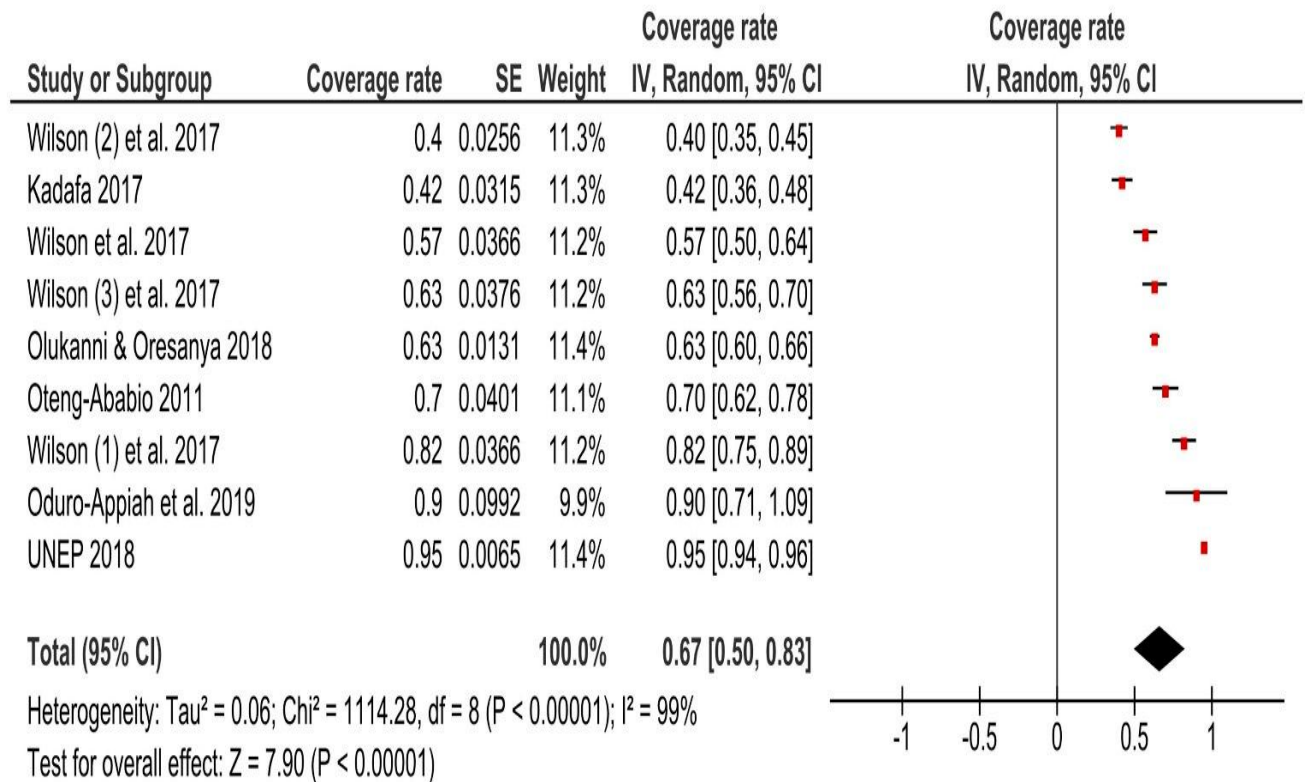


Figure 9. Forest plot of sub-group analysis of waste collection rate based on country [1,35,38,40,42,66].

Due to the high heterogeneity ($I^2 = 99\%$) in the effect sizes of the studies, sub-group analysis was conducted to investigate the source of the heterogeneity. The result of the sub-group analysis is presented in Figure 11, and it shows that the summary effects of waste collection coverage rate in Nigeria, Ghana, and other countries are 67, 78, and 60%, respectively. This shows that the coverage rate is not statistically different across the three groups as their coverage rate is similar. This is also confirmed by the test for sub-group difference, as the I^2 is 0%. Summarily, the waste collection coverage rate in SSA countries is less than the ideal 100%, and it is important to explore potential solutions to improve waste management services availability and accessibility in SSA countries. Potential solutions include (1) investment in waste management infrastructure such as waste treatment facilities, recycling plants, and waste transfer stations; (2) encouraging more public-private partnerships to increase investment in waste management services; and (3) encouraging research and development in waste management technologies that are suitable for the African context.

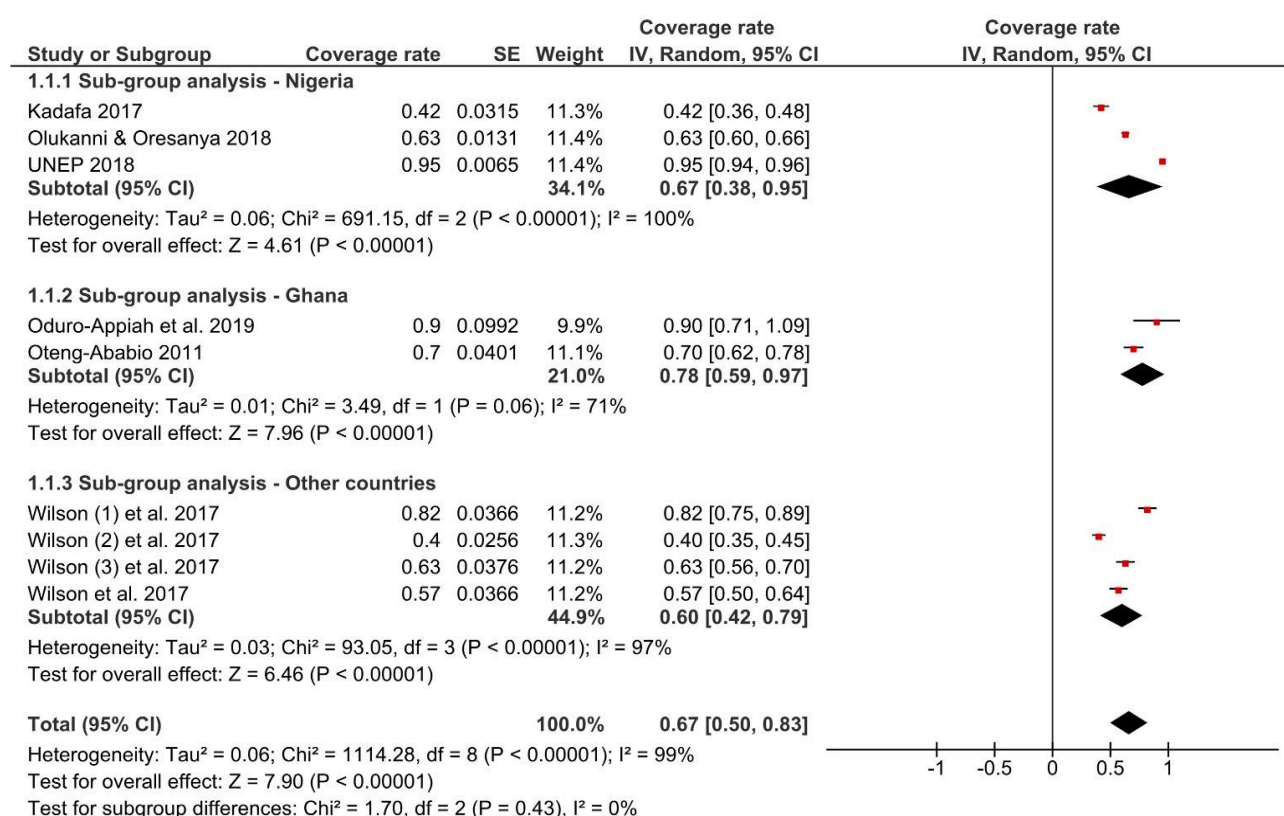


Figure 11. Forest plot of sub-group analysis of waste coverage rate based on country [3,43,45,48,49,51]

5.0 Conclusions and Recommendations

The review reveals that cities in SSA are currently overwhelmed by lingering backlogs of uncollected waste, with collection rate and coverage still below 100%, despite the involvement of private waste collectors in MSW collection. The meta-analysis result indicates that waste collection and coverage rates are both below 70% in SSA. While several studies have explored the various aspects of waste treatment methods and recycling, only a handful have directly addressed the urgent need to increase the collection rate and coverage of MSW in low-income neighbourhoods with poor sanitary conditions. Hence, there is a pressing need for more research and concerted efforts towards improving WM services availability and accessibility in SSA countries. In some SSA cities, there are instances where waste segregation at source has been practised, but unfortunately, the unavailability or inadequate supply of waste treatment technology for processing the collected waste defeats the purpose of the segregation since the collected waste eventually ends up in the region's mostly un-engineered landfills.

Given the current situation, as a first step, it has become inevitable for countries in SSA to further open up the market of waste collection by enacting a waste policy that allows direct investments in waste treatment technology, which should also licence waste processing companies to collect

MSW needed for their plants directly from residential and commercial premises. This would increase competition in MSW collection in the high- medium-, and low-income neighbourhoods and ultimately result in the quick mop-up of waste backlogs with the overall impact of increasing collection rate and coverage above current levels. It is essential to note, however, that the involvement of waste processing companies in improving the efficiency of the collection system has its associated challenges. One challenge might be the inadequacy of current data on the volume of waste generated by households and commercial premises, which the waste processing companies need to forecast the supply of materials to their processing plants, including planning for personnel and facilities for efficient collection. Where this is not addressed before investing in the market, waste materials supply could fall below what is required for the plants to function at full capacity, thereby affecting the sustainability of the business in the long run. Moreover, the possibility of existing private waste collectors feeling threatened by the entry of competitors cannot be ruled out. This may result in the refusal of older market players to share relevant information with the new entrants at the initial stage. In the interest of public health, the process of upgrading major landfills in the region to the status of “controlled landfills” where a material recovery facility (MRF) is built should be given urgent consideration by municipal governments. Scavengers can be shielded from the potential health hazards associated with their activities by engaging them in the sorting of recyclables in the MRF and then paying them in proportion to the weight of materials sorted, which is the same thing that happens when they sell scavenged materials to local recycling industries. An empirical case that demonstrates this possibility is the revamping of the “Awotan” dumpsite in Ibadan, South-Western Nigeria to the status of a “controlled landfill” where former open dump Figure now sort about 50 tonnes of recyclables daily in the newly built MRF located at the landfill site [143]. Although it is expected that scavengers would express worries that their means of livelihood is now being threatened with this strategy, as the case was when scavengers were told to vacate the “Awotan dumpsite”, their fears could be allayed by ensuring they are co-opted into the new plan at the MRF so that they can continue to earn money while benefiting from safer working conditions.

While more research on MSW collection in SSA is needed, given how critical it is in achieving a sustainable WM system, further research efforts can be focused on monitoring the progress made towards increasing the collection rate and coverage beyond current levels through studies that quantitatively compare the before and after scenarios following the introduction of an intervention in this area. In such studies, research studies should seek to measure the impact of increased competition in the collection system in lowincome neighbourhoods where the figures of collection rate and coverage are abysmally low compared to the middle- and high-income

areas of the city. Moreso, it would be worthwhile to also quantify the impact of upgrading an open dumpsite to a controlled landfill on scavenging activities within a catchment area as a way of assessing how the government's efforts in this direction are improving public health while ensuring income security for former scavengers and gradually reducing scavenging in SSA. Another aspect aimed at promoting the CE would be to measure the impact of continuous grassroots awareness campaigns targeted at waste reduction and reuse in high-, medium-, and low-income neighbourhoods on the volume of waste generated and disposed of over some time. Specifically, areas with presently low collection coverage should be chosen for this study and checked over two years to compare the results, before and after. A study like this might serve as an insight into how to reduce the waste disposed of in landfills.

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References

1. Kaza, S.; Yao, L.; Bhada-Tata, P.; Van Woerden, F. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*; World Bank: Washington, DC, USA, 2018. [[Google Scholar](#)]
2. Hoornweg, D.; Bhada, P. *What a Waste 2012—A Global Review of Solid Waste Management*; World Bank: Washington, DC, USA, 2012. [[Google Scholar](#)]
3. UNEP. *Africa Waste Management*; United Nations Environment Programme: Nairobi, Kenya, 2018; ISBN 978-92-807-3704-2. [[Google Scholar](#)]
4. Rodić, L.; Wilson, D.C. Resolving Governance Issues to Achieve Priority Sustainable Development Goals Related to Solid Waste Management in Developing Countries. *Sustainability* **2017**, *9*, 404. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
5. Odonkor, S.T.; Salar, A.M. Correlates of Household Waste Management in Ghana: Implications for Public Health. *Heliyon* **2021**, *7*, e08227. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)]
6. Pires, A.; Graca, M.; Rodrigues, S.; Gomes, M.I. *Sustainable Solid Waste Collection and Management*; SpringerLink; Springer International Publishing: Cham, Switzerland, 2019. [[Google Scholar](#)]
7. Carlos-Alberola, M.; Izquierdo, A.G.; Colomer-Mendoza, F.J.; Barreda-Albert, E. Design of a Municipal Solid Waste Collection System in Situations with a Lack of Resources: Nikki (Benin), a Case in Africa. *Sustainability* **2021**, *13*, 1785. [[Google Scholar](#)] [[CrossRef](#)]
8. UN-HABITAT. *Collection of Municipal Solid Waste in Developing Countries*; United Nations Human Settlements Programme: Nairobi, Kenya, 2010; ISBN 978-92-1-132254-5. [[Google Scholar](#)]
9. Diaz, L.F. Waste Management in Developing Countries and the Circular Economy. *Waste Manag. Res.* **2017**, *35*, 1–2. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)]
10. Mlilo, P.; Marufu-Dzangare, I.T.; Chigugudhlo, P.N.; Chitongo, L. Waste Management in Cowdray Park Suburb of Bulawayo, Zimbabwe. *J. Public Adm. Dev. Altern.* **2021**, *6*, 48–64. [[Google Scholar](#)]
11. Wilson, D.C.; Velis, C.A.; Rodic, L. Integrated Sustainable Waste Management in Developing Countries. *Proc. Inst. Civ. Eng. Waste Resour. Manag.* **2013**, *166*, 52–68. [[Google Scholar](#)] [[CrossRef](#)]
12. Innocent, N.M.; Dieudonné, B.; Jose, S.N. Modeling the Temporal Variations of Municipal Solid Waste Generation for Future Projection in the Douala Municipality, Cameroon. *J. Multidiscip. Eng. Sci. Technol. JMEST* **2016**, *3*, 2458–9403. [[Google Scholar](#)]

13. Mbeng, L.O. Informal Waste Recovery and Recycling: Alleviating Poverty, Environmental Pollution and Unemployment in Douala, Cameroon. *J. Sci. Res. Rep.* **2013**, *2*, 474–490. [[Google Scholar](#)] [[CrossRef](#)]
14. Tassie, K.; Endalew, B.; Mulugeta, A. Composition, Generation and Management Method of Municipal Solid Waste in Addis Ababa City, Central Ethiopia: A Review. *Asian J. Environ. Ecol.* **2019**, *9*, 1–19. [[Google Scholar](#)] [[CrossRef](#)]
15. Dlamini, S.; Simatele, M.D.; Serge Kubanza, N. Municipal Solid Waste Management in South Africa: From Waste to Energy Recovery through Waste-to-Energy Technologies in Johannesburg. *Local Environ.* **2019**, *24*, 249–257. [[Google Scholar](#)] [[CrossRef](#)]
16. Maqhuzu, A.B.; Yoshikawa, K.; Takahashi, F. Estimation of Leachate Generated from Zimbabwe's Municipal Solid Wastes (MSW) Landfills Using a Simple Stochastic Water Balance Model. *App. Environ. Res.* **2018**, *40*, 40–50. [[Google Scholar](#)] [[CrossRef](#)]
17. Idowu, I.A.; Atherton, W.; Hashim, K.; Kot, P.; Alkhaddar, R.; Alo, B.I.; Shaw, A. An Analyses of the Status of Landfill Classification Systems in Developing Countries: Sub Saharan Africa Landfill Experiences. *Waste Manag.* **2019**, *87*, 761–771. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)]
18. Nyathi, S.; Olowoyo, J.O.; Oludare, A. Perception of Scavengers and Occupational Health Hazards Associated with Scavenging from a Waste Dumpsite in Pretoria, South Africa. *J. Environ. Public Health* **2018**, *2018*. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)] [[Green Version](#)]
19. Nambuli, F.; Togarepi, C.; Shikongo, A. Waste Scavenging a Problem or an Opportunity for Integrated Waste Management in Namibia: A Case of Keetmanshoop Municipality, Namibia. *Environ. Pollut.* **2021**, *10*, 47. [[Google Scholar](#)] [[CrossRef](#)]
20. Couth, R.; Trois, C. Waste Management Activities and Carbon Emissions in Africa. *Waste Manag.* **2011**, *31*, 131–137. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)]
21. Agbefe, L.E.; Lawson, E.T.; Yirenya-Tawiah, D. Awareness on Waste Segregation at Source and Willingness to Pay for Collection Service in Selected Markets in Ga West Municipality, Accra, Ghana. *J. Mater. Cycles Waste Manag.* **2019**, *21*, 905–914. [[Google Scholar](#)] [[CrossRef](#)]
22. Yong, Z.J.; Bashir, M.J.K.; Ng, C.A.; Sethupathi, S.; Lim, J.W.; Show, P.L. Sustainable Waste-to-Energy Development in Malaysia: Appraisal of Environmental, Financial, and Public Issues Related with Energy Recovery from Municipal Solid Waste. *Processes* **2019**, *7*, 676. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
23. Aziz, S.Q.; Aziz, H.A.; Bashir, M.J.; Yusoff, M.S. Appraisal of Domestic Solid Waste Generation, Components, and the Feasibility of Recycling in Erbil, Iraq. *Waste Manag. Res.* **2011**, *29*, 880–887. [[Google Scholar](#)] [[CrossRef](#)]
24. Purkayastha, D.; Majumder, M.; Chakrabarti, S. Collection and Recycle Bin Location-Allocation Problem in Solid Waste Management: A Review. *Pollution* **2015**, *1*, 175–191. [[Google Scholar](#)]

25. World Bank Sub-Saharan Africa|Data. Available online: <https://data.worldbank.org/country/ZG> (accessed on 23 November 2022).
26. Ministry of Foreign Affairs, Japan. *Chapter 2 Specific Initiatives of Japan's Official Development Assistance. Section 2 Assistance for Each Region*; Tokyo, Japan, 2014. Available online: <https://www.mofa.go.jp/files/000119328.pdf> (accessed on 21 March 2023).
27. Baumgartner, B. The Position of Sub-Saharan Countries in the World Economy. *Stud. Commer. Bratisl.* **2016**, *9*, 5–16. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
28. World Population Review Population of Cities in Ghana. 2022. Available online: <https://worldpopulationreview.com/countries/cities/ghana> (accessed on 23 November 2022).
29. Accra Metropolitan Assembly Republic of Ghana Local Government Bulletin (*Bye-Laws 2017*); 2019. Available online: <https://ama.gov.gh/doc/bye-laws.pdf> (accessed on 23 November 2020).
30. World Urban Forum. *UN-HABITAT Lagos: Citizen Participation in a Multi-Cultural City Organization*. 2020. Available online: <https://wuf10.unhabitat.org/wuf10-programme/voices-cities/lagos-citizen-participation-multi-cultural-city> (accessed on 28 November 2020).
31. Mackelprang, A.W.; Nair, A. Relationship between Just-in-Time Manufacturing Practices and Performance: A Meta-Analytic Investigation. *J. Oper. Manag.* **2010**, *28*, 283–302. [[Google Scholar](#)] [[CrossRef](#)]
32. Zouine, A.; Fenies, P. The Critical Success Factors Of The ERP System Project: A Meta-Analysis Methodology. *J. Appl. Bus. Res. JABR* **2014**, *30*, 1407–1448. [[Google Scholar](#)] [[CrossRef](#)]
33. Salihu, C.; Hussein, M.; Mohandes, S.R.; Zayed, T. Towards a Comprehensive Review of the Deterioration Factors and Modeling for Sewer Pipelines: A Hybrid of Bibliometric, Scientometric, and Meta-Analysis Approach. *J. Clean. Prod.* **2022**, *351*, 131460. [[Google Scholar](#)] [[CrossRef](#)]
34. Borenstein, M.; Hedges, L.V.; Higgins, J.P.T.; Rothstein, H.R. Subgroup Analyses. In *Introduction to Meta-Analysis*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2009; pp. 149–186. ISBN 978-0-470-74338-6. [[Google Scholar](#)]
35. Anyaegbunam, N.C. Environmentally Friendly and Sustainable Municipal Solid Waste Management in Abuja. *Int. J. Eng. Sci. Invent.* **2013**, *2*, 42–50. [[Google Scholar](#)]
36. Macrotrends LLC Abuja, Nigeria Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/21976/abuja/population> (accessed on 18 February 2023).
37. Macrotrends LLC Lagos, Nigeria Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/22007/lagos/population> (accessed on 18 February 2023).

38. Ojolowo, S.; Wahab, B. Municipal Solid Waste and Flooding in Lagos Metropolis, Nigeria: Deconstructing the Evil Nexus. *J. Geogr. Reg. Plan.* **2017**, *10*, 174–185. [Google Scholar] [CrossRef] [Green Version]
39. Macrotrends LLC Accra, Ghana Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/21107/accra/population> (accessed on 18 February 2023).
40. Oduro-Kwarteng, S.; Van Dijk, M.P. The Effect of Increased Private Sector Involvement in Solid Waste Collection in Five Cities in Ghana. *Waste Manag. Res.* **2013**, *31*, 81–92. [Google Scholar] [CrossRef]
41. Macrotrends LLC Kumasi, Ghana Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/21108/kumasi/population> (accessed on 18 February 2023).
42. Oteng-Ababio, M. Rethinking Waste as a Resource: Insights from a Low-Income Community in Accra, Ghana. *City Territ. Archit.* **2014**, *1*, 1–14. [Google Scholar] [CrossRef] [Green Version]
43. Wilson, D.C.; Kanjogera, J.B.; Soós, R.; Briciu, C.; Smith, S.R.; Whiteman, A.D.; Spies, S.; Oelz, B. Operator Models for Delivering Municipal Solid Waste Management Services in Developing Countries. Part A: The Evidence Base. *Waste Manag. Res.* **2017**, *35*, 820–841. [Google Scholar] [CrossRef]
44. Macrotrends LLC Dar Es Salaam, Tanzania Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/22894/dar-es-salaam/population> (accessed on 18 February 2023).
45. Kadafa, A.A. Solid Waste Management Practice of Residents in Abuja Municipalities (Nigeria). *IOSR J. Environ. Sci. Toxicol. Food Technol.* **2017**, *11*, 87–106. [Google Scholar] [CrossRef]
46. Macrotrends LLC Bamako, Mali Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/21818/bamako/population> (accessed on 18 February 2023).
47. Macrotrends LLC Lusaka, Zambia Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/23277/lusaka/population> (accessed on 18 February 2023).
48. Olukanni, D.O.; Oresanya, O.O. Progression in Waste Management Processes in Lagos State, Nigeria. *Int. J. Eng. Res. Afr.* **2018**, *35*, 11–23. [Google Scholar] [CrossRef]
49. Oteng-Ababio, M. The Role of the Informal Sector in Solid Waste Management in the GAMA, Ghana: Challenges and Opportunities. *J. Econ. Hum. Geography* **2011**, *103*, 412–425. [Google Scholar] [CrossRef]
50. Macrotrends LLC Maputo, Mozambique Metro Area Population 1950–2023. Available online: <https://www.macrotrends.net/cities/21910/maputo/population> (accessed on 18 February 2023).

51. Oduro-Appiah, K.; Afful, A.; Kotey, V.N.; de Vries, N. Working with the Informal Service Chain as a Locally Appropriate Strategy for Sustainable Modernization of Municipal Solid Waste Management Systems in Lower-Middle Income Cities: Lessons from Accra, Ghana. *Resources* **2019**, *8*, 12. [Google Scholar] [CrossRef] [Green Version]
52. Taiwo, R.; Hussein, M.; Zayed, T. An Integrated Approach of Simulation and Regression Analysis for Assessing Productivity in Modular Integrated Construction Projects. *Buildings* **2022**, *12*, 2018. [Google Scholar] [CrossRef]
53. Tawfik, G.M.; Dila, K.A.S.; Mohamed, M.Y.F.; Tam, D.N.H.; Kien, N.D.; Ahmed, A.M.; Huy, N.T. A Step by Step Guide for Conducting a Systematic Review and Meta-Analysis with Simulation Data. *Trop. Med. Health* **2019**, *47*, 1–9. [Google Scholar] [CrossRef] [PubMed]
54. The Cochrane Collaboration. Review Manager Web. Version 5.4. 2020. Available online: <http://revman.cochrane.org> (accessed on 21 March 2023).
55. Higgins, J.; Green, S. *Cochrane Handbook for Systematic Reviews of Interventions*, 1st ed.; Wiley: Hoboken, NJ, USA, 2019. [Google Scholar]
56. Horman, M.J.; Kenley, R. Quantifying Levels of Wasted Time in Construction with Meta-Analysis. *J. Constr. Eng. Manag.* **2005**, *131*, 52–61. [Google Scholar] [CrossRef]
57. Taiwo, R.; Wang, K.C.; Olanrewaju, O.I.; Tariq, S.; Abimbola, O.T.; Mehmood, I.; Zayed, T. An Analysis of Employee Motivation in the Construction Industry: The Case of Hong Kong. *Eng. Proc.* **2022**, *22*, 11. [Google Scholar] [CrossRef]
58. Miezah, K.; Obiri-Danso, K.; Kádár, Z.; Fei-Baffoe, B.; Mensah, M.Y. Municipal Solid Waste Characterization and Quantification as a Measure towards Effective Waste Management in Ghana. *Waste Manag.* **2015**, *46*, 15–27. [Google Scholar] [CrossRef] [PubMed] [Green Version]
59. Hirpe, L.; Yeom, C. Municipal Solid Waste Management Policies, Practices, and Challenges in Ethiopia: A Systematic Review. *Sustainability* **2021**, *13*, 11241. [Google Scholar] [CrossRef]
60. Oyeboode, O.J. Evaluation of Municipal Solid Waste Management for Improved Public Health and Environment in Nigeria. *Eur. J. Adv. Eng. Technol.* **2018**, *5*, 525–534. [Google Scholar]
61. Scarlat, N.; Motola, V.; Dallemand, J.F.; Monforti-Ferrario, F.; Mofor, L. Evaluation of Energy Potential of Municipal Solid Waste from African Urban Areas. *Renew. Sustain. Energy Rev.* **2015**, *50*, 1269–1286. [Google Scholar] [CrossRef]
62. Sechoala, T.D.; Popoola, O.M.; Ayodele, T.R. A Review of Waste-to-Energy Recovery Pathway for Feasible Electricity Generation in Lowland Cities of Lesotho. In Proceedings of the IEEE AFRICON Conference, Jeju Island, South Korea, 1 September 2019; Institute of Electrical and Electronics Engineers Inc.; Volume 2019. [Google Scholar]

63. Matheri, A.N.; Ndiweni, S.N.; Belaid, M.; Muzenda, E.; Hubert, R. Optimising Biogas Production from Anaerobic Co-Digestion of Chicken Manure and Organic Fraction of Municipal Solid Waste. *Renew. Sustain. Energy Rev.* **2017**, *80*, 756–764. [[Google Scholar](#)] [[CrossRef](#)]
64. Cudjoe, D.; Han, M.S.; Nandiwardhana, A.P. Electricity Generation Using Biogas from Organic Fraction of Municipal Solid Waste Generated in Provinces of China: Techno-Economic and Environmental Impact Analysis. *Fuel Process. Technol.* **2020**, *203*, 106381. [[Google Scholar](#)] [[CrossRef](#)]
65. Asare, W.; Andrews, A.; Asare, R. Households Solid Waste Generation and Disposal in Some Selected Communities in Ejisu–Juaben Municipality, Ghana. *J. Sci. Res. Rep.* **2015**, *6*, 371–382. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)]
66. Paul, S.-M.; Kwaku, O.-O.; Albert, A.A.; Theophilus, K.A.; Richard, T.O. Solid Waste Management in Urban Communities in Ghana: A Case Study of the Kumasi Metropolis. *Afr. J. Environ. Sci. Technol.* **2019**, *13*, 342–353. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
67. Osei-Appiah, N.A.; Dioha, M.O. Techno-Economic Assessment of Waste-to-Energy Technologies in Ghana. *J. Sustain. Energy* **2019**, *10*, 112–121. [[Google Scholar](#)]
68. Benedicta, A.; Susanne, H.; Bradl, H.B.; Pishva, D.; Ahiakpa, J.K. Resource Prospects of Municipal Solid Wastes Generated in the Ga East Municipal Assembly of Ghana. *J. Health Pollut.* **2017**, *7*, 37–47. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
69. Frazier, T.J. Opportunities and Challenges for Sustainability in an Urbanizing World: Selections from the UGEC2010 Conference Transforming Accra towards a Sustainable Future: Comprehensive Land Use Planning and the Greater Accra Urban Simulation System (GAUSS). In Proceedings of the UGEC Viewpoints, Tempe, AZ, USA, 15–17 October 2010. [[Google Scholar](#)]
70. Owusu-Sekyere, E.; Harris, E.; Bonyah, E. Forecasting and Planning for Solid Waste Generation in the Kumasi Metropolitan Area of Ghana: An ARIMA Time Series Approach. *Intern. J. Sci.* **2013**, *2*, 69–83. [[Google Scholar](#)]
71. Kawai, K.; Tasaki, T. Revisiting Estimates of Municipal Solid Waste Generation per Capita and Their Reliability. *J. Mater. Cycles Waste Manag.* **2016**, *18*, 1–13. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
72. Ghana Statistical Service. *Ghana Statistical Yearbook*; Accra, Ghana, 2013. Available online: www.statsghana.gov.gh (accessed on 27 November 2020).
73. Oduro-Kwarteng, S.; Anarfi, K.P.; Essandoh, H.M.K. Source Separation and Recycling Potential of Municipal Solid Waste in Ghana. *Manag. Environ. Qual. Int. J.* **2016**, *27*, 210–226. [[Google Scholar](#)] [[CrossRef](#)]
74. Atta, A.Y.; Aminu, M.A.Y.; Yusuf, N.; Gano, Z.S.; Ahmed, O.U.; Fasanya, O.O. Potentials of Waste to Energy in Nigeria. *J. Appl. Sci. Res.* **2016**, *12*, 1–6. [[Google Scholar](#)]
75. Nnaji, C.C. Status of Municipal Solid Waste Generation and Disposal in Nigeria. *Manag. Environ. Qual. Int. J.* **2015**, *26*, 53–71. [[Google Scholar](#)] [[CrossRef](#)]

76. Vij, D. Urbanization and Solid Waste Management in India: Present Practices and Future Challenges. In *Procedia—Social and Behavioral Sciences*; Elsevier: Amsterdam, The Netherlands, 2012; Volume 37, pp. 437–447. [Google Scholar]
77. Adeniran, A.E.; Nubi, A.T.; Adelopo, A.O. Solid Waste Generation and Characterization in the University of Lagos for a Sustainable Waste Management. *Waste Manag.* **2017**, *67*, 3–10. [Google Scholar] [CrossRef] [PubMed]
78. Anestina, A.I.; Adetola, A.; Odafe, I.B. Performance Assessment of Solid Waste Management Following Private Partnership Operations in Lagos State, Nigeria. *J. Waste Manag.* **2014**, *2014*, 1–8. [Google Scholar] [CrossRef]
79. Roberts, C.L.; Watkin, G.D.; Ezeah, C.; Phillips, P.S.; Odunfa, A. Seasonal Variation and Municipal Solid Waste Composition—Issues for Development of New Waste Management Strategies in Abuja, Nigeria. *J. Solid Waste Technol. Manag.* **2010**, *36*, 210–219. [Google Scholar] [CrossRef]
80. Ezeah, C.; Roberts, C.L. Waste Governance Agenda in Nigerian Cities: A Comparative Analysis. *Habitat Int.* **2014**, *41*, 121–128. [Google Scholar] [CrossRef]
81. Abomeh Ofobruku, S.; Nkiruka Okafor, C.; Agbaeze, E.K.; Ozioma Obi-Anike, H. Entrepreneurial Potentials of Solid Waste Management in the Federal Capital Territory Abuja, Nigeria. *Niger. J. Soc. Sci.* **2016**, *12*, 1–15. [Google Scholar]
82. Salami, H.A.; Adegite, J.O.; Bademosi, T.T.; Lawal, S.O.; Olutayo, O.O.; Olowosokedile, O. A Review on the Current Status of Municipal Solid Waste Management in Nigeria: Problems and Solutions. *J. Eng. Res. Rep.* **2018**, *3*, 1–16. [Google Scholar] [CrossRef]
83. Joseph, F.G.; Folorunsho, J.O.; Yusuf, Y.O.; Aruya, E.I. Assessment of Solid Waste Management Techniques in Maitama, Abuja, Nigeria. *Int. J. Sustain. Dev. Plan.* **2020**, *15*, 227–233. [Google Scholar] [CrossRef]
84. World Population Review Africa Cities by Population. 2022. Available online: <https://worldpopulationreview.com/continents/africa/cities> (accessed on 23 November 2022).
85. Aliu, I.R.; Adeyemi, O.E.; Adebayo, A. Municipal Household Solid Waste Collection Strategies in an African Megacity: Analysis of Public Private Partnership Performance in Lagos. *Waste Manag. Res.* **2014**, *32*, 67–78. [Google Scholar] [CrossRef]
86. Oladepo, A.S.; Rafiu, O.O. Challenges of Waste Management and Climate Change in Nigeria: Lagos State Metropolis Experience. *Afr. J. Sci. Res.* **2012**, *7*. [Google Scholar]
87. Oyeboode, O.J. Solid Waste Management for Sustainable Development and Public Health: A Case Study of Lagos State in Nigeria. *Univers. J. Public Health* **2013**, *1*, 33–39. [Google Scholar] [CrossRef]
88. Olowookere, D. Investigation Shows How Inexperienced Visionscape Got Lagos Waste Management Deal. *Business Post Nigeria*. 2018. Available

- online: <https://businesspost.ng/general/investigation-shows-how-inexperienced-visionscape-got-lagos-waste-management-deal/> (accessed on 3 August 2021).
89. Laurieri, N.; Lucchese, A.; Marino, A.; Digiesi, S. A Door-to-Door waste Collection System Case Study: A Survey on Its Sustainability and Effectiveness. *Sustainability* **2020**, *12*, 5520. [[Google Scholar](#)] [[CrossRef](#)]
 90. Seyring, N.; Dollhofer, M.; Weißenbacher, J.; Bakas, I.; McKinnon, D. Assessment of Collection Schemes for Packaging and Other Recyclable Waste in European Union-28 Member States and Capital Cities. *Waste Manag. Res.* **2016**, *34*, 947–956. [[Google Scholar](#)] [[CrossRef](#)]
 91. Beliën, J.; De Boeck, L.; Van Ackere, J. Municipal Solid Waste Collection and Management Problems: A Literature Review. *Transp. Sci.* **2014**, *48*, 78–102. [[Google Scholar](#)] [[CrossRef](#)]
 92. Mora, C.; Manzini, R.; Gamberi, M.; Cascini, A. Environmental and Economic Assessment for the Optimal Configuration of a Sustainable Solid Waste Collection System: A Kerbside Case Study. *Prod. Plan. Control* **2014**, *25*, 737–761. [[Google Scholar](#)] [[CrossRef](#)]
 93. Umweltbundesamt Waste Collection and Transport. Umweltbundesamt. Available online: <https://www.umweltbundesamt.de/en/topics/waste-resources/waste-disposal/waste-collection-transport> (accessed on 23 November 2022).
 94. Owusu, G. Social Effects of Poor Sanitation and Waste Management on Poor Urban Communities: A Neighborhood-Specific Study of Sabon Zongo, Accra. *J. Urban.* **2010**, *3*, 145–160. [[Google Scholar](#)] [[CrossRef](#)]
 95. Boateng, S.; Amoako, P.; Poku, A.A.; Appiah, D.O.; Garsonu, E.K. Household Willingness to Pay for Solid Waste Disposal Services in Urban Ghana: The Kumasi Metropolis Situation. *Ghana J. Geogr.* **2016**, *8*, 1–17. [[Google Scholar](#)]
 96. Abdulai, H.; Hussein, R.; Bevilacqua, E.; Storrings, M. GIS Based Mapping and Analysis of Municipal Solid Waste Collection System in Wa, Ghana. *J. Geogr. Inf. Syst.* **2015**, *7*, 85–94. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
 97. Udofia, E.A.; Yawson, A.E.; Aduful, K.A.; Bwambale, F.M. Residential Characteristics as Correlates of Occupants' Health in the Greater Accra Region, Ghana. *BMC Public Health* **2014**, *14*, 224. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
 98. Owusu, V.; Boaheng, J.M.; Sundberg, C. Are Households Willing to Pay for Full-Cost Solid Waste Collection? Evidence from Kumasi Metropolis of Ghana. *J. Environ. Stud. Sci.* **2011**, *1*, 144–153. [[Google Scholar](#)] [[CrossRef](#)]
 99. Oduro-Appiah, K.; Aidoo, D.O.; Graham, S. Fee-Based Solid Waste Collection in Economically Developing Countries: The Case of Accra Metropolis. *Int. J. Dev. Sustain.* **2013**, *2*, 629–639. [[Google Scholar](#)]
 100. Opoko, A.P.; Oluwatayo, A.A. Private Sector Participation in Domestic Waste Management in Informal Settlements in Lagos, Nigeria. *Waste Manag. Res.* **2016**, *34*, 1217–1223. [[Google Scholar](#)] [[CrossRef](#)]

101. Alban Chidiebere, O.; Abubakar, M.; Shabako, G.J. Municipal Solid Waste Management in African Cities: A Case Study of Lagos State, Nigeria. *Malays. J. Civ. Eng.* **2018**, *30*, 1–12. [Google Scholar] [CrossRef] [Green Version]
102. Adedara, M.L. Assessment of the Source Separation of Household Solid Wastes in Nigeria (A Case Study of Alimosho Local Government Area, Lagos). Master's Thesis, University of Kiel, Kiel, Germany, 2018. [Google Scholar]
103. Amasuomo, E.; Tuoyo, O.J.A.; Hasnain, S.A. Analysis of Public Participation in Sustainable Waste Management Practice in Abuja, Nigeria. *Environ. Manag. Sustain. Dev.* **2015**, *4*, 180. [Google Scholar] [CrossRef] [Green Version]
104. Adeyemi, B. Waste Management in Contemporary Nigeria: The Abuja Example. *Int. J. Polit. Good Gov.* **2011**, *2*, 1–18. Available online: <http://www.onlineresearchjournals.com/ijopagg/previousissues.php?jn=22#> (accessed on 21 March 2023).
105. Asante, O.B.; Yanful, E.; Yaokumah, E.B. Healthcare Waste Management. Its Impact: A Case Study of the Greater Accra Region, Ghana. *Int. J. Sci. Technol. Res.* **2014**, *3*, 106–112. Available online: <https://www.ijstr.org/research-paper-publishing.php?month=mar2014> (accessed on 21 March 2023). [CrossRef]
106. Padmanabhan, K.K.; Barik, D. Health Hazards of Medical Waste and Its Disposal. In *Energy from Toxic Organic Waste for Heat and Power Generation*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 99–118. ISBN 978-0-08-102528-4. [Google Scholar]
107. Yeboah-Assiamah, E.; Asamoah, K.; Kyeremeh, T.A. Decades of Public-Private Partnership in Solid Waste Management: A Literature Analysis of Key Lessons Drawn from Ghana and India. *Manag. Environ. Qual. Int. J.* **2017**, *28*, 78–93. [Google Scholar] [CrossRef]
108. Bosompem, C.; Stemn, E.; Fei-Baffoe, B. Multi-Criteria GIS-Based Siting of Transfer Station for Municipal Solid Waste: The Case of Kumasi Metropolitan Area, Ghana. *Waste Manag. Res.* **2016**, *34*, 1054–1063. [Google Scholar] [CrossRef]
109. Addo, I.B.; Adei, D.; Acheampong, E.O. Solid Waste Management and Its Health Implications on the Dwellers of Kumasi Metropolis, Ghana. *Curr. Res. J. Soc. Sci.* **2015**, *7*, 81–93. [Google Scholar] [CrossRef]
110. Awunyo-Vitor, D.; Ishak, S.; Seidu Jasaw, G. Urban Households' Willingness to Pay for Improved Solid Waste Disposal Services in Kumasi Metropolis, Ghana. *Urban Stud. Res.* **2013**, *2013*, 1–8. [Google Scholar] [CrossRef]
111. Oteng-Ababio, M. Private Sector Involvement in Solid Waste Management in the Greater Accra Metropolitan Area in Ghana. *Waste Manag. Res.* **2010**, *28*, 322–329. [Google Scholar] [CrossRef] [PubMed]
112. Oduro-Appiah, K.; Scheinberg, A.; Mensah, A.; Afful, A.; Boadu, H.K.; de Vries, N. Assessment of the Municipal Solid Waste Management System in Accra, Ghana: A 'Wasteaware' Benchmark Indicator Approach. *Waste Manag. Res.* **2017**, *35*, 1149–1158. [Google Scholar] [CrossRef]

113. Ayuba, K.A.; Manaf, L.A.; Sabrina, A.H.; Azmin, S.W.N. Current Status of Municipal Solid Waste Management Practise in FCT Abuja. *Res. J. Environ. Earth Sci.* **2013**, *5*, 295–304. [Google Scholar] [CrossRef]
114. Idowu, O.B.A.; Omirin, M.M.; Osagie, J.U. Outsourcing for Sustainable Waste Disposal in Lagos Metropolis: Case Study of Agege Local Government, Lagos. *J. Sustain. Dev.* **2011**, *4*, 116. [Google Scholar] [CrossRef]
115. Ilechukwu, V.U.; Aminu, T.O. Operational Factors Affecting Public-Private Partnership (PPP) in Sustainable Solid Waste Management in Lagos Metropolis. *J. Geogr. Issues* **2014**, *2*, 20–34. [Google Scholar]
116. Maton, D.J.; Kigun, P.A.; Ogalla, M. Integrated Solid Waste Management—A Palliative to Existing Waste Mgt Challenges in Jabi District, Abuja. *Ethiop. J. Environ. Stud. Manag.* **2016**, *9*, 769–779. [Google Scholar] [CrossRef]
117. Chen, B.; Lee, J. Household Waste Separation Intention and the Importance of Public Policy. *Int. Trade Polit. Dev.* **2020**, *4*, 61–79. [Google Scholar] [CrossRef]
118. European Bioplastics the Benefits of Separate Organic Waste Collection—European Bioplastics e.V. Available online: <https://www.european-bioplastics.org/the-benefits-of-separate-organic-waste-collection/> (accessed on 23 November 2022).
119. European Commission. *Separate Waste Collection in the Context of a Circular Economy in Europe Charlemagne Building Brussels Draft Conference Report*. 2016. Available online: http://ec.europa.eu/environment/waste/eventspast/separate_waste.htm (accessed on 21 March 2023).
120. Yoada, R.M.; Chirawurah, D.; Adongo, P.B. Domestic Waste Disposal Practice and Perceptions of Private Sector Waste Management in Urban Accra. *BMC Public Health* **2014**, *14*, 697. [Google Scholar] [CrossRef] [Green Version]
121. Otchere, A.F.; Sarpong, K.O.; Okyere, S. Assessing the Challenges Affecting Solid Waste Management System in the Kumasi Metropolis. *J. Arts Humanit.* **2014**, *3*, 50–63. [Google Scholar] [CrossRef]
122. Agbesola, Y.O. Sustainability of Municipal Solid Waste Management in Nigeria: A Case Study of Lagos. Master's Thesis, Linköping University, Linköping, Sweden, 2013. [Google Scholar]
123. Lagos State Government About Lagos—Lagos State Government. Available online: <https://lagosstate.gov.ng/about-lagos/> (accessed on 23 November 2022).
124. Fagariba, C.; Song, S. Assessment of Impediments and Factors Affecting Waste Management: A Case of Accra Metropolis Farmers' Climate Change Adaptation Constraints in Ghana: Evidence of Micro Climate Adaptation Strategy View Project Impact of Small Scale Mining on Soil and Water. *Acad. J. Environ. Sci.* **2016**. [Google Scholar] [CrossRef]
125. Samwine, T. Challenges and Prospects of Solid Waste Management in Ghana. *Int. J. Environ. Monit. Anal.* **2017**, *5*, 96. [Google Scholar] [CrossRef] [Green Version]

126. Ellen MacArthur Foundation What Is a Circular Economy? Ellen MacArthur Foundation. Available online: <https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview> (accessed on 23 November 2022).
127. Bashir, M.J.; Jun, Y.Z.; Yi, L.J.; Abushammala, M.F.; Amr, S.S.A.; Pratt, L.M. Appraisal of Student's Awareness and Practices on Waste Management and Recycling in the Malaysian University's Student Hostel Area. *J. Mater. Cycles Waste Manag.* **2020**, *22*, 916–927. [[Google Scholar](#)] [[CrossRef](#)]
128. Van Caneghem, J.; Van Acker, K.; De Greef, J.; Wauters, G.; Vandecasteele, C. Waste-to-Energy Is Compatible and Complementary with Recycling in the Circular Economy. *Clean Technol. Environ. Policy* **2019**, *21*, 925–939. [[Google Scholar](#)] [[CrossRef](#)]
129. Lam, C.H.K.; Ip, A.W.M.; Barford, J.P.; McKay, G. Use of Incineration MSW Ash: A Review. *Sustainability* **2010**, *2*, 1943–1968. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
130. Salah, W.A.; Abuhelwa, M.; Abusafa, A.; Bashir, M.J.K. The Feasibility of Renewable Energy Recovery from Municipal Solid Wastes in Palestine Based on Different Scenarios. *Biofuels* **2022**, 1–9. [[Google Scholar](#)] [[CrossRef](#)]
131. Yong, Z.J.; Bashir, M.J.K.; Hassan, M.S. Biogas and Biofertilizer Production from Organic Fraction Municipal Solid Waste for Sustainable Circular Economy and Environmental Protection in Malaysia. *Sci. Total Environ.* **2021**, *776*, 145961. [[Google Scholar](#)] [[CrossRef](#)] [[PubMed](#)]
132. Antwi, Y.B.; Koranteng, J.; Odei, S.; Anabila, E. Determinants of an Effective Solid Wastes Collection at the Workplace Accra. *Int. J. Emerg. Sci. Res.* **2020**, *1*, 20–27. [[Google Scholar](#)] [[CrossRef](#)]
133. Gyimah, P.; Mariwah, S.; Antwi, K.B.; Ansah-Mensah, K. Households' Solid Waste Separation Practices in the Cape Coast Metropolitan Area, Ghana. *GeoJournal* **2019**, *86*, 567–583. [[Google Scholar](#)] [[CrossRef](#)]
134. Savini, F. The Economy That Runs on Waste: Accumulation in the Circular City. *J. Environ. Policy Plan.* **2019**, *21*, 675–691. [[Google Scholar](#)] [[CrossRef](#)] [[Green Version](#)]
135. Gutberlet, J.; Uddin, S.M.N. Household Waste and Health Risks Affecting Waste Pickers and the Environment in Low- and Middle-Income Countries. *Int. J. Occup. Environ. Health* **2017**, *23*, 299–310. [[Google Scholar](#)] [[CrossRef](#)]
136. Kwarteng, I.K.; Kontić, D.; Bizjak, T.; Kontić, B. Assessing the Role of Waste Pickers in the Recycling Industry in Accra Metropolis. *J. Geosci. Environ. Prot.* **2020**, *08*, 73–87. [[Google Scholar](#)] [[CrossRef](#)]
137. Ogbonna, A.C.; Mikailu, A. The Role of the Informal Sector in Sustainable Municipal Solid Waste Management: A Case Study of Lagos State, Nigeria. *Int. J. Eng.* **2019**, *17*, 117–122. [[Google Scholar](#)]

138. Ezeah, C.; Roberts, C.L.; Phillips, P.S.; Mbeng, L.O.; Nzeadibe, T.C. Evaluation of Public Health Impacts of Scavenging in Abuja, Nigeria Using Q Methodology. In Proceedings of the International Solid Waste Association World Congress, Lisbon, Portugal, 12–15 October 2009; ISWA: Rotterdam, The Netherlands, 2010; pp. 300–310. [Google Scholar]
139. Owusu-Sekyere, E. Scavenging for Wealth or Death? Exploring the Health Risk Associated with Waste Scavenging in Kumasi, Ghana. *Ghana J. Geogr.* **2014**, *6*, 63–80. Available online: <https://www.ajol.info/index.php/gjg/article/view/111135> (accessed on 21 March 2023).
140. Afon, A. A Survey of Operational Characteristics, Socioeconomic and Health Effects of Scavenging Activity in Lagos, Nigeria. *Waste Manag. Res.* **2012**, *30*, 664–671. [Google Scholar] [CrossRef] [PubMed]
141. Manhart, A.; Schleicher, T.; Degreif, S. *Global Circular Economy of Strategic Metals—The Best-of-Two-Worlds Approach (Bo2W)*; Oeko-Institut e.V.: Freiburg, Germany, 2014. [Google Scholar]
142. Manhart, A.; Osibanjo, O.; Aderinto, A.; Prakash, S. *Informal E-Waste Management in Lagos, Nigeria-Socio-Economic Impacts and Feasibility of Inter-National Recycling Co-Operations*; Final Report of Component 3 of the UNEP SBC E-Waste Africa Project; Oeko-Institut e.V.: Freiburg, Germany, 2011. [Google Scholar]
143. Governor Makinde Commissions Awotan Landfill Project—YouTube. 2021. Available online: <https://www.youtube.com/watch?v=COBHAbFIJ8> (accessed on 15 December 2021).

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CHAPTER TWO

Evaluating Recycling Initiatives for Landfill Diversion in Developing Economies Using Integrated Machine Learning Techniques

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Abstract

This study investigates the effectiveness of the Lagos Recycle Initiative (LRI) on landfill diversion (LFD) in Lagos, Nigeria, where evidence-based assessments of such initiatives are lacking. It evaluates the recycling diversion rate (RDR) of household recyclables (HSRs) across local government areas using field surveys and population data. Machine learning algorithms (logistic regression, random forest, XGBoost, and CatBoost) refined with Bayesian optimisation were employed to predict household recycling motivation. The findings reveal a low RDR of 0.37%, indicating that only approximately 2.47% (31,554.25 metric tonnes) of recyclables are recovered annually compared to a targeted 50% (638,750 metric tonnes). The optimised CatBoost model (accuracy and F1 score of 0.79) identified collection time and the absence of overflowing HSR bins as key motivators for household recycling via the SHapley Additive exPlanations (SHAP) framework. This study concludes that current LRI efforts are insufficient to meet recycling targets. It recommends expanding recovery efforts and addressing operational challenges faced by registered recyclers to improve recycling outcomes. The policy implications of this study suggest the need for stricter enforcement of recycling regulations, coupled with targeted financial incentives for both recyclers and households to boost recycling participation, thereby enhancing the overall effectiveness of waste diversion efforts under the LRI. This research provides a benchmark for assessing urban recycling initiatives (RIs) in rapidly growing African cities.

Keywords: recycling diversion rate; municipal solid waste; Lagos recycle initiative; machine learning; SHAP; Bayesian optimisation

1.0 Introduction

Waste is generally defined as any material for which the generator has no further use either for the purpose of production, transformation, or consumption and is therefore discarded [1,2]. According to the recent report of the United Nations Environment Programme (UNEP), global municipal solid waste (MSW) generation is projected to increase from ~2.1 billion tonnes in 2020 to ~3.8 billion tonnes in 2050. The report shows Sub-Saharan Africa (SSA) as the region with the highest proportion of uncontrolled disposal (open dumping and open burning) of MSW in the global waste stream [3,4]. The implication of this is that, as industrialisation and urbanisation rates increase in SSA, the upsurge in MSW volume will cause a rise in the global share of uncontrolled disposal from the region [3]. In many developing countries (DCs) (countries with low levels of economic growth and inadequate technical and social infrastructures [5] like those in the SSA region), the uncontrolled disposal of MSW is primarily in unsanitary landfills without the segregation of recyclables from non-recyclables [6,7,8,9]. The disposal of co-mingled MSW in unsanitary landfills poses a threat to human health and the environment [10]. Moreover, the constraint of land for the construction of new landfill facilities in the urban areas of DCs is becoming more pronounced even as the current landfills are reaching their full capacity, which is further exacerbating the poor management of MSW in SSA and particularly in Nigeria [11]. Nigeria's population was estimated at ~220 million as of 2022 [12], and is projected to be the third largest country by population globally, surpassing the population of the United States before 2050 [13]. Annual waste generation in Nigeria is ~30 million tonnes, with a paltry collection rate of 20–30% [14]. This implies that about 70% of the national waste stream containing valuable recyclables that could be diverted from landfills is lost through uncontrolled waste disposal. The continued rise in Nigeria's population, among other factors, will cause an exponential rise in the volume of MSW in the coming years. In many Nigerian cities, including Lagos, MSW is disposed of primarily in landfills, which are mostly open dumps [15,16,17]. As of 2020, the population of Lagos, Nigeria's largest city by population, was estimated at ~26 million [18] at a growth rate of ~3.2% higher than the national average of ~2.6% [19]. Lagos residents generate ~14,000 metric tonnes of waste daily [20], out of which ~3500 metric tonnes (25% of the waste stream) are recyclables like plastics, bottles, and paper [21]. At the current population growth rate, the waste management (WM) authority in Lagos would need to gear up efforts to match the pace of MSW collection with the rate of generation, especially prioritising the recovery and diversion of household recyclables (HSR) from its limited number of landfills. The Lagos State Government (LASG) is aware of the current challenges with landfill disposal and has rebranded its previous Blue Box Initiative (BBI) into the Lagos Recycle Initiative (LRI) in December 2020. The aim of

the LRI is to encourage Lagos residents to recycle their waste as a way of contributing to the circular economy (CE) [22]. Using recycling as a tool to mop up recyclables generated through human activities contributes to minimising the impacts of mismanaged waste on the environment [23].

However, when compared to South Africa, Canada, and Australia where national waste diversion rates (WDRs) have been reported as 11% [24], 26% [25], and 64% [26], respectively, there is a paucity of data on Nigeria's WDR, which could have been referenced in this study. Moreover, unlike in China where the national recycling rate is known to be below 20% (National Bureau of Statistics of China, 2023 as cited in [27]), there is no known record of recycling rate in Nigeria. To the best of the authors' knowledge, no studies from any Nigerian city have ever evaluated the effectiveness of recycling initiatives (RIs) in Nigeria. This lack of data is not merely a statistical oversight but represents a significant gap in understanding the effectiveness of RIs in Africa's most populous black nation. The dearth of information is of particular concern, given Nigeria's rapid urbanisation and constant proliferation of MSW generation. Unlike its global counterparts, Nigeria, and indeed most of the Nigerian cities, have not been the subject of rigorous studies in evaluating the effectiveness of recycling programmes. This absence of empirical data hampers evidence-based policymaking and impedes the development of targeted, effective waste management strategies.

Therefore, this study aims to gather evidence on the performance of RIs in Nigeria regarding landfill diversion (LFD) and to identify the significant factors limiting their effectiveness in a bid to propose data-driven solutions. LFD (also known as waste diversion) is the process of reducing the amount of waste sent to landfills through reuse, recycling, composting, and other forms of recovery such as waste-to-energy [28]. It is hypothesised that the current LRI, despite its adoption, has not achieved substantial landfill diversion rates due to operational challenges and insufficient household participation. To test this hypothesis and effectively evaluate the LRI's impact, this research has three specific objectives: (1) to determine the recycling diversion rate (RDR) of HSR in Lagos over a one-year period (January–December 2021); (2) to develop machine learning algorithms that can predict household motivation for recycling participation; and (3) to identify key factors influencing household recycling decisions using the SHapley Additive exPlanations (SHAP) framework. The novelty of this research lies in two key aspects. Firstly, the use of machine learning (ML) algorithms to evaluate the drivers of recycling motivation in Nigeria has not been explored. Secondly, there is a lack of empirical evidence on the performance of a city-wide recycling initiative in Lagos or any other Nigerian city using the RDR as an indicator. By focusing on Lagos, one of the economic hubs in Nigeria and Africa's

largest megacity in terms of population, this study provides a benchmark for assessing urban recycling initiatives in the context of rapidly growing African cities.

2.0 Literature Review

2.1. Recycling in Africa

The environmental impact of landfill disposal has become a critical concern worldwide, particularly in developing regions. RIs play a vital role in diverting waste from landfills, which not only conserves natural resources but also helps mitigate serious environmental risks associated with landfill leachate. Landfill leachate contains four major categories of pollutants: dissolved organic matter, inorganic macro-components, heavy metals, and xenobiotic organic compounds [29,30]. This toxic mixture poses significant threats to groundwater and surface water quality, with ammonia often persisting as a major long-term pollutant even as organic components decrease over time. The environmental hazards posed by landfills are particularly acute in developing nations where approximately 93% of waste ends up in open dumpsites, compared to just 2% in high-income countries [31]. This stark contrast underscores the urgent need for effective recycling programs (RPs) in African nations to reduce landfill dependency.

Several studies on recycling in Africa have focused on waste characterisation and composition analysis, informal waste sector contributions, policy challenges, and opportunities in recycling, as well as public perception and participation [32,33,34,35,36,37]. However, there is a critical gap in empirical assessments that quantify the impact of city-wide RIs on LFD on the continent, compared to the situation in the Global North. A few studies in South Africa [2,38,39] have also conducted an analysis of people's perception of recycling and the determinants of their involvement. While the authors acknowledged the potential of achieving a higher LFD rate through increased investments in recycling infrastructure and more public engagement, as many other studies do, none of the studies presented empirical evidence of the RDR in the areas under consideration in this study. Similarly, a study in Kinshasha, Democratic Republic of Congo [40], analysed seven scenarios to determine the most optimised WM model for the city. After applying the lifecycle assessment approach (LCA), scenario 7, which adopted the process of waste valorisation through various treatment processes proved effective at cutting greenhouse gas emissions by half compared to scenario 4. Additionally, scenario 7 showed the potential to increase LFD rate up to 70%, although at a much higher cost to the city government. This result assumes that waste collection coverage in the city is at the 100% mark and confirms that efforts targeted at optimising the collection system can potentially increase the LFD rate. However, while an assumption like this provides insights for municipal authorities to improve their WM system, they do not replace the need for empirical evidence aimed at determining the actual RDR in a city. Furthermore, Kinobe et al. [41] examined the potential to recover recyclables from the city landfill in Kampala, Uganda using the reverse logistics system (reverse logistics refers to the

pick-up of recyclables from the waste stream by traders who sell them directly to recycling industries). The authors quantified the various fractions of the waste stream at the site and found that a high proportion (about 63%) of recyclables are left in the landfill due to reasons such as limited materials processing power and the absence of a market for the recyclables, among others. This situation revealed existing WM challenges in DCs that prevented effective LFD through recycling. While it is in line with best recycling practice to recover recyclables at the source to achieve higher LFD rates and mitigate greenhouse gas emissions [42], the situation in Kampala further highlights the lingering challenges with MSW collection in Africa that persistently prevent a data-driven approach to determining the RDR of a recycling initiative. Furthermore, Louziz et al. [43], in their assessment of the WM challenges in Morocco, noted that to boost the government's ambition of decreasing waste disposed in landfills, emphasis should be placed on enlightening the citizens on waste sorting at the source to achieve higher LFD. While the study added that collection at the source could potentially reduce landfill disposal by as much as 80%, a realistic analysis of what is diverted under an existing RI can provide reliable data on the effectiveness of such an initiative.

The success of RIs in enhancing LFD rates ultimately depends on infrastructure design that promotes sustainability and social well-being. Gardoni and Murphy [44] emphasised that infrastructure plays a critical role in ensuring community sustainability and resilience, as it directly influences individuals' genuine opportunities to achieve different dimensions of well-being. They proposed a "society-based design" approach that considered not only the technical aspects of infrastructure but also how it affects societal outcomes, particularly for vulnerable populations who often face disproportionate impacts from environmental hazards. Applied to recycling infrastructure in African contexts, this perspective suggests that effective recycling systems must be designed with consideration of social justice elements, ensuring that benefits are equitably distributed and that recovery processes after disruptions provide opportunities for all community members. This holistic approach to recycling effectiveness connects the technical aspects of waste diversion with broader societal goals of sustainability and equitable development.

Recycling Effectiveness

The effectiveness of an RI or RP can be quantified using the recycling rate (RR), which can also take the form of WDR depending on how a country defines it [25,45,46]. WDR is the amount of waste diverted from disposal in landfills divided by the total amount of MSW generated, expressed as a percentage [45]. Waste diversion from landfills can be achieved through recycling, composting, or reuse [47], including waste-to-energy (WTE) [26]. The RR, also expressed as a

percentage, is the amount of waste materials recycled from the total recyclables collected for diversion [47]. WDR is calculated as follows:

$$\text{WDR} = \frac{\text{Total Waste Diverted (recycling + reuse + compost + other forms of recovery)}}{\text{Total Waste Generated}} \times 100\%$$

While WDR is a holistic measure of LFD, as shown in the above formula, it is possible to specifically assess only the recycling component, as shown in a study conducted in New York City (NYC) [48]. In that case, the study addressed the RDR, which is the proportion of the MSW stream that was collected for the purpose of recycling, expressed as a percentage [48]. In essence, the RDR is a component of the overall WDR. To incorporate this into the above formula, this is expressed as follows:

$$\text{RDR} = \frac{\text{Total waste diverted for recycling}}{\text{Total Waste Generated}} \times 100\%$$

In the NYC study [48], a city-wide assessment of 59 community districts was carried out by computing the tonnage per day of recyclables diverted for recycling in each district over the total waste generated. The resulting figure was then expressed as a percentage to determine the RDR for each district. In the current research, the LRI does not include the capture of materials diverted through composting, reuse, or WTE. Hence, the calculation is focused on the recycling component in the formula to determine the RDR, which aligns with the methodology used in the NYC study. A few studies have carried out a percentage quantification of HSR diverted from landfills. For example, Ali et al. [49] quantified fractions of MSW in Peshawar city in Pakistan, South Asia and obtained the value of 13.71% as the city's WDR. The authors found that whereas the amount of recyclables, reusable materials, and organic components in the waste stream with a high potential for diversion was ~70%, ~86.8% were disposed of in landfills without recovery [49]. Like the work of Ali et al. [49], in Kumasi, Ghana, West Africa, Wahabu et al. [50] equally quantified the fractions of MSW diverted from landfills. In their study, they examined the impact of the Pay-As-You-Throw (PAYT) economic instrument on the amount of waste diverted from landfills through communal collection points where informal waste pickers are operating. Their findings showed that with the implementation of the PAYT, the deposit of HSR at the collection points was reduced. It was revealed that for each waste picker studied at the seven communal collection points, there was a contribution of ~6 metric tonnes of diversion rate of recyclables from landfills. When compared to the findings from the Pakistani study, it was observed that

~70% of the recyclables in the waste stream had the potential to be recovered and diverted from landfills. The Ghanaian study further noted that if the efforts of the waste pickers are aggregated across one hundred collection points, ~300 tonnes of recyclables could be diverted from landfills within a year [50].

Another study from London [46], United Kingdom, reported on home composting, an organic recycling process. In that study, a quantitative assessment of survey data obtained from 64 homeowners involved in home composting showed 20% WDR of biodegradable waste from landfills. Although the London study was carried out on a small scale, nonetheless, it contributed to the discourse on LFD, which can be applicable to many countries in SSA where the organic component of the MSW stream is the highest compared to other MSW fractions [51,52]. In another research study carried out in Brazil, South America, before the introduction of a private RI in a residential complex, all waste was landfilled with a zero per cent WDR. However, with the application of reverse logistics, coupled with effective implementation and monitoring over ten years, 67% of the total waste volume in the complex was diverted from landfill. This was achieved at no cost to the municipal government, nearly meeting the targeted 70% diversion rate [53]. The reverse logistics approach used in the Brazilian study is like the situation in many SSA cities, including Lagos, where the trade in recyclables is common.

In two Australian states (New South Wales and Victoria), a survey of some residential projects in the construction and demolition (C & D) sector showed a WDR of ~95% in each project compared to the Australian WDR average of ~64% [26]. However, while the study emphasised the significance of using WDR in assessing WM performance, the authors noted that the high WDR recorded in the study could not be guaranteed due to the non-reliability of waste data used for the analysis [26]. A study carried out by Pan et al. [25] in Canada, applied three novel metrics, which included WDR to assess the effectiveness of non-hazardous waste diversion models of public and private WM services in four Canadian provinces. The results of a time-series analysis used in the study showed that British Columbia had the highest average diversion rate of 32.7%. In their study, the authors suggested that WDR could be combined with other indicators in determining the effectiveness of an RI [25]. It is pertinent to note from these studies that in SSA, aside from the Ghanaian study where WDR among informal waste pickers was quantified, there is a lack of research on the effectiveness of city-wide RIs in SSA region, including Nigeria; hence, this study attempts to fill the research gap.

Beyond the environmental benefits of LFD, RIs can also create economic value through resource recovery. Yadav et al. [54] demonstrated that various types of waste—agricultural, industrial, and domestic—can yield valuable minerals and materials when properly processed. For instance,

agricultural waste like rice husks and sugarcane bagasse can be sources of silica, while incense stick ash and eggshell waste can yield calcium-related products. In the context of SSA countries, where organic waste constitutes the highest fraction of MSW compared to other components [49], there are significant opportunities for value creation through composting and biofuel production. Such value-added approaches to waste management align with CE principles and could enhance the economic viability of recycling initiatives in African urban centres.

ML has recently started gaining traction for waste management applications globally. The implementation of smart city technologies offers promising solutions to waste management challenges in Africa. Kontokosta et al. [55] demonstrated that high spatial resolution waste generation estimates can significantly improve collection efficiency in urban environments. Their research developed an ML and small area estimation approach to predict waste generation at the building level in NYC, allowing more efficient collection routing and better targeting of behaviour change initiatives. This approach is particularly relevant for African cities facing rapid urbanisation and increasing waste volumes.

Chen [56] further explored how ML techniques combined with Internet of Things (IoT) technologies can enhance waste recycling processes in smart cities by automatically classifying and separating materials. The proposed Automatic ML-Based Waste Recycling Framework (AMLWRF) demonstrated the potential for IoT-powered devices installed in waste containers to provide real-time data on waste generation behaviour, achieving significant improvements in accuracy (96.1%), efficiency (97.1%), and recycling rates (91.6%) compared to conventional methods.

Building on these approaches, Erkinay Ozdemir et al. [57] comprehensively reviewed different ML algorithms being applied to recycling systems. They found that various algorithms including convolutional neural networks (CNNs), support vector machines (SVMs), decision trees, k-Nearest Neighbour (k-NN), and artificial neural networks (ANNs) have been successfully implemented in waste sorting and classification with accuracies often exceeding 93%. These algorithms have proven particularly effective in the separation of recyclable materials such as paper, plastic, metal, and glass, which is a critical step in improving recycling rates. As the authors noted, “The recycling rates are continuously increasing; however, assessments showed that humans will be creating more waste than ever before” [57], highlighting the urgent need for more efficient recycling systems powered by ML.

Despite the demonstrated effectiveness of ML applications in WM in developed countries—from predictive waste generation modelling to automated sorting and recycling—these technologies have rarely been applied in the African context, particularly for predicting household motivation

for recycling. This represents a significant gap, as understanding the factors that drive recycling behaviour at the household level could inform more effective policies and interventions to increase recycling rates across Africa's rapidly growing urban centres.

The review of these studies highlights a significant research gap in Africa, particularly regarding the evaluation of city-wide RIs. While the Ghanaian study by Wahabu et al. [50] quantified WDRs among informal waste pickers, there is a notable lack of comprehensive research on the effectiveness of large-scale RIs in African countries, including Nigeria. This scarcity of data and analysis presents a critical challenge in understanding and improving WM practices across the region. The present study aims to address this research gap by providing a detailed assessment of the LRI, a city-wide programme in Nigeria's largest metropolis. Analysis of the extant literature on waste recycling in Africa further strengthens our position that there is currently a lack of empirical evidence on the evaluation of recycling initiatives on the continent. This study, rather than focusing on general WM discussions, closes this gap by providing a data-driven evaluation of the LRI, estimating the RDR and analysing the key factors for recycling motivation using ML techniques.

3.0 The Lagos Recycle Initiative

There had been other RIs in Lagos before the launch of the LRI. For example, in 2017, when the Environmental Management Protection Law of Lagos was signed into law, the Clean Lagos Initiative (CLI) was introduced by a former governor of Lagos State to achieve a more sustainable and cleaner Lagos [58]. Although the CLI had its own gains and challenges, it was short-lived and was replaced by the BBI, which was launched by the incumbent governor in 2019. The focus of the BBI was to ensure the capture of 50% of recyclables in the waste stream by 2021 through the source separation of domestic waste using two colour-coded bags: a blue bag for recyclables and a black bag for non-recyclable waste [20]. It is interesting to note that while the BBI was yet to become fully operational, it was rebranded into the LRI. The LRI aims to address the challenges of plastic pollution through recycling and the use of a financial incentive system to encourage participation. While the use of a financial tool to spur motivation for recycling has been widely used, a study in China showed that its effectiveness remains unclear [59]. During the launch of the initiative, the officials of the Lagos State Waste Management Authority (LAWMA) noted that Lagos State has limited landfill space, hence the need to proactively step up the recovery efforts on the collection of recyclables from the waste stream to reduce the amount of waste going to the landfills [60]. The initiative started as a pilot scheme in some organised housing estates in Lagos, where recyclables (mainly plastics) were collected in receptacles provided by LAWMA and sorted for sale to off-takers who processed them into other

products [60]. The locations selected for the pilot scheme were the Lagos State Development and Property Corporation (LSDPC) Estates at Adeola Odeku, Victoria Island; Glover Street, Ebute Meta, and Akerele, Surulere. The rationale for the choice of these locations could probably be due to the organised nature of estate developments, which made such a scheme easier to test. As at the beginning of the second quarter of 2021, the programme had been extended to 42 Local Council Development Areas (LCDAs) out of the 57 LCDAs in the state with 48 recyclers who carried out the door-to-door collection of recyclables [22] (Figure 1). Although LAWMA stated that there are plans to extend the initiative to other LCDAs, we could not confirm how many more had been added at the time the field survey was carried out.



Figure 1. A tricycle and receptacle for recyclables [61].

In 2021, the LAWMA commissioned ~400 aggregators at Olusosun landfill (the city's largest landfill site), to ensure the proper aggregation of recyclables [21]. It is imperative to note that

according to the LAWMA website, collectors of recyclables (registered recyclers) also function as aggregators. This information was further confirmed via a phone call with one of the registered recyclers.

The Pakam App

The Pakam app (PA) is an innovative approach to household recycling in Lagos. It connects all the stakeholders working on the LRI together—the households, recyclers (aggregators), and LAWMA [21]. According to LAWMA’s video explanation via its Instagram handle [62], to use the PA as a collector, an individual requires authorisation from a registered recycling company, after which an identity card would be issued. As soon as this procedure is completed, available recyclables in households can be picked up via a “pick up task” button in the app. Depending on the collector’s choice, specific tasks or all tasks can be accepted. An aggregator (or collector) is deemed to have completed the pickup of HSR once the recyclables are weighed in kilograms, and the data are transmitted to the LAWMA waste database via the PA. Households who do not use the PA to place their collection requests have the opportunity to bring their sorted HSR to community recycling centres (CRCs) operated by aggregators for weighing and payment. This ensures wider coverage for the collection of recyclables, especially for those who are not digitally savvy. Since the app is not utilised in this case, the aggregators collate the total number of collected recyclables at their CRCs and send the data manually to LAWMA after weighing. The app contains a wallet through which households can request payment from collectors for the recyclables collected from them by filling in their bank details. The amount due for payment is easily determined as the app automatically calculates the value of the recyclables. In situations where a recycler cannot meet up with a collection request due to a busy schedule, LAWMA has a backup collection plan (Figure S1) in all the 20 local government areas (LGAs), and this is to ensure that no HSR available for pick up is left uncollected. This information was confirmed during an interview with LAWMA’s Central Head of Recycling. All collated recyclables are then sold to off-takers for processing in recycling facilities.

4. Results and Discussion

4.1. Analysis of Data from the Recyclers

In this section, the results of two datasets are presented—one from the recyclers in Section 4.1 and the other from the households in Section 4.2. This is to ensure a clearer presentation of findings from the two stakeholders, given that two sets of questionnaire surveys were administered.

4.1.1. Distribution of the Collectors

Figure S2 illustrates the distribution of collectors of HSR across the studied areas. The data revealed that Surulere and Agege have the highest number of collectors, with three collectors each, while Eti-Osa has the lowest representation, with one collector. The equal distribution between Surulere and Agege may indicate a balanced approach to recycling implementation in these areas, which represent a mix of residential and commercial zones. This parity might reflect similar waste generation patterns or equally effective local implementation strategies in these LGAs. As noted earlier, the collectors surveyed in the three LGAs were names given to us by the Central Head of Recycling of LAWMA. Inappropriately, unlike Agege and Surulere, only one recycler appeared to be active in Eti-Osa LGA as of the time of the field survey. This could be due to Eti-Osa's status as a high-income area with a predominantly busy working-class population who may not have the time or motivation to sort recyclables. Unlike areas such as Agege and Surulere, where there are more recyclers because there are probably more people interested in trading in recyclables, Eti-Osa has shown relatively low engagement in this practice.

4.1.2. Waste Bin Distribution Coverage

Figure S3 demonstrates the waste bin distribution coverage for recyclable waste storage across the studied areas. The majority of collectors (57.1%) reported a coverage between ~50% and 79%, indicating a substantial progress in establishing recycling infrastructure at the household level. However, 28.6% of collectors reported no involvement in bin distribution, suggesting potential gaps in implementation or areas where distribution was deemed unnecessary. A smaller portion (14.3%) reported coverage below 49%, highlighting areas that might require additional attention. Markedly, no collectors reported coverage of 80% or above, indicating that there was room for improvement even in well-served areas. These findings underscore both the achievements and challenges of the LRI's bin distribution efforts, providing insights for targeted improvements to enhance recycling participation and LFD rates.

4.1.3. Waste Collection Frequency

The frequency of waste collection in the studied areas revealed significant patterns, as shown in Figure S4. A large majority of waste collectors (71.4%) conducted daily collections, indicating a high frequency of service. This may reflect the substantial volume of recyclable waste generated in these urban areas. In contrast, a smaller portion (14.3%) of collectors reported weekly collections, which might be attributed to lower waste generation in certain areas or logistical challenges that hinder daily collection. Additionally, 14.3% did not provide data on collection frequency, potentially indicating inconsistent collection schedules. The dominance of daily waste collections suggested that the initiative aims to maintain a consistent and frequent

waste removal service, a critical factor in encouraging continued participation in recycling and managing urban waste effectively. Nevertheless, the observed variation in collection frequency underscores the need for adaptable WM strategies to address the specific needs of different areas in Lagos.

4.1.4. Truck Capacity and the Weekly Volume of HSR Collected

Figure S5 presented the comparison between total truck capacity and the weekly volume of HSR waste collected by each collector. The data revealed noticeable variations among collectors in both their truck capacities and collection volumes. Collector 2 stands out with the highest truck capacity (75 metric tonnes) and weekly collection volume (62.5 metric tonnes), indicating efficient resource utilisation. Most collectors demonstrated underutilisation of their truck capacities, with weekly collection volumes significantly lower than their potential capacity. This disparity is particularly notable for collectors 6 and 7, who had substantial truck capacities (60 and 15 metric tonnes, respectively) but collected only 2.0 and 0.5 metric tonnes weekly. Interestingly, collector 5 did not provide a response regarding truck capacity during data collection but reported a weekly collection volume of 0.5 metric tonnes, suggesting possible use of alternative collection methods or data reporting inconsistencies. These findings highlighted opportunities for optimizing resource allocation and improving collection efficiency across the initiative, potentially through better route planning, increased community engagement, or reallocation of resources to match actual collection needs in different areas.

4.1.5. HSR Material Type Collected

The distribution of collectors by HSR material type revealed distinct patterns in the material collection (Figure S6). Plastics were the most frequently collected material, with all collectors (100%) participating in their collection. Used beverage containers (UBCs) followed, with five collectors (71.4%) engaged in their collection, while four collectors (57.1%) handled paper. Glass was collected by only three collectors (42.9%), indicating it was less commonly targeted. The prominence of plastics in collection efforts highlights their significance in the urban waste stream and their central role in the recycling economy. The variations in collection across other materials likely reflected differences in material prevalence, recyclability, market demand, or processing capacity. These findings suggest potential opportunities to expand and diversify recycling efforts, capturing a wider range of materials and enhancing the effectiveness of the LRI.

4.1.6. HSR Collected Versus Targeted

Figure 2 illustrates the actual versus target monthly HSR waste collection for each collector in the LRI, measured in metric tonnes. The data showed significant variations in both collection targets and performance across collectors. Collector 2 demonstrated optimal performance, achieving 100% of their substantial 250-metric tonnes target. Similarly, collectors 3 and 6 also reached 100% of their targets, collecting 10 and 8 metric tonnes, respectively. However, other collectors showed varying degrees of underperformance. Collector 4 achieved 30% of their target, collecting 6 out of 20 metric tonnes, while collector 7 met 20% of their goal, gathering 2 out of 10 metric tonnes. The most notable discrepancies were observed with collectors 1 and 5; collector 1 achieved only 0.64% of their target, collecting 0.96 metric tonnes against a substantial 150-metric tonnes goal, while collector 5 reached 6.67% of their target, gathering 2 out of 30 metric tonnes. These disparities highlighted the challenges in setting and achieving collection targets across different areas or operational contexts within Lagos. The data suggests a need for reviewing and potentially adjusting targets, as well as investigating and addressing factors contributing to underperformance in some areas to enhance the overall effectiveness of the RP.

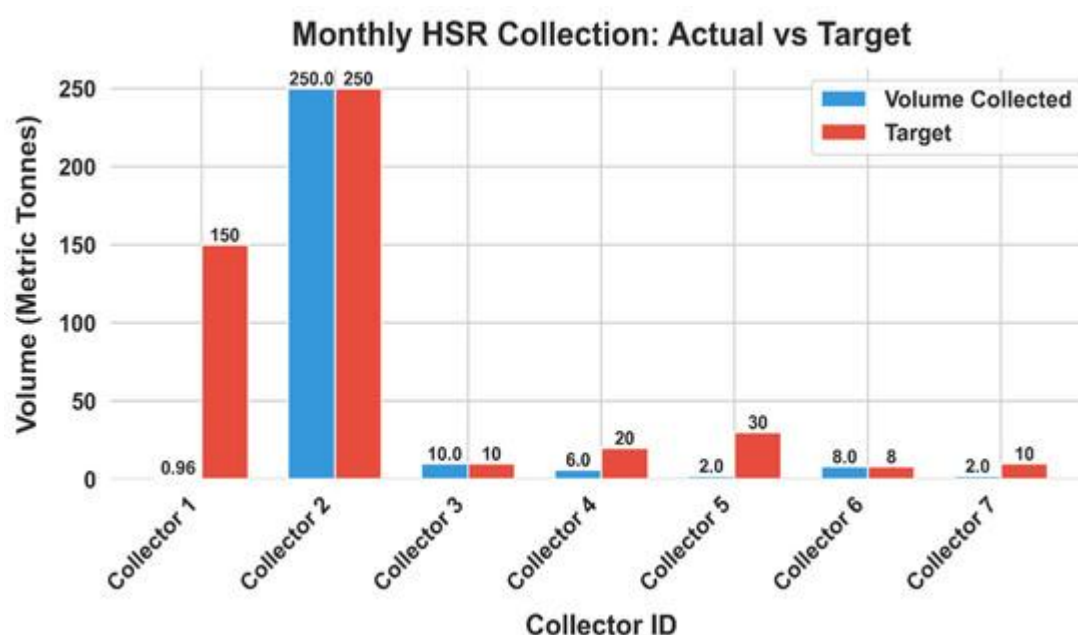


Figure 2. Actual and target monthly HSR collections.

4.1.7. Challenges Faced by the Collectors

The distribution of challenges encountered by collectors in the LRI revealed several critical issues, as depicted in Figure S7. Logistics is the most common challenge, affecting 57.1% of collectors, and reflecting significant operational difficulties in waste collection and

transportation. Additionally, two challenges—lack of awareness and extortion by hoodlums—were reported by 28.6% of collectors, indicating substantial barriers related to community engagement and security. Other challenges affecting 14.3% of collectors, include a range of issues such as insufficient funds, inadequate equipment, competition, corruption, multiple taxation, inability to meet set-targets, inadequate storage, non-inclusivity, and lack of truck ownership. This wide variety of challenges highlights the complexity of implementing an efficient RP. While logistics appeared to be a common issue, many other challenges might be more localised or specific to individual collectors. The diverse nature of the challenges underscores the need for a comprehensive, multi-faceted approach. Hence, to address the underperformance of recyclers under the LRI, policymakers could provide financial support, leverage data-driven approaches to optimise collection logistics, and invest in the waste-sorting infrastructure to improve the operational efficiency of the recyclers.

4.1.8. Estimation of the RDR

In estimating the RDR from the formula stated earlier, the total annual tonnage of HSR collected from the three LGAs was divided by the estimated total waste (annual) generated in the LGAs in 2021 (the assessment year). The total tonnage (annual) was obtained by converting the weekly tonnage collected by each recycler to an annual figure (Table 1). This compares well with the methodology used in the NYC study [48] where an average daily tonnage (ADT) of HSR and ADT of the total waste generated in each of the 59 districts was cumulated to annual figures to arrive at an estimate of the RDR for each district. The data used in the NYC study were obtained directly from the city's sanitation department. In the current research, since the data on the total waste generated in the LGAs in 2021 were not available, the 2019 population figures from the Lagos Bureau of Statistics (LSBS) [63] were extrapolated to estimate the 2021 population for each LGA using the geometric growth model formula $[P_t = P_o (1 + r)^t]$ [64]: where P_t is the projected population at time, t ; P_o is the initial population; r is the annual growth rate expressed as a decimal; and t is the number of years into the future.

Table 1. The tonnage of recyclables collected by recyclers in the three LGAs.

Respondent's ID	Weekly Tonnage (Metric Tonnes)	Estimated Annual Tonnage (Metric Tonnes)
Collector 1	0.24	12.48
Collector 2	62.5	3250
Collector 3	2.5	130
Collector 4	1.5	78
Collector 5	0.5	26
Collector 6	2	104
Collector 7	0.5	26

This method is commonly used in demographic and WM studies for estimating population over short periods [64,65,66]. The total daily waste generated in each LGA in 2021 was then estimated by multiplying the 2021 population of the LGAs with the waste per capita/day for Lagos (0.51 kg/capita per day), which is the average for cities in SSA [3,67]. The resultant data were converted to annual values and summed up for the RDR calculation. The estimated RDR from the three LGAs was 0.37% (this represents the proportion of HSR in the annual MSW waste stream in Lagos that was diverted from landfills in 2021). This implies that of the officially reported 3500 metric tonnes per day of recyclables (1,277,500 metric tonnes/year) in the waste stream, the three LGAs contributed to the recovery and potential diversion of ~4730 metric tonnes of HSR from landfills in one year. Assuming the data are taken as a yearly average for every three LGAs in Lagos, cumulatively, it means recyclers in the 20 LGAs could potentially recover about 31,554.25 (2.47%) metric tonnes of HSR from the estimated 1,277,500 metric tonnes/year of HSR in the waste stream. This assumption may not hold true for all the LGAs due to factors like the number of recyclers in each LGA and their operational efficiency, among other considerations. In any case, it showed that the LRI, if well monitored, can continue to contribute to increasing LFD rate for recyclables. However, comparing the 2.47% with LAWMA's targeted recovery of 50% (638,750 metric tonnes/year) of recyclables from the waste stream by June 2021, this figure is far below the projection and calls for an urgent review of the city's approach to the recovery of HSRs.

Undoubtedly, it is possible that sometimes targets set by municipal waste authorities might be confronted with challenges which impeded the achievement of the recycling targets. For instance, in the study carried out in NYC [48], the city sanitation department in New York (whose role was

closely comparable to that of LAWMA in Lagos) had targeted the recovery of about 50% recyclables from the city's daily waste generation of 13,000 metric tonnes [68]. Due to the sudden changes made to the city's recycling programmes by the government, among other reasons; recycling participation dropped, and that negatively impacted the RDR bringing it below the previous rates. It is worth noting that the sanitation department did a lot regarding the education of the public on RIs. Also, it was ensured that recyclables were collected consistently weekly from the neighbourhoods within the city, all in a bid to strengthen recycling participation. Although NYC has a lower population and a more advanced WM system compared to Lagos, the waste generation per day and recycling target were related. While Lagos residents generated ~14,000 metric tonnes of MSW per day, LAWMA aimed to have achieved a recycling target of 50% since 2021, but this is way below the projection, given the abysmally low RDR from the three LGAs. Despite the challenges discussed in the NYC study, RDR values ranging from 9% to 31% were achieved in each of the 59 districts, while about 20% was realised for the entire NYC compared to 0.37% from the three LGAs in Lagos and the hypothetical 2.4% from all the LGAs. This indicated that the challenges could be surmounted. Aggregating the collection efforts of recyclers across the 20 LGAs in Lagos, like the projected combined efforts of waste pickers studied by Wahabu et al. [50], could contribute substantially to increasing the tonnage of recyclables collected in Lagos. To raise the RDR above current rates, as highlighted in the preceding section, the challenges faced by the recyclers need to be addressed. A good starting point could be LAWMA's increased engagement with its registered recyclers to understand critical challenges limiting their collections below monthly targets and finding joint solutions.

4.2. Analysis of Data from the Households

4.2.1. Profile of the Respondents

The demographic profile of household respondents in the LRI is presented in Figure S8. Regarding the age distribution, the majority of respondents (58.0%) fall within the 30–49 age group, indicating a strong representation of working-age adults. This was followed by the 50–64 age group at 23.5%, suggesting significant participation from older adults as well. Younger adults (18–29) comprised 14.3% of respondents, while those at 65 and above represented 4.2%, showing a diverse age range in the study. Figure S8b revealed a highly educated sample, with 66.9% of respondents having attained tertiary education. Secondary school certificate holders made up 24.6% of the sample, while 8.5% had primary school certificates. The educational profile suggested that the initiative had engaged a predominantly well-educated segment of the population. The working status of respondents showed a diverse distribution. Full-time workers constituted the largest group at 38.8% of the sample, followed closely by those who owned

businesses at 27.6%. The two categories accounted for 66.4% of respondents, representing a significant majority of employed and self-employed individuals. Part-time workers made up 12.9% of the sample, while those not working represented 14.7%. Job applicants constituted the smallest group at 6.0%. The distribution reflected a broad mix of employment statuses among participants in the RI, with a strong representation of full-time workers and business owners, balanced by a notable presence of part-time workers, unemployed individuals, and job seekers.

4.2.2. Data Preprocessing

In this study, a total of 137 questionnaires were distributed to the households of which 127 were considered valid for analysis. Many studies have also used similar data sizes to build efficient ML models in different domains [69,70,71]. Table 2 presents a detailed overview of the variables used in the analysis, including their codes, descriptions, data types, and unique values. The data preprocessing involved careful encoding of variables and standardisation to ensure optimal analysis [72,73], as follows:

Table 2. Encoding and description of the datasets.

Variables	Codes	Description	Type	Unique Values
Age	Age	Age of the respondent	Ordinal	18–29 (1) 30–49 (2) 50–64 (3) 65 and above (4)
Working status	Wks	Employment status of respondent	Categorical	Full-time worker Part-time worker Not working Own business Job applicant
Educational level	Edl	Highest educational level of respondent	Ordinal	Pry. Schl. cert. (1) Sec. Schl. cert. (2) Tertiary inst. (3)
LRI awareness	Aws	Awareness of respondent about LRI	Binary	Yes (1) No (2)
Type of waste sorted	Tws	Types of HSR sorted by respondent	Categorical	Plastics Paper UBCs Glass

Frequency of HSR pick up	Fwp	Frequency of HSR collection	Ordinal	Once in 3 weeks (1) Once in two weeks (2) Once a month (3) Once a week (4) Twice a week (5)
No overflow of HSR bin	Nob	Respondent's agreement with statement that HSR bin does not overflow	Ordinal	Strongly agree (5) Agree (4) Neutral (3) Disagree (2) Strongly disagree (1)
Regularity of HSR collection	Rwc	Whether HSR collection is regular	Binary	Yes (1) No (2)
Adequacy of HSR bin received	Awb	Whether HSR bin received by respondent is adequate	Binary	Yes (1) No (2)
Service quality during HSR collection	Sqc	Rating of service quality during HSR collection	Ordinal	Excellent (3) Fair (2) Poor (1)
Communication quality during HSR collection	Cqc	Rating of communication quality during HSR collection	Ordinal	Excellent (3) Fair (2) Poor (1)
Usage of Pakam app	Upa	Whether respondents use Pakam app during HSR collection	Binary	Yes (1) No (2)
HSR weighing at collection point	Hwc	Whether collectors weigh HSR at collection point	Binary	Yes (1) No (2)
Perception of household about recycling	Phr	Whether household perceives recycling as beneficial	Binary	Yes (1) No (2)
Perception of recycling productivity	Prp	Whether household perceives recycling as productive/time wasting	Binary	Yes (1) No (2)
Societal influence on recycling	Sir	Whether societal views on importance of recycling influence respondent's recycling behaviour	Binary	Yes (1) No (2)
HSR collection time	Hct	Whether the time of HSR collection is regular	Binary	Yes (1) No (2)
Motivation to recycle	Mtc	To assess if respondents are motivated to recycle or not	Binary	Yes (1) No (2)

1. Ordinal data: Variables such as age, education level (Edl), frequency of HSR pick up (Fwp), no overflow of HSR bin (Nob), service quality during HSR collection (Sqc), and communication quality during HSR collection (Cqc) were encoded using label encoding. This method assigned numerical values to ordered categories, preserving the inherent order of the data (Table 1).
2. Binary data: Variables like LRI awareness (Aws), regularity of HSR collection (Rwc), adequacy of HSR bin received (Awb), usage of Pakam app (Upa), HSR weighing at collection point (Hwc), perception of household regarding recycling (Phr), perception of recycling productivity (Prp), societal influence on recycling (Sir), HSR collection time (Hct), and motivation to recycle (Mtc) were encoded as binary values (1 for Yes, 0 for No).
3. Categorical data: For variables such as working status (Wks) and type of waste sorted (Tws), one-hot encoding was employed. This technique created separate binary columns for each category, allowing for non-ordinal categorical data to be effectively used in various analytical models.
4. Data standardisation: After encoding, numerical features were standardised to ensure all variables contribute equally to the model and to improve the convergence of ML algorithms. The standardisation process involved scaling the features to have a mean of 0 and a standard deviation of 1, using Equation (1):

$$X_{standardized} = \frac{(X - \mu)}{\sigma} \quad (1)$$

where X is the original feature vector; μ is the mean of the feature; and σ is its standard deviation.

4.2.3. Results of the ML Models

The performance of the base and optimised ML models on the testing dataset is presented in Table 3 and Table 4, respectively. Among the base models, CatBoost demonstrated the highest performance across all metrics, achieving an accuracy, weighted precision, weighted recall, and weighted F1 score of 0.75. LR showed moderate performance with an accuracy of 0.67 and a weighted F1 score of 0.68. In contrast, RF and XGBoost models exhibited lower performance, with accuracies of 0.50 and 0.51, respectively, and a weighted F1 score of 0.53. These results suggested that, without optimisation, CatBoost was the most effective in capturing the underlying patterns in the household recycling behaviour data. The application of the BO algorithm led to substantial improvements in the model performance across all algorithms. Table 3 showed that

the optimised models achieved consistently higher metrics compared to their base counterparts. Interestingly, LR + BO, RF + BO, and XGBoost + BO all converged to an identical performance level, with accuracy, weighted precision, weighted recall, and a weighted F1 score of 0.75, matching the performance of the base CatBoost model. This convergence suggested that the dataset might have inherent characteristics or limitations that cap the predictive power at that level for most models. It could indicate that the algorithms when optimised were capturing similar underlying patterns in the data, possibly reaching the maximum predictive capacity given the available features and data quality [74,75]. The optimised CatBoost model (CatBoost + BO), however, managed to surpass that apparent threshold, achieving the highest overall performance with an accuracy of 0.79 and a weighted F1 score of 0.79. These findings underscored the importance of hyperparameter optimisation in enhancing model performance and demonstrated that CatBoost, when optimised, provided the most accurate predictions for household participation in the LRI. The superior performance of CatBoost + BO might be attributed to its ability to handle categorical variables effectively and its robust handling of complex interactions within the data [75,76].

Table 3. Results of the base models on the testing dataset.

Models	Accuracy	Weighted Precision	Weighted Recall	Weighted F1 Score
LR	0.67	0.70	0.67	0.68
RF	0.50	0.62	0.50	0.53
XGBoost	0.51	0.63	0.50	0.53
CatBoost	0.75	0.75	0.75	0.75

Table 4. Results of the optimised models on the testing dataset.

Models	Accuracy	Weighted Precision	Weighted Recall	Weighted F1 Score
LR + BO	0.75	0.75	0.75	0.75
RF + BO	0.75	0.75	0.75	0.75
XGBoost + BO	0.75	0.75	0.75	0.75
CatBoost + BO	0.79	0.78	0.79	0.79

Figure S9 presented the precision–recall curves for the four optimised models. The precision–recall curve is a valuable tool for evaluating the performance of classification models, especially in scenarios with imbalanced datasets. It plotted the trade-off between precision (the proportion of true positive predictions among all positive predictions) and recall (the proportion of true positive predictions among all actual positive instances) at various classification thresholds. The average precision (AP) score, shown in parentheses for each model, represented the area under the precision–recall curve. Higher AP scores indicated better overall performance. In this case, LR + BO and CatBoost + BO showed the highest AP of 0.87, followed closely by XGBoost + BO (0.85) and RF + BO (0.81). The curves for all models started at high precision and low recall, gradually decreasing in precision as recall increases, which was the typical pattern for precision–recall curves. Comparing the models, CatBoost + BO (red line) maintains the highest precision across most recall values, indicating robust performance. LR + BO (blue line) showed a strong performance, particularly at lower recall values where it maintained very high precision. XGBoost + BO (green line) performed well, often matching or closely trailing the top performers, while RF + BO (orange line) generally showed lower precision compared to the other models, especially at higher recall values.

4.2.4. Factors Influencing Household Motivation to Recycle

The SHAP analysis of the best-performing model, CatBoost + BO, provided valuable insights into the factors that most significantly influence household motivation to participate in the LRI. Figure 3 and Figure 4 illustrated the importance of the feature and its impact on the model’s predictions for the top 20 features, respectively. The Hct emerged as the most influential factor by a significant margin, suggesting that the regularity of waste collection services plays a crucial role in motivating households to participate in recycling programmes. The timely collection of waste is essential in the WM process [77]. Where there is an irregularity in the collection, bins tend to overflow and can result in the inappropriate segregation of recyclables at the source [78]. When this happens repeatedly, households may become demotivated to recycle over time. Following Hct, the next most important features are the Nob, Upa, and Phr. These factors underscore the importance of proper WM infrastructure, technology adoption, and household attitudes toward recycling in driving participation behaviour. Regarding the essence of WM infrastructure, one study [79] observed that the availability of waste segregation facilities tend to improve waste sorting, thereby improving the separate collection of recyclables. The visualisations also revealed that Edl, Fwp, and age had moderate impacts on recycling participation. Interestingly, the employment status, particularly part-time work (Wks_Part time worker), showed a notable influence, ranking higher than some service-related factors. Sqc, Aws,

and Cqc showed relatively minor influences yet still contributed to the model's predictions. It is pertinent to note that while the two dominant factors of Nob and Hct may be peculiar to the situation in Lagos under the LRI, some scholars in SSA have identified other significant factors such as household income, formal education, access to social grants, and age as motivators of recycling participation [80]. This implies that under diverse conditions and circumstances, people's motivations for recycling might differ. As such, it is essential to understand the local situation when making policies aimed at improving recycling outcomes.

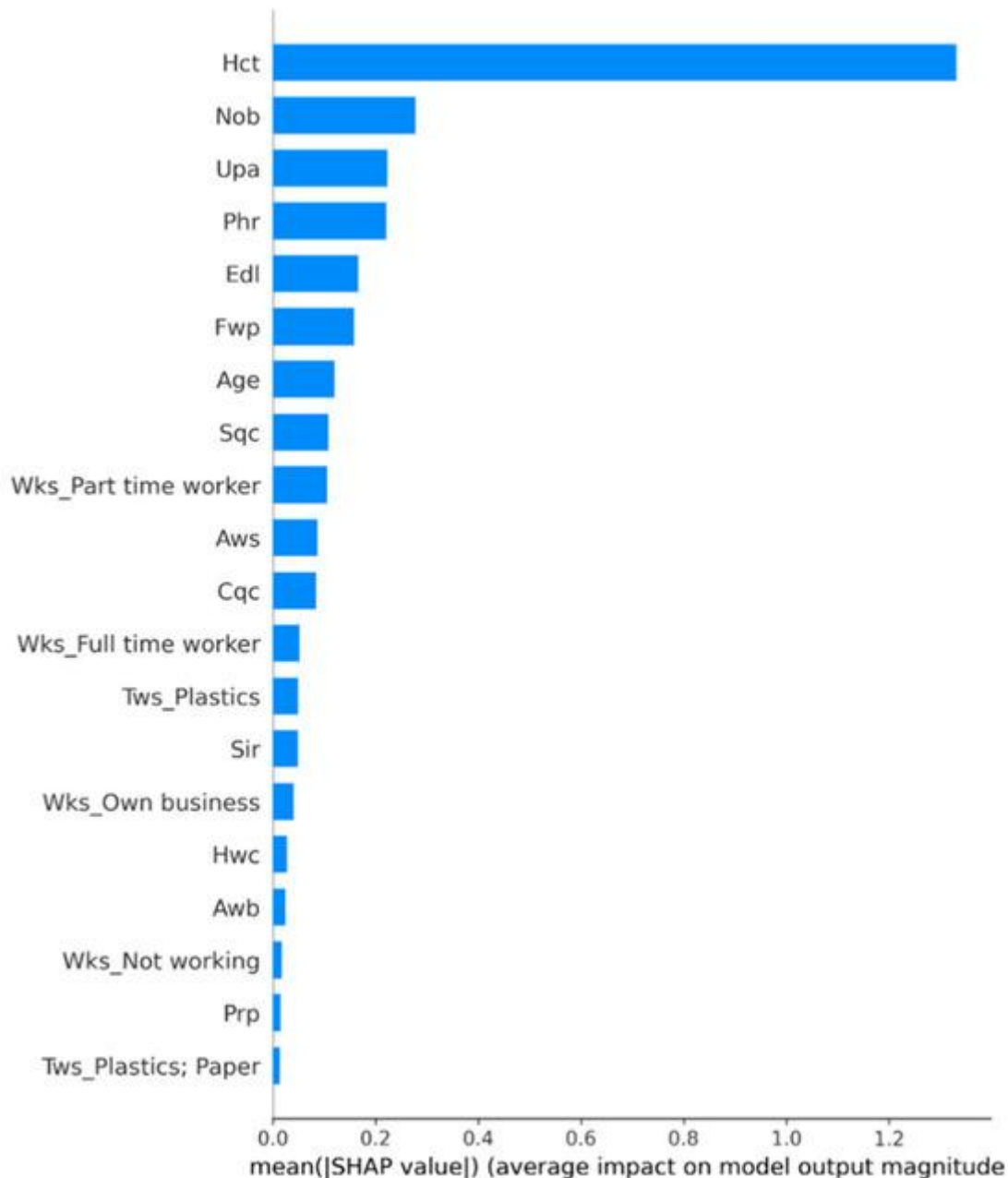


Figure 3. Feature importance of the best model using SHAP.

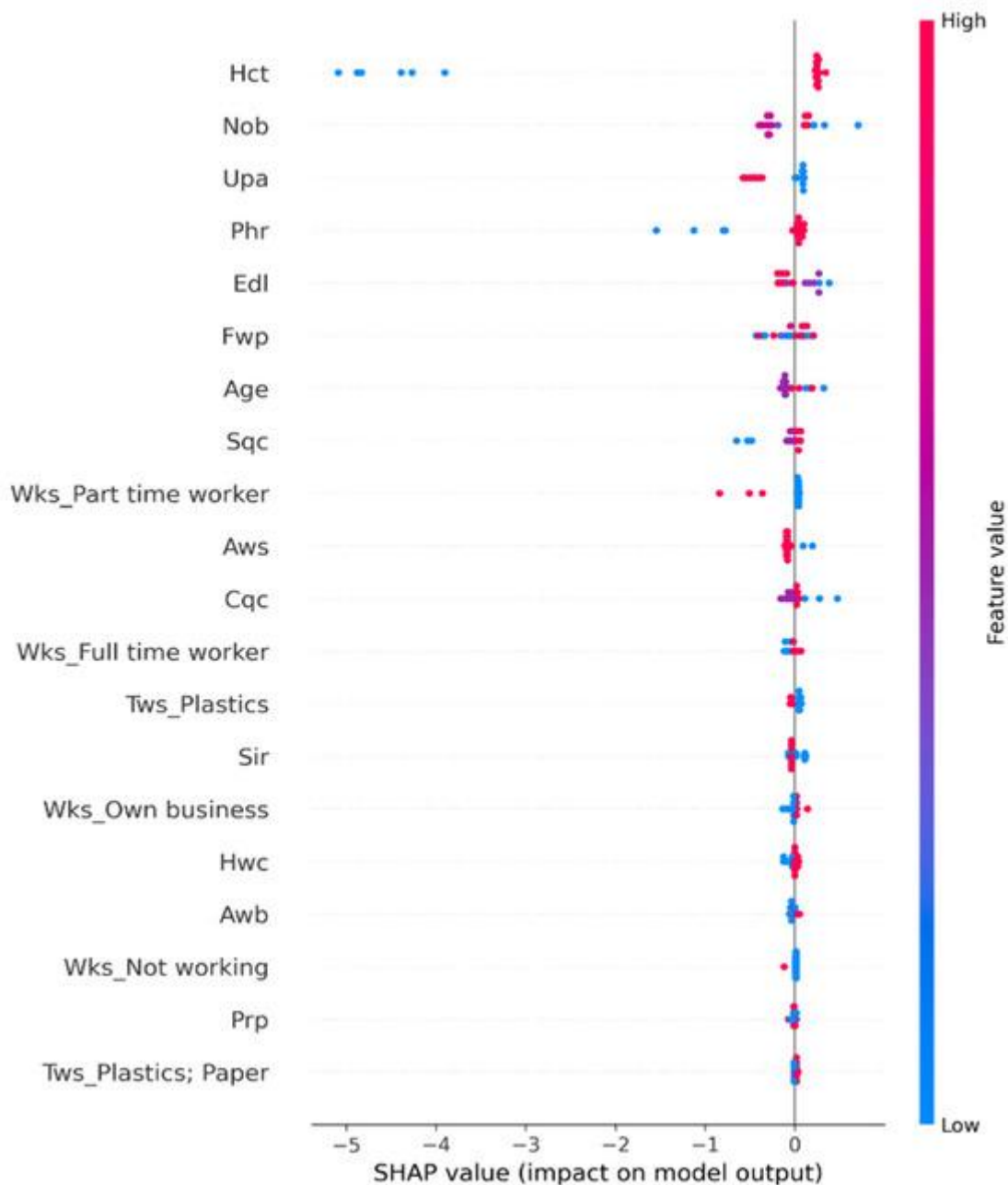


Figure 4. Feature impact on the best model.

The SHAP values plot in Figure 4 provided a more nuanced view of each feature’s impact, with the colour gradient from blue to red representing low to high feature values. HSR collection time displayed a clear pattern where longer collection times strongly decreased participation likelihood, while shorter times increased it. The absence of overflow in HSR bins showed a positive correlation with participation, suggesting that adequate WM capacity encouraged engagement. Remarkably, the usage of the Pakam app exhibited a negative correlation with SHAP values, indicating that higher app usage is associated with lower participation likelihood. This unexpected result might warrant further investigation into the effectiveness of the app or

user experience. Combining the theory of planned behaviour (TPB) and the technology assessment model (TAM), a study on the use of mobile apps to encourage environmental behaviour like recycling observed that two predictors of app use intentions (attitude towards the app and its perceived usefulness) should be considered when promoting the usage of such apps [81]. While the study concluded that using a green app can encourage recycling behaviour, the negative correlation observed with the Upa, might necessitate the need to carry out a study assessing factors that can motivate increased Upa under the LRI. Such factors, coupled with awareness, are then targeted when promoting the app, with a view to increasing usage.

The perception of households regarding recycling showed a positive impact when values were high, reflecting the influence of favourable attitudes on recycling behaviour. This finding is consistent with the results of a study in one of the LGAs in Lagos, where it was shown that when people perceive recycling as beneficial to the environment, they tend to show a positive attitude towards it to avoid its negative impacts on the environment [82]. Edl demonstrated a mixed effect, with both positive and negative impacts across different education levels, suggesting a complex relationship between education and recycling participation among the sampled population. Evidence from some studies showed that, as the educational level rises, the interest in pro-environmental behaviour increases correspondingly [83,84]. The negative impacts observed here suggested that this might not always be the case, as a study [85] found that the percentage of educated individuals in a population did not necessarily influence the willingness to engage in pro-environmental behaviour.

The frequency of HSR pickup showed a slightly positive influence, emphasizing the importance of delivering quality WM services. Tabernero et al. [86] affirmed that a strong relationship exists between service quality and recycling behaviour. Their research showed that individuals who were satisfied with the services offered by a recycling provider would show a higher willingness to recycle compared to those who did not. It was then suggested that other studies could test the frequency of pickup as one of the objective indicators of service quality. The findings from the current research affirmed that the frequency of pickup was one of those measures employed by households to test the quality of service they received from providers of recycling services. Thus, recyclers in Lagos might need to engage more with their customers on grey areas of service improvement. Age also displayed a mixed effect, with both positive and negative impacts across different age groups, indicating that the relationship between age and recycling participation was not straightforward. Although, 72.3% of respondents in this study were aged 30–49 and only 27.9% were 50 or older, 78.9% of the older group demonstrated active involvement in recycling compared to the younger respondents. This is consistent with previous studies, which have found

that older adults tend to exhibit greater interest in pro-environmental behaviours compared to younger individuals [83,86]. However, in future studies, the proportion of older people sampled could be increased to an appreciable level to better understand the relationship between age and recycling in the studied areas.

4.3. Sensitivity Analysis and Cross-Validation

Sensitivity analysis is crucial for evaluating model robustness and determining the optimal features for deployment in real-world applications. This section presents the results of feature subset sensitivity analysis, sample size sensitivity analysis, and cross-validation for the optimised CatBoost model that achieved the highest performance in predicting household recycling motivation in Lagos.

4.3.1. Feature Subset Sensitivity Analysis

Feature subset sensitivity analysis was conducted to examine how model performance varies when key features are included or excluded from the predictive model. The analysis focused on the five most important features identified through SHAP analysis: Hct, Nob, Upa, Phr, and Edl. Table 5 reveals significant insights into the relative importance of each feature for predicting household recycling motivation. When all five top features are included, the model achieves optimal performance with a weighted accuracy of 79.17% and an F1 score of 78.50%. The exclusion of Hct causes the most substantial performance degradation, with weighted precision dropping dramatically from 78.16% to 56.25% and F1 score declining from 78.50% to 64.29%. This confirms Hct as the most critical predictor of recycling motivation, consistent with its highest SHAP importance value.

Table 5. Result of feature subset sensitivity analysis using the selected model.

Feature _Setup	Included _Features	Excluded _Features	Weighted _Accuracy	Weighted _Precision	Weighted _Recall	Weighted _F1_Score
All Top 5	Hct, Nob, Upa, Phr, Edl	None	0.791667	0.781579	0.791667	0.785012
Excluding Hct	Nob, Upa, Phr, Edl	Hct	0.75	0.5625	0.75	0.642857
Excluding Nob	Hct, Upa, Phr, Edl	Nob	0.75	0.725	0.75	0.731579
Excluding Upa	Hct, Nob, Phr, Edl	Upa	0.791667	0.781579	0.791667	0.785012
Excluding Phr	Hct, Nob, Upa, Edl	Phr	0.791667	0.781579	0.791667	0.785012
Excluding Edl	Hct, Nob, Upa, Phr	Edl	0.791667	0.781579	0.791667	0.785012

Excluding the Nob feature also negatively impacts model performance, though less severely than Hct, with weighted precision dropping to 72.50% and F1 score to 73.16%. This indicates that adequate waste bin capacity is a secondary but still important predictor of recycling participation. Interestingly, the exclusion of Upa, Phr, or Edl individually has no discernible impact on model performance, with metrics remaining identical to the full model. This suggests a potential correlation among these features, where information lost from excluding one feature can be compensated by the remaining features [87]. These findings demonstrate that Hct and Nob are the most critical operational factors influencing recycling motivation among Lagos households. When waste is collected at regular intervals, and bins do not overflow, households are significantly more likely to participate in recycling programs. The negligible impact of excluding Upa aligns with the unexpected negative correlation observed in the SHAP analysis, suggesting that improving the Pakam app's effectiveness or user experience might be necessary to enhance its contribution to recycling participation.

4.3.2. Sample Size Sensitivity Analysis

Sample size sensitivity analysis evaluates how model performance varies with different training/test split ratios. This analysis is essential for understanding the data volume necessary for reliable predictions and assessing model generalisability across different test set sizes.

The results in Table 6 reveal an interesting pattern: model performance on test data generally improves as the test set size increases. With a small test set (10% of data), the model achieves 75% weighted accuracy and 73% F1 score. Performance increases as the test set grows, with

strong results at both the 50/50 split (83% accuracy, 82% F1 score) and the 30/70 split (82% accuracy, 81% F1 score). This relationship between test set size and performance metrics merits careful consideration. First, larger test sets typically provide more reliable performance estimates by capturing a wider range of household characteristics and recycling behaviours present in the population. The improved performance with larger test sets suggests that these sets better represent the diversity of recycling motivations in Lagos households. Second, the smaller test sets (particularly the 10% configuration) may suffer from increased variance in performance metrics due to their limited size. With only approximately 13 samples in the smallest test set, individual misclassifications can disproportionately affect overall performance metrics, potentially yielding less stable assessments of model performance. Third, the relatively consistent performance between the 50/50 and 30/70 splits indicates that even with a reduced training set (30% of data, approximately 38 samples), the model can effectively learn the key relationships governing recycling motivation. This suggests that the primary factors influencing household recycling behaviour in Lagos may be relatively straightforward and can be captured without extensive training data. The optimal performance at the 50/50 split represents a balanced approach that provides both adequate training data for model learning and a sufficiently large test set for reliable performance evaluation. This finding has practical implications for future research on recycling behaviour in developing economies, suggesting that moderate-sized, carefully collected datasets may be sufficient for identifying key motivational factors. These results also highlight the importance of careful consideration of test set size when evaluating model performance, particularly in studies utilizing convenience sampling in complex urban environments where demographic and socioeconomic factors may vary considerably across locations.

Table 6. Result of sample size sensitivity analysis.

Train Size	Test Size	Weighted Accuracy	Weighted Precision	Weighted Recall	Weighted F1 Score
0.3	0.7	0.82	0.83	0.82	0.81
0.5	0.5	0.83	0.83	0.83	0.82
0.7	0.3	0.77	0.77	0.77	0.76
0.9	0.1	0.75	0.74	0.75	0.73

4.3.3. Cross-Validation

To validate the robustness of the CatBoost model and ensure that performance metrics were not artifacts of a particular data split, a k-fold cross-validation ($k = 5$) was implemented. Cross-validation provides a more comprehensive assessment of model performance by evaluating the model on multiple subsets of the data, thus mitigating the risk of overfitting and yielding more reliable performance estimates [88]. Figure 5 presents the cross-validation performance of the optimised CatBoost model across four key metrics: weighted accuracy, weighted precision, weighted recall, and weighted F1 score. Each bar represents the mean performance metric over five folds, with error bars indicating the standard deviation of each metric across folds. The cross-validation results demonstrate strong and consistent performance across all metrics, with weighted precision showing the highest value at 0.859 ± 0.016 . Weighted accuracy and weighted recall both achieved identical mean scores of 0.823 ± 0.027 , indicating balanced performance between correctly identifying positive and negative instances of recycling motivation. The weighted F1 score, which represents the harmonic mean of precision and recall, showed a solid performance of 0.811 ± 0.030 . Importantly, the relatively small standard deviations (ranging from 0.016 to 0.030) across all metrics indicate high stability in model performance across different data partitions. This consistency is particularly important given the convenience sampling method used in data collection, as it suggests that the model's predictive capacity is not overly sensitive to the specific subset of households included in the training or testing sets. The cross-validation results confirm and strengthen the findings from the initial model evaluation. The optimised CatBoost model demonstrates reliable performance in predicting household recycling motivation, with weighted precision consistently exceeding 85%. This high precision is particularly valuable in the context of recycling program management, as it indicates that the model is especially effective at correctly identifying households likely to participate in recycling initiatives, allowing for more targeted interventions and resource allocation. The robust cross-validation performance further validates the importance of the key features identified through SHAP analysis. The stability of model performance across different data subsets reinforces the conclusion that Hct and Nob are indeed critical factors influencing household recycling motivation in Lagos, and not merely artefacts of a particular data partition.

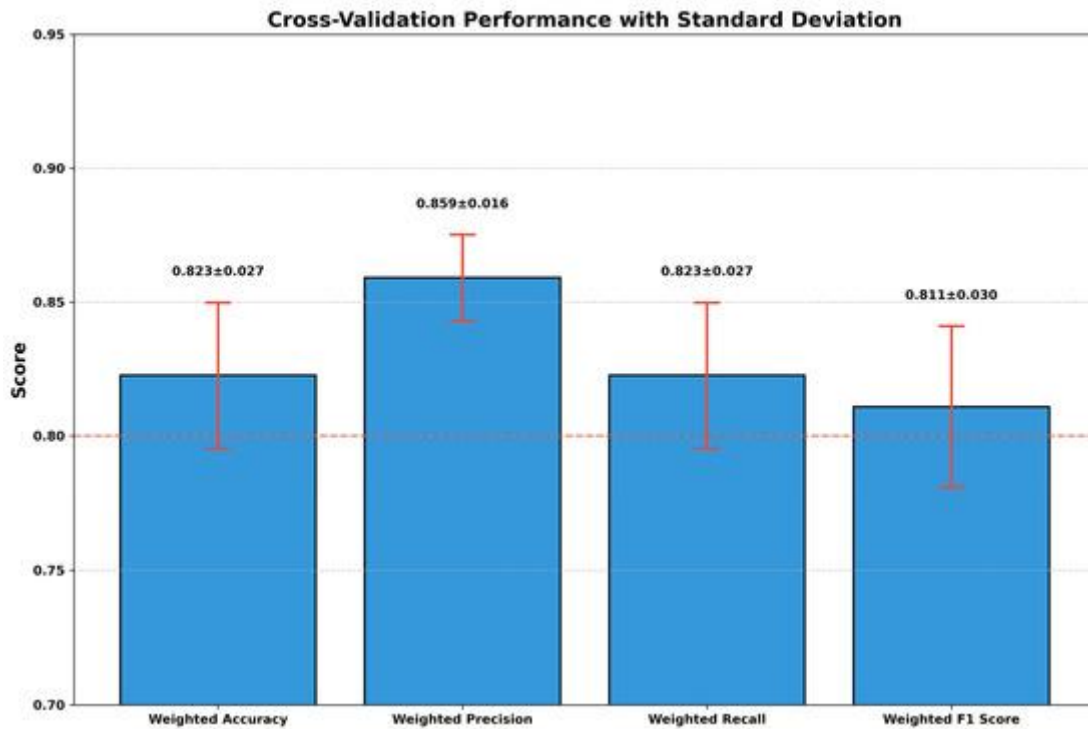


Figure 5. Cross-validation performance with standard deviation of the selected model.

These findings provide solid evidence that despite the limitations of the dataset size and sampling methodology, the identified factors influencing recycling motivation represent genuine patterns in household behaviour that can reliably inform policy and operational improvements for the LRI.

5.0 Methodology

5.1. Design

This study employed the quantitative research method (QRM) to evaluate the impact of the LRI on LFD by providing data-driven insights into the effectiveness of recycling in Lagos. A questionnaire survey was conducted among selected households and collectors of HSRs across three LGAs to gather quantitative data. At the same time, ML was applied to determine the significant factors of recycling motivation. The QRM involves the selection of a sample from a population using one or more sampling techniques; data obtained from the sample are then analysed and verified with appropriate statistical tools to make generalisations about the larger population from where the sample was taken. The choice of this method is predicated on the fact that the structured survey and ML models can be reproduced, implying that other researchers can either validate or refute the results due to its structured methodology [89]. One of the strengths of this approach is the systematic and objective collection of quantifiable data from the sampled population [90]. Also, the findings can be generalised across different contexts [89], thus

providing insights to policymakers based on empirical evidence. However, a limitation of the QRM is sometimes in the improper representation of the target population when the collected sample is compared with the larger population, which then impedes the possibility of generalising the findings [91]. Some other weaknesses of the method are the high cost of gathering field data for large-scale studies and the limited contextual understanding, which results in overlooking essential nuances, thereby limiting the depth and interpretation of research findings [89].

5.2. The Study Area

Lagos is situated on an area of 351,861 hectares and has five administrative divisions (AD) (including Ikeja, Badagry, Ikorodu, Lagos (Eko), and Epe) [92]. The locations selected for this study are three of the twenty local government areas in Lagos (including Agege, Eti-Osa, and Surulere LGAs). Both Surulere and Eti-Osa LGAs fall under the Lagos (Eko) AD, while Agege is under the Ikeja AD [92]. Socio-economically, Eti-Osa LGAs are mostly household income earners, while Surulere and Agege LGAs can be categorised as medium and low-income areas, respectively [93]. According to the LSBS [94], both Agege and Surulere LGAs have higher population density compared to Eti-Osa. An examination of waste collection data in the three LGAs published in 2016 by the LSBS [94] showed that the volume of MSW collected in Eti-Osa is about 16 times the volume collected in Agege and Surulere LGAs as of 2015. A further investigation of the data indicated that Eti-Osa appeared to have more waste pick-up points compared to the other two locations. This could be attributed to the more organised nature of buildings in Eti-Osa, which makes accessibility easier for waste collection companies. The basis for the selection of the study areas is that two of the three LSDPC estates, where the pilot scheme for the LRI was tested, were in Surulere and Eti-Osa LGAs. Agege LGA was included because some active recyclers whose contacts were obtained from the LAWMA officials and were interviewed, operated in that area. Hence, conducting field surveys in locations where the LRI had been tested and where active recyclers are currently operational was considered very appropriate. Figure 6 shows the map of Nigeria and indicates the location of Lagos.



Figure 6. Map of Nigeria showing Lagos. Adapted from [95].

Institutional Framework for Waste Management in Lagos

The WM system in Lagos comprises a network of formal and informal institutions operating from the urban to the household level (Figure 7). At the urban level, the Lagos State Ministry of the Environment and Water Resources (MOE) is responsible for the overall management of the environment and all environmental-related matters in the State [96]. To ensure effective and efficient environmental administration, the MOE currently supervises 11 state-owned agencies, one of which is the LAWMA, the sole regulator of the WM sector. In LAWMA's bid to bring its services to the grassroots, it concedes public and domestic WM operations, landfill operations, and transfer loading station responsibilities to private sector partnerships (PSPs), while it guides, models, and appraises the performance of these practitioners in line with international best practices [97]. The PSPs carry out the door-to-door collection of waste (mainly general waste) across the 20 LGAs, while the registered recyclers focus on the collection of recyclables in areas assigned to them. Both the PSPs and registered recyclers operate at the household level and are formally recognised by the state government, whereas the informal waste pickers and cart pushers (also operating at the household level) do not have formal recognition as they are not

licenced to operate in the state. As in many other DCs, the informal waste pickers operate both at the household and urban scales, collecting recyclables from households, streets, and dumpsites under health-threatening conditions [98,99], which is one of the reasons why the state government regulates their activities. Although there have been deliberate efforts by the state government to permanently stop the operations of these informal operators [100,101], they continue to proliferate due to the critical service gaps in the collection of MSW, which remains a challenge in several DCs. It is therefore not surprising that after a 7-year ban, cart pushers have returned to Lagos streets, owing largely to the inefficiency of the licenced waste collectors [102]. The interactions between the LAWMA and its formal actors are characterised by challenges, particularly in areas of regulation and service consistency. This institutional complexity significantly impacts the effectiveness of the LRI and underscores the need for a multi-faceted approach to improving waste management and recycling outcomes in the city.

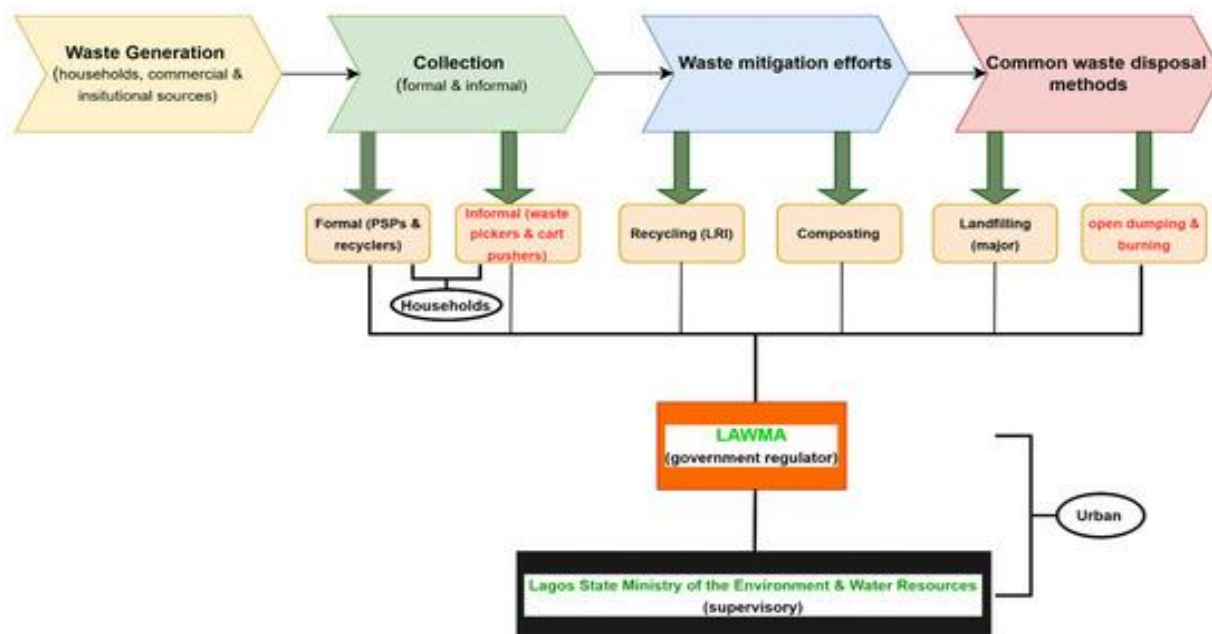


Figure 7. Illustration of waste generation and mitigation cum institutional framework of WM in Lagos (created by the authors).

5.3. Data Collection and Analysis

A total of 137 questionnaires (Agege = 20; Eti-Osa = 107; Surulere = 10) were administered on different days at the three locations to both recyclers and households. The selection of survey participants employed the convenience sampling method. Convenience sampling is a non-probability technique where individuals are selected based on ease of access for the researcher, rather than being representative of the entire population [103]. At the outset of the field survey, contact details of active recyclers that could easily be surveyed were provided by the Central

Head of Recycling of the LAWMA. Apart from households in the locations where the pilot scheme of the LRI was tested, other households surveyed were individuals that supply HSRs to some of the recyclers. As these individuals could also be easily reached, they were included in the sample. In Agege, 17 residents and 3 recyclers were interviewed. In Eti-Osa, 106 residents and 1 recycler were surveyed, while in Surulere, 7 residents and 3 recyclers were interviewed. After a review of the responses provided by the respondents, a total of 127 questionnaires were considered valid for the analysis, while 10 were deemed invalid. The basis for invalidation is that some questions considered critical to the analysis were unanswered. The questionnaire for the households fielded questions on respondents' demographic data, awareness of the LRI and the Pakam App, types of HSR separated for collection, collection frequency, household rating of recycling, and what motivates them to recycle, among others.

5.3.1. Exploratory Data Analysis

Exploratory data analysis (EDA) was conducted on the data obtained from the recyclers to gain initial insights into the LRI's operations. The analysis focused on key aspects of the RP, including the distribution of collectors across the three LGAs. EDA techniques were applied to examine waste bin distribution coverage, waste collection frequency, estimation of the RDR, and other relevant factors. Descriptive statistics and visual representations such as bar charts and pie charts were used to illustrate patterns in collector demographics, RRs, and operational efficiencies. This exploratory phase provided an overview of the recycling landscape in the studied LGAs, setting the foundation for more detailed statistical analyses and interpretation of the initiative's effectiveness.

5.3.2. Machine Learning Modelling

Four ML models—logistic regression, random forest (RF), XGBoost, and CatBoost—were employed to build classification models for predicting household motivation for recycling based on the survey data [27,104]. LR is a linear model commonly used for binary classification tasks. It estimates the probability of an instance belonging to a particular class using the logistic function presented in Equation (2) [73,105]:

$$P(y = 1 | x) = \frac{1}{1+e^{-z}} \quad (2)$$

where $z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n$.

RF is an ensemble learning method that constructs multiple decision trees and combines their predictions. The final prediction is the average of individual tree predictions, which is represented by Equation (3) [71,106]:

$$f(x) = \frac{1}{n} \sum_{i=1}^n t_i(x) \quad (3)$$

where $t_i(x)$ is the prediction of the i – th tree.

XGBoost is a gradient boosting algorithm that builds decision trees sequentially, each tree correcting the errors of its predecessors. The objective function is a combination of a loss function and a regularisation term, as shown in Equation (4) [74]:

$$Obj(\theta) = \sum_{i=1}^n l(y_i, \hat{y}_i) + \sum_{k=1}^K \Omega(f_k) \quad (4)$$

where l is the loss function; \hat{y}_i is the predicted value; and Ω is the regularisation term.

CatBoost is another gradient boosting algorithm employed in this study to predict household motivation for recycling. It employs a novel, ordered boosting approach with the following loss function shown in Equation (5) [75]:

$$L = \sum_{i=1}^n l(y_i, F(x_i)) + \Omega(F) \quad (5)$$

where l is the loss function; F is the model; and Ω signifies the regularisation parameter.

Bayesian optimization (BO) was used to optimise the hyperparameters of these ML models. This approach employs probabilistic models to guide the exploration of the hyperparameter space, enabling efficient identification of the optimal configurations for improved model performance [107].

5.3.3. Evaluation Metrics

Given the unbalanced nature of the data employed in this study, the following evaluation metrics were used to assess the performance of the ML models: accuracy (Equation (6)), weighted recall (Equation (7)), weighted precision (Equation (8)), and weighted F1 score (Equation (9)). These metrics provided a more robust evaluation of model performance when dealing with imbalanced classes [73,108].

1. Accuracy

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (6)$$

where TP is the true positives; TN is the true negatives; FP is the false positives; and FN is the false negatives.

2. Weighted Recall

$$Weighted Recall = \sum w_i \times Recall_i \quad (7)$$

where w_i is the proportion of samples in class i and $Recall_i = \frac{TP_i}{TP_i+FN_i}$ for class i

3. Weighted Precision

$$Weighted Precision = \sum w_i \times Precision_i \quad (8)$$

where w_i is the proportion of samples in class i and $Precision_i = \frac{TP_i}{TP_i+FP_i}$ for class i

4. Weighted F1 Score

$$Weighted F1 Score = \sum w_i \times F1_i \quad (9)$$

where w_i is the proportion of samples in class i and $F1_i = 2 * \frac{Precision_i * Recall_i}{Precision_i + Recall_i}$ for class i .

These weighted metrics accounted for the class imbalance by incorporating the proportion of each class in the dataset. This ensures a more accurate and comprehensive evaluation of model performance across all classes.

5.3.4. Interpretability Using SHAP

To present the interpretability of the best-performing model and understand the factors influencing household recycling motivation in Lagos, SHAP values were utilised. SHAP is a game-theoretic approach that explains ML model outputs by calculating the contribution of each feature to a prediction. The SHAP value for a given feature i is computed using Equation (10):

$$\phi_j = \sum_{S \subset N \setminus \{j\}} \frac{k!(p-k-1)!}{n!} [f(S \cup \{j\}) - f(S)] \quad (10)$$

where n is the total number of features; $N \setminus \{j\}$ is a set of all possible feature combinations, excluding \emptyset_j ; S is a subset of $N \setminus \{j\}$; and $f(S \cup \{j\})$ is the prediction of the model, including features in S and \emptyset_j while $f(S)$ is the prediction of the model with feature S .

5.3.5. Data Validation and Cross-Validation Approach

To ensure the reliability and validity of the model findings, a comprehensive data validation protocol was implemented. Data cleaning was performed to identify and handle missing values, inconsistent responses, and outliers. From the 137 questionnaires administered, 10 were invalidated due to these irregularities. Moreover, feature transformation was conducted to transform categorical variables into numeric representations suitable for ML algorithms while preserving their semantic meaning. The data validation process also included checks for multicollinearity among predictor variables to avoid redundancy in the feature set and ensure stable model performance

5.3.6. Addressing Sampling Biases

The convenience sampling method employed in this study may present inherent limitations regarding the representativeness of the sample. Several strategies were implemented to address potential sampling biases. First, k-fold cross-validation ($k = 5$) was employed during model training to ensure that performance metrics were not artifacts of a particular data split, thus providing a more robust assessment of model generalisability. Second, sample size sensitivity analysis was conducted by varying the training/test split ratios (30:70, 50:50, 70:30, and 90:10) to determine how model performance varied with different data partitions and to identify how it affected the stability of the model. Third, potential demographic biases were acknowledged, particularly the uneven distribution of respondents across the selected LGAs and socioeconomic factors. This geographical imbalance was considered during result interpretation, with findings explicitly framed within the context of these sampling limitations. These validation approaches collectively strengthen the reliability of our findings while acknowledging the constraints of the sampling methodology.

6. Conclusions and Recommendations

6.1. Conclusions

The findings from this research strongly support the hypothesis that the LRI has not achieved substantial landfill diversion rates due to operational challenges and insufficient household participation. In addressing the first research objective, the evaluation revealed a significantly underperforming RP with a low RDR of just 0.37%, falling dramatically short of the city's ambitious 50% target. For the second objective, we successfully developed ML models to predict household recycling motivation, with the optimised CatBoost algorithm demonstrating the highest performance (accuracy and F1 score of 0.79). The third objective was fulfilled through SHAP analysis, which confirmed that operational factors, specifically Hct and Nob, are the most critical determinants of household recycling motivation, validating the operational challenges component of the hypothesis. By quantifying this performance gap and identifying key motivators for recycling participation through robust ML techniques, these findings address a critical gap in the literature on RIs in SSA where such evidence-based assessments are scarce. Although the analysis identified Hct and Nob as primary motivators of recycling specific to the LRI implementation, it should be noted that other researchers in SSA have identified additional factors such as household income, formal education, and age as general determinants of recycling behaviour. These results could serve as a benchmark for future investigations and policy formulations in other African cities grappling with similar WM challenges, potentially catalysing more effective and data-driven approaches to recycling and waste diversion across the region. Future research could expand data collection to cover a wider range of LGAs in Lagos, incorporating all waste diversion strategies, including reuse, composting, and waste-to-energy, to enable a more holistic assessment of the WDR in Lagos.

6.2. Recommendations

To improve the performance of the LRI beyond the current level, the LAWMA could make efforts to increase city-wide awareness of the programme through targeted public campaigns and engage frequently with the registered recyclers to understand and address their operational challenges. To further enhance the effectiveness of the initiative, policymakers could also implement financial incentives, such as subsidies or tax breaks for households and recyclers who participate actively in recycling. Also, investments in infrastructure, such as the provision of more recycling bins in high-density areas as well as the modernisation of waste collection fleets will improve the performance of the LRI. Additionally, the imposition of penalties for non-compliance with existing recycling regulations can boost participation rates, thereby ensuring the LRI meets its waste diversion targets. There is equally a need for the authority to focus on expanding the

coverage of collectors across all the 20 LGAs to increase the collection rate of recyclables. These efforts would collectively contribute to enhancing the efficiency and effectiveness of the LRI, ultimately leading to improved WM practices across the Lagos metropolis. By addressing these recommendations and learning from the Lagos experience, cities across SSA and other developing regions could make substantial progress toward their waste diversion goals, thus contributing to improved environmental sustainability, public health, and economic opportunities for their residents. Moreover, the findings from this study could serve as a benchmark for future investigations and policy formulations in other African cities, potentially catalysing more effective and data-driven approaches to recycling and waste diversion across the region.

Supplementary Materials

The following supporting information can be downloaded at:

<https://www.mdpi.com/article/10.3390/recycling10030100/s1>, File S1: additional figures: Figure S1: process flow for the collection of recyclables; Figure S2: distribution of collectors of HSR; Figure S3: waste bin distribution coverage, Figure S4: frequency of waste collection; Figure S5: truck capacity and weekly volume of HSR collected; Figure S6: HSR material type collected; Figure S7: distribution of the challenges faced by the collectors; Figure S8: profile of the household respondents: (a) age distribution, (b) educational level distribution, and (c) working status distribution; Figure S9: precision–recall curve for the optimized models; File S2: list of acronyms; File S3: codes for the modelling variables.

Author Contributions

Conceptualisation, M.L.A.; methodology, M.L.A. and R.T.; validation, M.L.A., R.T. and O.O.A.; formal analysis, M.L.A. and R.T.; writing—original draft preparation, M.L.A. and R.T.; writing—review and editing, M.L.A., R.T., O.O.A. and H.-R.B.; visualization, M.L.A., R.T., O.O.A. and H.-R.B.; supervision, H.-R.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data are contained within the article and Supplementary Materials.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

1. United Nations Statistics Division UN Data. Glossary. Available online: <https://data.un.org/Glossary.aspx?q=waste+datamart%5bEnvironmentG%5d> (accessed on 23 March 2025).
2. Ayeleru, O.O.; Fewster-Young, N.; Gbashi, S.; Akintola, A.T.; Ramatsa, I.M.; Olubambi, P.A. A Statistical Analysis of Recycling Attitudes and Behaviours Towards Municipal Solid Waste Management: A Case Study of the University of Johannesburg, South Africa. *Clean. Waste Syst.* 2023, 4, 100077. [Google Scholar] [CrossRef]
3. UNEP Global Waste Management Outlook 2024. UNEP—UN Environment Programme. Available online: <https://www.unep.org/resources/global-waste-management-outlook-2024> (accessed on 19 August 2024).
4. Ayeleru, O.O.; Dlova, S.; Akinribide, O.J.; Ntuli, F.; Kupolati, W.K.; Marina, P.F.; Blencowe, A.; Olubambi, P.A. Challenges of Plastic Waste Generation and Management in Sub-Saharan Africa: A Review. *Waste Manag.* 2020, 110, 24–42. [Google Scholar] [CrossRef] [PubMed]
5. Gutierrez, M.A.; Moreno, R.A.; Rebelo, M.S. Chapter 3—Information and Communication Technologies and Global Health Challenges. In *Global Health Informatics*; de Fátima Marin, H., Massad, E., Gutierrez, M.A., Rodrigues, R.J., Sigulem, D., Eds.; Academic Press: Cambridge, MA, USA, 2017; pp. 50–93. ISBN 978-0-12-804591-6. [Google Scholar]
6. Adedara, M.L.; Taiwo, R.; Bork, H.-R. Municipal Solid Waste Collection and Coverage Rates in Sub-Saharan African Countries: A Comprehensive Systematic Review and Meta-Analysis. *Waste* 2023, 1, 389–413. [Google Scholar] [CrossRef]
7. Agbefe, L.E.; Lawson, E.T.; Yirenya-Tawiah, D. Awareness on Waste Segregation at Source and Willingness to Pay for Collection Service in Selected Markets in Ga West Municipality, Accra, Ghana. *J. Mater. Cycles Waste Manag.* 2019, 21, 905–914. [Google Scholar] [CrossRef]
8. Couth, R.; Trois, C. Waste Management Activities and Carbon Emissions in Africa. *Waste Manag.* 2011, 31, 131–137. [Google Scholar] [CrossRef]
9. Vaccari, M.; Vinti, G.; Tudor, T. An Analysis of the Risk Posed by Leachate from Dumpsites in Developing Countries. *Environments* 2018, 5, 99. [Google Scholar] [CrossRef]

10. Wielenga, K. *Separate Waste Collection in the Context of a Circular Economy in Europe*; Report; FFact: Delft, The Netherlands, 2016; Available online: <https://www.yumpu.com/xx/document/view/55565080/separate-waste-collection-in-the-context-of-a-circular-economy-in-europe#> (accessed on 13 May 2025).
11. Suberu, M.Y.; Mokhtar, A.S.; Bashir, N. Renewable Power Generation Opportunity from Municipal Solid Waste: A Case Study of Lagos Metropolis (Nigeria). *J. Energy Technol. Policy* 2012, 2. Available online: <https://www.iiste.org/Journals/index.php/JETP/article/view/1554> (accessed on 23 March 2025).
12. World Bank. World Bank Open Data. Available online: <https://data.worldbank.org> (accessed on 18 May 2024).
13. United Nations Department of Economic and Social Affairs. World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100. Available online: <https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100> (accessed on 18 May 2024).
14. Adeniran, A.E.; Nubi, A.T.; Adelopo, A.O. Solid Waste Generation and Characterization in the University of Lagos for a Sustainable Waste Management. *Waste Manag.* 2017, 67, 3–10. [Google Scholar] [CrossRef]
15. Aboyeji, O.S.; Eigbokhan, S.F. Evaluations of Groundwater Contamination by Leachates around Olusosun Open Dumpsite in Lagos Metropolis, Southwest Nigeria. *J. Environ. Manag.* 2016, 183, 333–341. [Google Scholar] [CrossRef]
16. Ajibade, F.O.; Adelodun, B.; Ajibade, T.F.; Lasisi, K.H.; Abiola, C.; Adewumi, J.R.; Akinbile, C.O. The Threatening Effects of Open Dumping on Soil at Waste Disposal Sites of Akure City, Nigeria. *Int. J. Environ. Waste Manag.* 2021, 27, 127–146. [Google Scholar] [CrossRef]
17. Akpeimeh, G.F.; Fletcher, L.A.; Evans, B.E. Exposure to Bioaerosols at Open Dumpsites: A Case Study of Bioaerosols Exposure from Activities at Olusosun Open Dumpsite, Lagos Nigeria. *Waste Manag.* 2019, 89, 37–47. [Google Scholar] [CrossRef]
18. Lagos State Resilience Office. Lagos Resilience Strategy. Available online: <https://www.thegpsc.org/knowledge-products/cities-biodiversity/lagos-resilience-strategy> (accessed on 21 August 2024).

19. World Bank. Lagos Diagnostic Study and Pathway for Transformation. Available online: <https://documents1.worldbank.org/curated/en/099062123034023646/pdf/P1750310c8d0390000afa70e5c583aa3b87.pdf> (accessed on 21 September 2024).
20. Kadiri, F.; Still on the LAWMA Blue Box Initiative. Business Day 17 October 2019. Available online: <https://businessday.ng/opinion/article/still-on-the-lawma-blue-box-initiative> (accessed on 21 August 2024).
21. Oghifo, B. LAWMA Seeks Collaboration to Recycle Plastics—THISDAYLIVE. Available online: <https://www.thisdaylive.com/index.php/2021/02/16/lawma-seeks-collaboration-to-recycle-plastics/> (accessed on 4 July 2024).
22. Vanguard Media Limited. Lagos Generates 14,000 Metric Tonnes Waste Daily—Commissioner. *Vanguard News*. Available online: <https://www.vanguardngr.com/2021/04/lagos-generates-14000-metric-tonnes-waste-daily-commissioner/> (accessed on 21 August 2024).
23. Yu, K.H.; Zhang, Y.; Li, D.; Montenegro-Marin, C.E.; Kumar, P.M. Environmental Planning Based on Reduce, Reuse, Recycle and Recover Using Artificial Intelligence. *Environ. Impact Assess. Rev.* 2021, *86*, 106492. [Google Scholar] [CrossRef]
24. Barnes, K.; Blaauw, D.; Schenck, R.; Pretorius, A. Buyback Centres in Cape Town: The Key Integration Point between Formal and Informal Sectors in the Waste Economy of the Western Cape. *GeoJournal* 2022, *87*, 2051–2065. [Google Scholar] [CrossRef]
25. Pan, C.; Bolingbroke, D.; Ng, K.T.W.; Richter, A.; Vu, H.L. The Use of Waste Diversion Indices on the Analysis of Canadian Waste Management Models. *J. Mater. Cycles Waste Manag.* 2018, *21*, 478–487. [Google Scholar] [CrossRef]
26. Ratnasabapathy, S.; Alashwal, A.; Perera, S. Investigation of Waste Diversion Rates in the Construction and Demolition Sector in Australia. *Built Environ. Proj. Asset Manag.* 2020, *11*, 427–439. [Google Scholar] [CrossRef]
27. Cheng, X.; Zhang, L.; Li, W.; Long, R. Intentions and Actions in Household Waste Separation: A Machine Learning Approach on the Gap and Determinants. *Environ. Impact Assess. Rev.* 2024, *107*, 107566. [Google Scholar] [CrossRef]
28. Trash Butler. What Is Waste Diversion And How Can You Improve It? Available online: <https://www.trashbutler.com/waste-diversion/> (accessed on 23 March 2025).
29. Kjeldsen, P.; Barlaz, M.A.; Rooker, A.P.; Baun, A.; Ledin, A.; Christensen, T.H. Present and Long-Term Composition of MSW Landfill Leachate: A Review. *Crit. Rev. Environ. Sci. Technol.* 2002, *32*, 297–336. [Google Scholar] [CrossRef]

30. Psomopoulos, C.S.; Bourka, A.; Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Manag.* 2009, *29*, 1718–1724. [Google Scholar] [CrossRef]
31. Pariatamby, A.; Law, H.J. Do We Need Landfills? *Waste Manag. Res.* 2020, *38*, 1075–1077. [Google Scholar] [CrossRef]
32. Oke, A.; McDonald, S.; Korobilis-Magas, E.; Osobajo, O.A.; Awuzie, B.O. Reframing Recycling Behaviour Through Consumers' Perceptions: An Exploratory Investigation. *Sustainability* 2021, *13*, 13849. [Google Scholar] [CrossRef]
33. Ayeleru, O.O.; Okonta, F.N.; Ntuli, F. Cost Benefit Analysis of a Municipal Solid Waste Recycling Facility in Soweto, South Africa. *Waste Manag.* 2021, *134*, 263–269. [Google Scholar] [CrossRef]
34. Owojori, O.; Edokpayi, J.N.; Mulaudzi, R.; Odiyo, J.O. Characterisation, Recovery and Recycling Potential of Solid Waste in a University of a Developing Economy. *Sustainability* 2020, *12*, 5111. [Google Scholar] [CrossRef]
35. Nzeadibe, C.; Eziuzor, O.J. Waste Scavenging and Recycling in Onitsha Urban Area, Nigeria. *CIWM Sci. Tech. Rev.* 2006, *7*, 26–31. [Google Scholar]
36. Ketlogetswe, C.; Mothudi, T.H. Botswana's Environmental Policy on Recycling. *Resour. Conserv. Recycl.* 2005, *44*, 333–342. [Google Scholar] [CrossRef]
37. Ayeleru, O.O.; Okonta, F.N.; Ntuli, F. Municipal Solid Waste Generation and Characterization in the City of Johannesburg: A Pathway for the Implementation of Zero Waste. *Waste Manag.* 2018, *79*, 87–97. [Google Scholar] [CrossRef]
38. Dlamini, B.R.; Rampedi, I.T.; Ifegbesan, A.P. Community Resident's Opinions and Perceptions on the Effectiveness of Waste Management and Recycling Potential in the Umkhanyakude and Zululand District Municipalities in the KwaZulu-Natal Province of South Africa. *Sustainability* 2017, *9*, 1835. [Google Scholar] [CrossRef]
39. Oyekale, A. Determinants of Households' Involvement in Waste Separation and Collection for Recycling in South Africa. *Environ. Dev. Sustain.* 2018, *20*, 2343–2371. [Google Scholar] [CrossRef]
40. Kang, Y.O.; Yabar, H.; Mizunoya, T.; Higano, Y. Environmental and Economic Performances of Municipal Solid Waste Management Strategies Based on LCA Method: A Case Study of Kinshasa. *Heliyon* 2023, *9*, e14372. [Google Scholar] [CrossRef]
41. Kinobe, J.R.; Gebresenbet, G.; Niwagaba, C.B.; Vinnerås, B. Reverse Logistics System and Recycling Potential at a Landfill: A Case Study from Kampala City. *Waste Manag.* 2015, *42*, 82–92. [Google Scholar] [CrossRef]

42. Wilson, D.C.; Paul, J.; Ramola, A.; Filho, C.S. Unlocking the Significant Worldwide Potential of Better Waste and Resource Management for Climate Mitigation: With Particular Focus on the Global South. *Waste Manag. Res.* 2024, *42*, 860–872. [Google Scholar] [CrossRef]
43. Louzizi, T.; Chakir, E.; Sadoune, Z. A Comprehensive Review on Solid Waste Management in Morocco: Assessment, Challenges and Potential Transition to a Circular Economy. *Euro-Mediterr. J. Environ. Integr.* 2024. [Google Scholar] [CrossRef]
44. Gardoni, P.; Murphy, C. Society-Based Design: Promoting Societal Well-Being by Designing Sustainable and Resilient Infrastructure. *Sustain. Resilient Infrastruct.* 2020, *5*, 4–19. [Google Scholar] [CrossRef]
45. Hotta, Y.; Visvanathan, C.; Kojima, M. Recycling Rate and Target Setting: Challenges for Standardized Measurement. *J. Mater. Cycles Waste Manag.* 2016, *18*, 14–21. [Google Scholar] [CrossRef]
46. Smith, S.R.; Jasim, S. Small-Scale Home Composting of Biodegradable Household Waste: Overview of Key Results from a 3-Year Research Programme in West London. *Waste Manag. Res. J. A Sustain. Circ. Econ.* 2009, *27*, 941–950. [Google Scholar] [CrossRef]
47. Plastic Action Centre. What Is a Diversion Rate? Available online: <https://plasticactioncentre.ca/directory/what-is-a-diversion-rate/> (accessed on 15 June 2024).
48. Clarke, M.J.; Maantay, J.A. Optimizing Recycling in All of New York City’s Neighborhoods: Using GIS to Develop the REAP Index for Improved Recycling Education, Awareness, and Participation. *Resour. Conserv. Recycl.* 2006, *46*, 128–148. [Google Scholar] [CrossRef]
49. Ali, G.; Saqib, Z.; Ziad, M.; Ali, J. Identification and Quantification of Major Components of Waste Diversion and Their Recovery Rates in Current Waste Management System in Peshawar, Pakistan. *Arab. J. Geosci.* 2022, *16*, 34. [Google Scholar] [CrossRef]
50. Wahabu, A.; Oduro-Kwarteng, S.; Monney, I.; Wahab, A. Characteristics of Diverted Solid Waste in Kumasi: A Ghanaian City. *Am. J. Environ. Prot.* 2014, *3*, 225–231. [Google Scholar] [CrossRef]
51. Olukanni, D.; Aipoh, A.; Kalabo, I. Recycling and Reuse Technology: Waste to Wealth Initiative in a Private Tertiary Institution, Nigeria. *Recycling* 2018, *3*, 44. [Google Scholar] [CrossRef]

52. Ayeleru, O.O.; Ntuli, F.; Mbohwa, C. Municipal Solid Waste Composition Determination in the City of Johannesburg. In Proceedings of the World Congress on Engineering and Computer Science 2016, San Francisco, CA, USA, 9–21 October 2016. [Google Scholar]
53. Fehr, M.; Melo Vasques de Castro, M.S.; Calçado, M. dos R. Condominium Waste Management by Private Initiative: A Report of a 10-Year Project in Brazil. *Waste Manag. Res.* 2009, 28, 309–314. [Google Scholar] [CrossRef]
54. Yadav, V.K.; Yadav, K.K.; Tirth, V.; Gnanamoorthy, G.; Gupta, N.; Algahtani, A.; Islam, S.; Choudhary, N.; Modi, S.; Jeon, B.-H. Extraction of Value-Added Minerals from Various Agricultural, Industrial and Domestic Wastes. *Materials* 2021, 14, 6333. [Google Scholar] [CrossRef]
55. Kontokosta, C.E.; Hong, B.; Johnson, N.E.; Starobin, D. Using Machine Learning and Small Area Estimation to Predict Building-Level Municipal Solid Waste Generation in Cities. *Comput. Environ. Urban Syst.* 2018, 70, 151–162. [Google Scholar] [CrossRef]
56. Chen, X. Machine Learning Approach for a Circular Economy with Waste Recycling in Smart Cities. *Energy Rep.* 2022, 8, 3127–3140. [Google Scholar] [CrossRef]
57. Erkinay Ozdemir, M.; Ali, Z.; Subeshan, B.; Asmatulu, E. Applying Machine Learning Approach in Recycling. *J. Mater. Cycles Waste Manag.* 2021, 23, 855–871. [Google Scholar] [CrossRef]
58. Vanguard Media Limited. Cleaner Lagos Initiative Takes off next Month—AMBODE. *Vanguard News*, 2017 August 2. Available online: <https://www.vanguardngr.com/2017/08/cleaner-lagos-initiative-takes-off-next-month-ambode/> (accessed on 21 August 2024).
59. Xu, L.; Yang, H.; Ling, M. Factors Moderating the Effect of Financial Incentives on Household Recycling: A Motivation Crowding Perspective. *Environ. Impact Assess. Rev.* 2023, 100, 107078. [Google Scholar] [CrossRef]
60. LAWMA. LAWMA Launches Lagos Recycle Initiative. Available online: <https://www.facebook.com/100064628231975/posts/3791920920826223/> (accessed on 13 April 2024).
61. Sweep Foundation. Training + Education + Advocacy. Available online: <https://sweepfoundation.org.ng/> (accessed on 10 December 2024).
62. LAWMA. LAWMA Recycling. Available online: <https://www.instagram.com/tv/CNlw9Tonqr5/> (accessed on 13 July 2024).

63. Lagos Bureau of Statistics. Abstract of Local Government Statistics Report. Available online: <https://lagosmepb.org/bureau-item/abstract-of-local-government-statistics-report/> (accessed on 11 September 2024).
64. Aryal, G.R. Methods of Population Estimation and Projection. *J. Popul. Dev.* 2020, *1*, 54–61. [Google Scholar] [CrossRef]
65. Nabaa, S.H. Estimation Of Municipal Solid Waste Generation Rate (Case Study Of Hilla City). *J. Kerbala Univ.* 2014, *12*, 72–80. [Google Scholar]
66. New South Wales Environmental Protection Authority EPA. Calculation-Method-for-Waste-Generation-Recycling-and-Diversion. Available online: <https://www.epa.nsw.gov.au/Publications/wastestrategy/19p1655-calculation-method-for-waste-generation-recycling-and-diversion> (accessed on 12 June 2024).
67. Kaza, S.; Yao, L.C.; Bhada-Tata, P.; van Woerden, F. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*; Urban Development Series; License: Creative Commons Attribution CC BY 3.0 IGO; World Bank: Washington, DC, USA, 2018. [Google Scholar] [CrossRef]
68. Spielberg, B. NYC Needs Common Sense Waste Management Now. Available online: <https://nylcv.org/news/nyc-needs-common-sense-waste-management-now/> (accessed on 25 September 2024).
69. Ben Seghier, M.E.A.; Plevris, V.; Solorzano, G. Random Forest-Based Algorithms for Accurate Evaluation of Ultimate Bending Capacity of Steel Tubes. *Structures* 2022, *44*, 261–273. [Google Scholar] [CrossRef]
70. Chou, J.-S.; Pham, A.-D. Enhanced Artificial Intelligence for Ensemble Approach to Predicting High Performance Concrete Compressive Strength. *Constr. Build. Mater.* 2013, *49*, 554–563. [Google Scholar] [CrossRef]
71. Taiwo, R.; Yussif, A.-M.; Ben Seghier, M.E.A.; Zayed, T. Explainable Ensemble Models for Predicting Wall Thickness Loss of Water Pipes. *Ain Shams Eng. J.* 2024, *15*, 102630. [Google Scholar] [CrossRef]
72. Schober, P.; Boer, C.; Schwarte, L.A. Correlation Coefficients: Appropriate Use and Interpretation. *Anesth. Analg.* 2018, *126*, 1763–1768. [Google Scholar] [CrossRef]
73. Taiwo, R.; Zayed, T.; Ben Seghier, M.E.A. Integrated Intelligent Models for Predicting Water Pipe Failure Probability. *Alex. Eng. J.* 2024, *86*, 243–257. [Google Scholar] [CrossRef]

74. Chen, T.; Guestrin, C. XGBoost: A Scalable Tree Boosting System. In Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, San Francisco, CA, USA, 13–17 August 2016; pp. 785–794. [Google Scholar]
75. Prokhorenkova, L.; Gusev, G.; Vorobev, A.; Dorogush, A.V.; Gulin, A. CatBoost: Unbiased Boosting with Categorical Features. In *Advances in Neural Information Processing Systems*; Curran Associates, Inc.: New York, NY, USA, 2018; Volume 31. [Google Scholar]
76. Islam, M.M.; Das, P.; Rahman, M.M.; Naz, F.; Kashem, A.; Nishat, M.H.; Tabassum, N. Prediction of Compressive Strength of High-Performance Concrete Using Optimization Machine Learning Approaches with SHAP Analysis. *J. Build. Pathol. Rehabil.* 2024, 9, 94. [Google Scholar] [CrossRef]
77. Aazam, M.; St-Hilaire, M.; Lung, C.-H.; Lambadaris, I. Cloud-Based Smart Waste Management for Smart Cities. In Proceedings of the 2016 IEEE 21st International Workshop on Computer Aided Modelling and Design of Communication Links and Networks (CAMAD), Toronto, ON, Canada, 23–25 October 2016; pp. 188–193. [Google Scholar] [CrossRef]
78. Barbariol, F.; Baid, H. Introduction to an Intensive Care Recycling Program. *Intensive Care Med.* 2023, 49, 327–329. [Google Scholar] [CrossRef]
79. Zhang, Y.; Wang, G.; Zhang, Q.; Ji, Y.; Xu, H. What Determines Urban Household Intention and Behavior of Solid Waste Separation? A Case Study in China. *Environ. Impact Assess. Rev.* 2022, 93, 106728. [Google Scholar] [CrossRef]
80. Omotayo, A.O.; Omotoso, A.B.; Daud, A.S.; Ogunniyi, A.I.; Olagunju, K.O. What Drives Households' Payment for Waste Disposal and Recycling Behaviours? Empirical Evidence from South Africa's General Household Survey. *Int. J. Environ. Res. Public Health* 2020, 17, 7188. [Google Scholar] [CrossRef]
81. De Wildt, K.K.; Meijers, M.H.C. Time Spent on Separating Waste Is Never Wasted: Fostering People's Recycling Behavior through the Use of a Mobile Application. *Comput. Hum. Behav.* 2023, 139, 107541. [Google Scholar] [CrossRef]
82. Abila, B. Households' Perception of Financial Incentives in Endorsing Sustainable Waste Recycling in Nigeria. *Recycling* 2018, 3, 28. [Google Scholar] [CrossRef]
83. Escario, J.-J.; Rodriguez-Sanchez, C.; Casaló, L.V. The Influence of Environmental Attitudes and Perceived Effectiveness on Recycling, Reducing, and Reusing Packaging Materials in Spain. *Waste Manag.* 2020, 113, 251–260. [Google Scholar] [CrossRef]

84. Wang, H.; Liu, X.; Wang, N.; Zhang, K.; Wang, F.; Zhang, S.; Wang, R.; Zheng, P.; Matsushita, M. Key Factors Influencing Public Awareness of Household Solid Waste Recycling in Urban Areas of China: A Case Study. *Resour. Conserv. Recycl.* 2020, *158*, 104813. [Google Scholar] [CrossRef]
85. Mikuła, A.; Raczowska, M.; Utzig, M. Pro-Environmental Behaviour in the European Union Countries. *Energies* 2021, *14*, 5689. [Google Scholar] [CrossRef]
86. Tabernero, C.; Hernández, B.; Cuadrado, E.; Luque, B.; Pereira, C.R. A Multilevel Perspective to Explain Recycling Behaviour in Communities. *J. Environ. Manag.* 2015, *159*, 192–201. [Google Scholar] [CrossRef]
87. Kuhn, M.; Johnson, K. *Feature Engineering and Selection: A Practical Approach for Predictive Models*; Chapman and Hall/CRC: New York, NY, USA, 2019; ISBN 978-1-315-10823-0. [Google Scholar]
88. Taiwo, R.; Zayed, T.; Bakhtawar, B.; Adey, B.T. Explainable Deep Learning Models for Predicting Water Pipe Failures. *J. Environ. Manag.* 2025, *379*, 124738. [Google Scholar] [CrossRef]
89. Lim, W.M. What Is Quantitative Research? An Overview and Guidelines. *Australas. Mark. J.* 2024. [Google Scholar] [CrossRef]
90. Queirós, A.; Faria, D.; Almeida, F. Strengths And Limitations Of Qualitative And Quantitative Research Methods. *Eur. J. Educ. Stud.* 2017, *3*, 369–387. [Google Scholar] [CrossRef]
91. Chetty, P. Limitations and Weakness of Quantitative Research Methods. Available online: <https://www.projectguru.in/limitations-quantitative-research/> (accessed on 23 March 2025).
92. Lagos State Government. About Lagos. Available online: <https://lagosstate.gov.ng/about-lagos/> (accessed on 16 November 2024).
93. Ajibade, I.; McBean, G.; Bezner-Kerr, R. Urban Flooding in Lagos, Nigeria: Patterns of Vulnerability and Resilience among Women. *Glob. Environ. Change* 2013, *23*, 1714–1725. [Google Scholar] [CrossRef]
94. LSBS. Abstract of Local Government Statistics. Available online: <https://mepb.lagosstate.gov.ng/wp-content/uploads/sites/29/2017/01/Abstract-Of-Local-Government-Statistics-2016.Pdf> (accessed on 11 September 2024).
95. Global Administrative Areas. Download GADM Data (Version 4.1)—Nigeria 2018–2022. Available online: https://gadm.org/download_country.html. (accessed on 8 February 2025).

96. Lagos State House of Assembly Bills. Lagos House of Assembly. Available online: <https://lagoshouseofassembly.gov.ng/home/bills/> (accessed on 22 March 2025).
97. Lagos State Waste Management Authority. LAWMA's Profile. Available online: <https://lawma.gov.ng/about/> (accessed on 22 March 2025).
98. Owusu-Sekyere, E. Scavenging for Wealth or Death? Exploring the Health Risk Associated with Waste Scavenging in Kumasi, Ghana. *Ghana J. Geogr.* 2014, 6, 63–80. [Google Scholar]
99. Afon, A. A Survey of Operational Characteristics, Socioeconomic and Health Effects of Scavenging Activity in Lagos, Nigeria. *Waste Manag. Res.* 2012, 30, 664–671. [Google Scholar] [CrossRef]
100. Vanguard Media. Limited Lagos Bans Cart Pushers, Wheel Barrow Operators from Streets. Available online: <https://www.vanguardngr.com/2018/01/lagos-bans-cart-pushers-wheel-barrow-operators-streets/> (accessed on 22 March 2025).
101. Ajose, T. Lagos Assembly Urges Action Against Scavengers, Manhole Thefts. Available online: <https://newscentral.africa/lagos-assembly-urges-action-against-savengers-manhole-thefts/> (accessed on 22 March 2025).
102. Ogundepo, J. Cart Pushers Return to Lagos Streets Seven Years after Ban. Available online: <https://punchng.com/cart-pushers-return-to-lagos-streets-seven-years-after-ban/> (accessed on 22 March 2025).
103. Simkus, J. Convenience Sampling (Accidental Sampling): Definition, Method & Examples. Available online: <https://www.simplypsychology.org/convenience-sampling.html> (accessed on 9 September 2024).
104. Momade, M.H.; Shahid, S.; Hainin, M.R.b.; Nashwan, M.S.; Tahir Umar, A. Modelling Labour Productivity Using SVM and RF: A Comparative Study on Classifiers Performance. *Int. J. Constr. Manag.* 2020, 22, 1924–1934. [Google Scholar] [CrossRef]
105. Książek, W.; Gandor, M.; Pławiak, P. Comparison of Various Approaches to Combine Logistic Regression with Genetic Algorithms in Survival Prediction of Hepatocellular Carcinoma. *Comput. Biol. Med.* 2021, 134, 104431. [Google Scholar] [CrossRef]
106. Breiman, L. Random Forests. *Mach. Learn.* 2001, 45, 5–32. [Google Scholar] [CrossRef]

107. Snoek, J.; Larochelle, H.; Adams, R.P. Practical Bayesian Optimization of Machine Learning Algorithms. In Proceedings of the 26th International Conference on Neural Information Processing Systems, Lake Tahoe, NV, USA, 3–6 December 2012; Curran Associates, Inc.: Red Hook, NY, USA, 2012; Volume 2, pp. 2951–2959. Available online: https://proceedings.neurips.cc/paper_files/paper/2012/file/05311655a15b75fab86956663e1819cd-Paper.pdf (accessed on 23 March 2025).
108. Zhang, L.; Pan, Y. Information Fusion for Automated Post-Disaster Building Damage Evaluation Using Deep Neural Network. *Sustain. Cities Soc.* 2022, 77, 103574. [Google Scholar] [CrossRef]

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CHAPTER THREE

3Rs (Reduce, Reuse, and Recycle) Coverage in Lagos Environmental Law: A Content Analysis

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Abstract

Despite global success in integrating the 3Rs into environmental policies, many developing countries face challenges in effective implementation. This short communication uses content analysis to evaluate the 3Rs (Reduce, Reuse, and Recycle) coverage and implementation mechanisms in the Lagos State Environmental Management and Protection Law (LASEMPLA) 2017. The analysis reveals an imbalanced focus on the 3Rs within the LASEMPLA, with recycling receiving the most attention, followed by waste reduction and minimal emphasis on waste reuse. While the legislation outlines funding mechanisms and specifies the agencies saddled with the enforcement of the law, it lacks actionable guidelines and concrete strategies for implementing the 3Rs. A comparative assessment with international best practices underscores the need for a supplementary waste management (WM) action plan that better balances the 3Rs and provides clear implementation pathways. This study contributes to the literature by demonstrating the utility of content analysis for evaluating environmental legislation in developing countries and offers practical insights for policy reform.

Keywords: 3Rs; environmental legislation; Lagos State Environmental Management and Protection Law, content analysis; circular economy, sustainable waste management

1.0 Introduction

The traditional method of waste management (WM), which involves collecting, transporting, and disposing of waste materials in landfills without treatment, poses significant threats to human health and the environment. (Salsabila et al., 2021). This approach is unsustainable as it adheres to the linear economy model, where products and materials are not utilised to their full potential before being discarded as waste (Afteni et al., 2021). In contrast, sustainable waste management (SWM) incorporates the circular economy (CE) model, treating waste as a resource that can be repurposed as raw materials in other processes. (Afteni et al., 2021). By reducing the reliance on virgin raw materials, SWM supports sustainable development (SD) and preserves finite natural resources for future generations.

SWM employs the waste management hierarchy (WMH) as a fundamental principle. The 3Rs (reduce, reuse, and recycle) form the backbone of the WMH, specifying the order of preference in the sustainable management of municipal solid waste (MSW) (Diaz, Luis, F., n.d.). These principles guide the sustainable management of MSW, prioritising reduction at the source, the reuse of materials, and recycling. However, while developed countries have successfully integrated the 3Rs into their environmental policies and waste management strategies (Luckert et al., 1996; Yoshida et al., 2007), many developing countries (DCs) struggle with effective implementation (Peprah et al., 2015; Salsabila et al., 2021). Despite references to the 3Rs in the environmental legislation of DCs, weak enforcement has hindered meaningful progress. (Ng et al., 2017).

In DCs, where non-sanitary landfilling remains the predominant method of waste disposal (Adedara et al., 2023), the adoption of the 3Rs could bring substantial benefits. For instance, waste reduction at source can significantly decrease the volume of MSW generated and subsequently reduce landfilled waste. (Mahartin, 2023), especially with land scarcity as a growing concern (Antonio, et al., 2009). Recycling allows recyclable materials to be repurposed, contributing to economic activities and providing income opportunities for those involved. (Kashyap & Visvanathan, 2014). Reuse keeps materials in circulation, extending their lifecycle and promoting the CE model (Kurniawan et al., 2022). Unfortunately, due to weak or non-existent implementation strategies for the 3Rs, unending heaps of refuse are often visible in landfills across many DCs. Coupled with poor management practices, fatal incidents such as landfill collapse and fires have been reported in some African cities. (Aderemi & Otitolaju, 2012; Aryampa et al., 2023). To effectively tackle persistent WM challenges in DCs, municipal authorities should incorporate the 3Rs into their environmental policies and seek effective

enforcement mechanisms and performance monitoring over time. Without urgent action, achieving SWM will remain elusive in many DCs.

A review of the literature on studies examining environmental legislation regarding the 3Rs reveals that developed economies have demonstrated effective implementation practices. Countries such as Germany, Austria, South Korea, and Wales have achieved recycling rates between 52% and 56%, significantly reducing landfilled waste (Gray, 2017). Conversely, most studies (Chi & Long, 2011; Wichai-utcha & Chavalparit, 2019; Widyastutie et al., 2022) on DCs primarily assess waste reduction components or analyze existing waste management legislation's performance on the 3Rs without addressing whether each R is proportionately captured or if one takes precedence over others. Furthermore, while some studies (Hall & Steiner, 2020; He et al., 2018) have applied the methodology of content analysis (CA) in the review of environmental policies, none has applied it in evaluating the 3Rs coverage in such policies. Hence, this short communication aims to address this gap by reviewing the coverage and implementation mechanisms of the 3Rs in the Lagos State Environmental Management and Protection Law (LASEMPLA) 2017 using CA. LASEMPLA consolidates the state's environmental policies, addressing waste management, sanitation, and compliance. The legislation outlines regulations governing solid waste management, wastewater management, environmental sanitation, and signage management. It also identifies relevant Lagos State agencies responsible for ensuring compliance with the law while detailing penalties for non-compliance.

Insights from this communication will assist relevant authorities in similar contexts to recognize the importance of adequately incorporating the 3Rs into their waste management legislation and pursuing effective implementation strategies. The study's methodological approach of using CA provides a systematic framework for evaluating environmental policies, which other developing nations can replicate to assess their legislative instruments. Furthermore, the comparative analysis with successful international practices offers practical examples of implementation mechanisms that could be adapted to local contexts.

3. Methodology

Content analysis (CA) was conducted to review the LASEMPLA 2017 and identify specific content related to the 3Rs. CA is the systematic analysis of qualitative data that leads to generalizations about the categories of interest to the researcher. (Haggarty, 2009). Where a researcher focuses on the frequency of a word/phrase in a document, this is known as conceptual content analysis. (Sabharwal et al., 2018). This short communication employed content analysis (CA) to systematically examine the Lagos State Environmental Management and Protection Law (LASEMPLA) 2017, specifically focusing on content related to the 3Rs principles. The study

specifically utilized conceptual content analysis, which involves analyzing the appearance and frequency of specific terms or concepts within a text. As illustrated in Figure 1, the analysis followed a systematic four-stage process that began with a comprehensive reading and document overview, followed by the identification of key 3Rs-related concepts, their categorization under the three principles (reduce, reuse, recycle), and concluded with frequency count analysis. This methodological approach was applied to an authentic PDF copy of LASEMPLA 2017. The process enabled both qualitative examination of how the 3Rs principles are represented in the legislation and quantitative analysis of their relative emphasis through frequency counting.

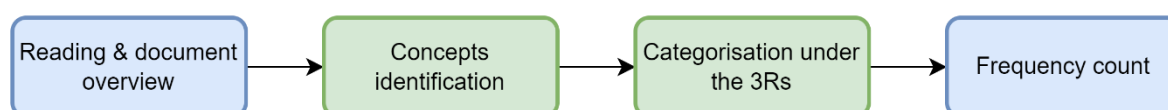


Fig. 1. Process chart of the methodology

3.1 Data collection

An authentic PDF copy of the LASEMPLA 2017 was obtained from Trees & Trees Justice Media Limited (owners of LAW Nigeria). This Nigerian-based organisation publishes laws passed by the federal and state governments in Nigeria. (Trees & Trees Justice Media, 2018).

3.2 Conceptual content analysis

The LASEMPLA 2017 comprises 526 sections categorised into 13 parts. However, since the focus of this research is to understand the coverage of the 3Rs, only three parts (2, 3, and 4 comprising sections 18, 28, 56, 57, 62, 63, 79, 88, 89, and schedule 2(7c) were considered relevant for the content analysis. These sections use some expressions that relate to the 3Rs and were first thoroughly read to get an overview of the thoughts expressed by the policymakers. Thereafter, a manual search for terms and concepts that explicitly capture the 3Rs was conducted using Acrobat 'Reader's pdf search tool. Every instance of terms/concepts related to the 3Rs in each section was then extracted and categorised under pre-defined categories of waste reduction, reuse, and recycling, and their frequencies were counted. Categorisation and frequency count of concepts extracted from text are common features of CA that have been employed in similar studies. (Hall & Steiner, 2020; Hecker et al., 2019). The document was further manually scanned for 3Rs implementation mechanisms, the enforcement agencies, and applicable penalties for non-compliance. To understand the balance between the Rs in the document, the keywords were analysed to see whether any of the Rs dominate over others.

4.0 Results and Discussion

As shown in Figure 2, the frequency count analysis of 3Rs concepts in LASEMPLA 2017 shows that waste recycling received the most attention with 16 mentions, followed by waste reduction with 10 mentions. Waste reuse received notably less coverage with only 4 mentions, indicating a significant imbalance in how the 3Rs principles are represented in the legislation.

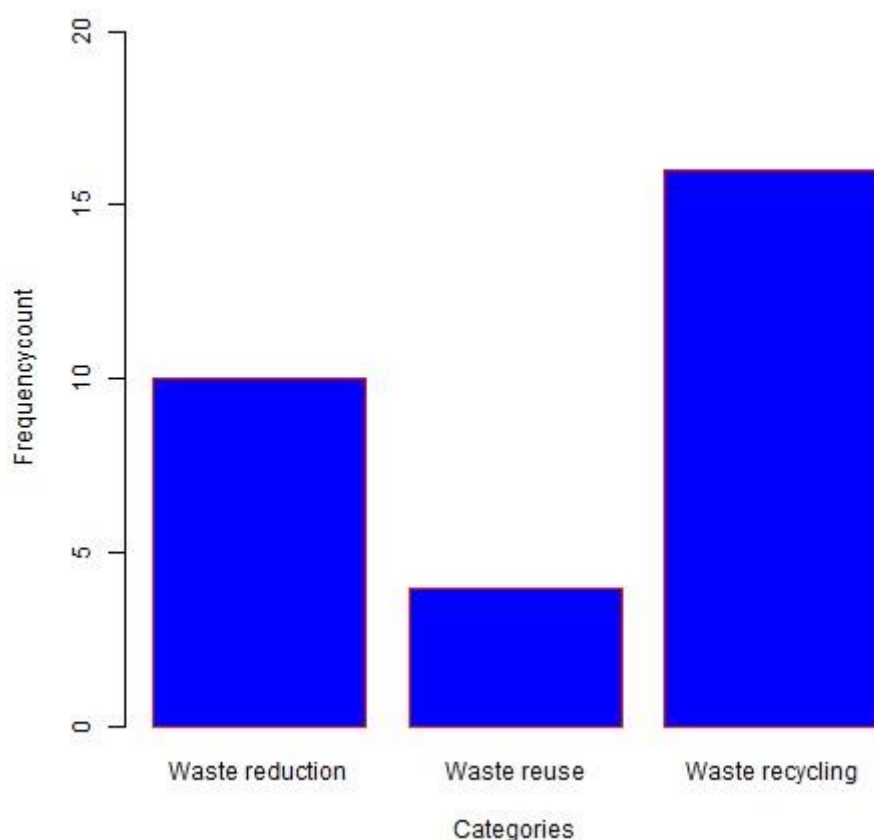


Fig. 2. Frequency count of 3Rs concepts in the LASEMPLA 2017

4.1 Waste Reduction

Fig. 2 shows that terms/concepts related to waste reduction were mentioned about 10 times in the sections reviewed. While this is higher than the emphasis on waste reuse, it is lower than the policy's focus on waste recycling. Similar policies in some Asian countries equally focus more on the reduction component as a strategy for reducing landfilled waste (Delufa Tuz Jerin et al., 2022; Widyastutie et al., 2022). A further reading of section 18, as shown in Table 1, reveals that there is no action plan for implementing waste reduction. This is much unlike in South Korea where waste reduction at source has been successfully achieved through the use of radio frequency identification (RFID), whereby the weight of waste deposited by households is logged

on chips ingrained in their access cards to waste dumpsters (Kaza et al., 2018). Rather, these sections merely stated the role of the relevant funding agency, which is to raise funds for executing projects that promote waste prevention, avoidance, and reduction. Section 56(1o) specifically states that the Lagos State Waste Management Authority (LAWMA) is to develop guidelines and targets for waste reduction at the source. This is an excellent provision in the policy, but it is unclear whether these guidelines have been made available to the public in Lagos. LAWMA can adopt a pragmatic measure similar to the South Korean example above to achieve its waste reduction targets. Section 61(1v) mentioned the fact that LAWMA is to promote research and development programmes for improved WM. The LAWMA Academy, a school where people are trained to be good waste resource managers provides a good opportunity to learn about treating waste as a resource. However, it does appear that regarding cooperation with academic researchers who work more actively on finding solutions to MSW issues, LAWMA has not been supportive enough with critical data as researchers end up working with the same old data they see in previous studies. The website of the authority hardly has records of critical data for researchers to reference. A good example to follow might be to take a cue from the Asia and Pacific regions where regular review of environmental policy performance is carried out from time to time to assess the impact of existing policies to improve on areas with obvious gaps using specific indicators (Hotta et al., 2016). Setting a clear waste reduction target like in Sukabumi City, Indonesia where the waste policy targets 30% waste reduction by 2025 (Widyastutie et al., 2022) would equally be helpful, as progress can easily be measured against such targets. The efficacy of the law at reducing landfill deposits may be far from realised if pragmatic steps are not taken to reduce waste at the source.

Table 1. 3Rs terms/concepts in the LASEMPLA 2017

Concepts & Sections	Categories	Count
18(1h) waste prevention projects. 18(1s) waste avoidance 18(1t) waste reduction. 56(1o) waste avoidance; volume reduction; source reduction; waste minimisation measures. 56(1v) resource conservation; waste reduction. 57(2c) minimization of waste.	Waste reduction	10

18(1t) waste reuse. 18(1n) reusing waste. 18(1h) waste reuse. 56(1v) reuse	Waste reuse	4
18(1h) community-based recycling. 18(1L) waste recycling business. 18(1n) recycling waste. 18(1s) resource recovery. 18(1t) campaigns relating to waste recycling. 28(4) operation of recycling plants. 56(1p) proper segregation. 56(1r) waste recycling plants. 56(1v) resource conservation techniques. 57(2c) recovery of waste. 62(4) recycling plant. 63(3f) recyclable waste. 79(2) recycling facility. 88(a) recycling it. 89(1) recycle waste. Schd 2(7c) separable for recycling.	Waste recycling	16

4.2 *Waste reuse*

As seen in Fig. 2, the policy's focus on waste reuse is by far the lowest of the 3Rs. This lopsided approach to waste reuse appears to be a recurring decimal in DCs where attempts have been made to implement 3Rs strategies (Widyastutie et al., 2022). Section 18(1h) talks about the promotion of community-based reuse projects and the funding of environmental community groups, for improved waste management by the Lagos State Environmental Trust Fund Board of Trustees (LASETFB). Again, while these are impressive provisions in the law that support the reuse of waste, it remains to be seen whether there is empirical evidence of existing waste reuse projects that the board has funded. It may also be necessary to investigate whether people in Lagos are aware that the government can fund their waste reuse projects. When people are not aware of such policy provisions, they may not be motivated to start waste reuse campaigns or participate in them. Section 18(1n) further states that local waste collectors would be trained on waste reuse. Since 2017, when the law was enacted, there has been no publicly reported case of waste collectors being trained on how to reuse waste, which further questions the implementation of the policy in this regard. An excellent example of where waste reuse and reduction have been successfully implemented can be seen in Toronto's "Community Reduce and Reuse Programmes", which is part of the city's long-term waste management strategy. Under the programme, residents are educated about the necessity of waste reuse and reduction,

opportunities are provided for people to share and repair materials, while also offering skills training and job creation opportunities (City of Toronto, 2018). Programmes like this can be tailored to the local situation in Lagos as part of the city's efforts to implement section 18(1n) of the policy in the long term. Additionally, Section 56(1v) refers to LAWMA's investment in the promotion of research and development on the reuse of waste. The efficacy of the policy in this area could be more pronounced if LAWMA's research findings on best international practices of waste reuse are communicated to the public from time to time. As of the time of carrying out this study, no such research findings have been made available by the authority to the Lagos public.

4.3 Waste recycling

Fig. 2 indicates that the policy appears to place more emphasis on the recycling of waste than reduction and reuse. This is probably because recycling is well-researched and much more globally discussed than reduction and reuse. Section 18(1L) talks about the funding of recycling-related activities by the LASETFB. The city authority's attention to recycling is evident by its investment of resources in various recycling programmes like the former Blue Box Initiative (Kadiri, Folashade, 2019), the Cleaner Lagos Initiative (Adama, 2022), and the current Lagos Recycle Initiative (LRI). The LRI targets the collection of recyclables from households through licensed recyclers across Lagos. Their collection efforts are supported by LAWMA's provision of communal waste recycling receptacles in some of its 57 LCDAs. Section 28(4) highlights that the board is also saddled with the task of funding the operation of recycling plants in the city. Perhaps if this had been properly implemented as it should, the mop-up of recyclables from the waste stream would have limited, to a large extent, the blockage of drains during the rainy seasons in Lagos. It remains to be seen whether the board uses its funding capacity to woo investors into setting up recycling plants in the city. Sections 56(1p), 57(2c), 88(a), and schedule 2(7c) are emphatic on LAWMA's role to ensure the recovery of useful waste materials through proper segregation and containerisation, for recycling. These are brilliant provisions in the law, and effectively implementing them will ensure the continuous supply of clean recyclables to the local recycling industries. However, currently in Lagos, aside from the active sale of plastic recyclables by those who earn some income from the trade, research and on-the-ground evidence has shown that the household segregation of MSW has not yet been implemented in Lagos (Adedara, 2018), resulting in low collection and coverage rates of materials needed in local recycling industries (Adedara et al., 2023). So, even if the policy promotes the establishment and funding of recycling plants, the operations of such industries will not be sustainable in the medium to long term if they lack a regular supply of clean recyclables from the waste stream. Adopting the Indian city of Pune's model, where 100% collection of MSW has been achieved through a public-private

partnership (Kaza et al., 2018) remains a good example for Lagos to consider. Section 89(1) further added that LAWMA is also to make arrangements with waste disposal contractors for the recycling of waste. Probably, the intention here is to link these contractors with recycling industries for the supply of likely contaminated recyclables, as the waste disposal contractors may not have the financial wherewithal to embark on large-scale recycling, simultaneously.

Table 2. Provisions for implementation of the LASEMPLA 2017

Sections	Implementation
5(a), 5(n)	The Ministry shall be responsible for the implementation of policies. Liaise with the agencies of other tiers of Government and donor agencies in the implementation of its environmental policies.
476. Duties of the Environmental Sanitation Corps. 476(l)	Implement the enforcement of the provisions of this Law.
57(2e)	LAWMA in collaboration with a Local Government, prepares and implements a long-term plan for the management of waste.
18(1s)	Lagos State Environ. Trust Fund (including funding enforcement.
506	The Ministry and the enforcing authority shall have a general power to enforce any of the provisions of this Law.

4.4 Implementation mechanisms

Table 2 shows that the LASEMPLA 2017 only contains general statements on the implementation of the law without actionable guidelines on how the 3Rs would be implemented. This leaves a wide policy gap that limits the realisation of sustainable WM in Africa's most populous city. Evidence has shown that it is not enough for policies to contain actionable guidelines without the policymakers seeking their implementation. For example, a study in Dhaka, Bangladesh, reviewed 24 solid WM policy documents and found that while there are well-drafted action plans in the policies, there were still obvious gaps in implementation and monitoring, which render the

policies weak (Delufa Tuz Jerin et al., 2022). However, there are some excellent examples of good policy implementation practices that might be useful for the authorities in Lagos. Singapore's pragmatic action plan, driven by scarcity of land (a similar challenge in Lagos) for continued landfilling was targeted at reducing waste generation per day and employed waste reduction, recycling, and waste minimisation strategies on a national scale. This resulted in reduced landfill disposal and an increased supply of waste materials to energy plants (Antonio, et al., 2009). In another example, Thailand came up with a National 3Rs Strategy and National Master Plan for WM where user fees were levied on citizens to reduce plastic waste generation (Wichai-utcha & Chavalparit, 2019). Equally, the Regional 3Rs Forum in Asia and the Pacific where indicators were developed to monitor the performance of 3Rs policies in these regions (Hotta et al., 2016) helps to know whether such policies fare well in the participating countries. After the formulation of actional guidelines in Lagos, LAWMA could develop indicators for measuring performance from time to time through the cooperation of its research and development department with academic researchers in WM. It is imperative to add that while policies may have all the provisions for effective implementation included, the officers charged with their enforcement must understand the objectives of such policies to ease the process of enforcement otherwise they will remain mere dreams on paper (Usman et al., 2021). A thorough reading of the entire implementation and enforcement guidelines reveals that while there are well-drafted provisions in the law, as it stands, the policy remains weak on the 3Rs without pragmatic implementation and enforcement of waste reduction, reuse, and recycling strategies.

5.0 Conclusion

This short communication examined the coverage of the 3Rs and implementation mechanisms in the LASEMPLA 2017. Content analysis of the policy revealed that while there are brilliant provisions for recycling waste, in addition to on-the-ground efforts in Lagos to support recycling, there is a lesser focus on waste reduction and the least attention on reuse. This obvious imbalance limits the combined effects of the 3Rs at achieving sustainable WM, especially in reducing the volume of landfill waste, which is imperative for efficient resource management. Notably, the absence of actionable guidelines and the lack of an implementation plan for the 3Rs inhibits the policy's performance at charting the pathway to a circular economy in Lagos. The provisions of the law on penalties for failure to comply with the policy are not specific to the 3Rs; rather, they address the generality of the regulation. Although the law empowers the LAWMA to synergise with local governments in Lagos in preparing an implementation plan for the long-term management of waste, it remains to be seen whether such powers have been utilized to design active strategies that promote citizenship involvement in the 3Rs at the grassroots level, given that local governments are closer to the people than the state government. This study recommends passing a supplementary waste management action plan in Lagos that clearly defines each of the 3Rs, balances their representation, and spells out actionable strategies for their implementation without missing out on the need for public awareness regarding the urgency of transitioning to a circular economy.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Adama, O. (2022). Garbage Politics: The Global Infrastructure Turn, Local Politics and Public-Private Partnership in Lagos, Nigeria. *Africa Review*, 15(2), 170-195. <https://doi.org/10.1163/09744061-bja10061>
- Adedara, M. L. (2018). *Assessment of the Source Separation of Household Solid Wastes in Nigeria (A case study of Alimosho Local Government Area, Lagos)* [Unpublished Master's thesis]. University of Kiel.
- Adedara, M. L., Taiwo, R., & Bork, H.-R. (2023). Municipal Solid Waste Collection and Coverage Rates in Sub-Saharan African Countries: A Comprehensive Systematic Review and Meta-Analysis. *Waste*, 1(2), Article 2. <https://doi.org/10.3390/waste1020024>
- Aderemi, A. O., & Otitoloju, A. A. (2012). An Assessment of Landfill Fires and Their Potential Health Effects- a Case Study of a Municipal Solid Waste Landfill in Lagos, Nigeria. *International Journal of Environmental Protection*, 2(2), 5.
- Afteni, C., Păunoiu, V., & Afteni, M. (2021). Study on the Transition from the Linear Economy to the Circular Economy. *Annals of "Dunarea de Jos" University of Galati, Fascicle V, Technologies in Machine Building*, 39, 49–55. <https://doi.org/10.35219/tmb.2021.08>
- Antonio, L. C., Mungcharoen, T., Mohamed, A. F., Guan, P. T., Huynh, hai T., Hotta, Y., Terazono, A., & Phechpakdee, P. (2009). *3R Policies for Southeast and East Asia* [ERIA Research Project Report 2008 No. 6-1]. <https://www.eria.org/research/3r-policies-for-southeast-and-east-asia/>
- Aryampa, S., Maheshwari, B., Sabiiti, E. N., Bukenya, B., & Namuddu, S. (2023). The Impact of Waste Disposal Sites on the Local Water Resources: A Case Study of the Kiteezi landfill, Uganda. *Ecohydrology & Hydrobiology*, 23(2), 280–289. <https://doi.org/10.1016/j.ecohyd.2022.12.002>
- Chi, N. K., & Long, P. Q. (2011). Solid waste management associated with the development of 3R initiatives: Case study in major urban areas of Vietnam. *Journal of Material Cycles and Waste Management*, 13(1), 25–33. <https://doi.org/10.1007/s10163-010-0312-y>
- City of Toronto. (2018, July 6). *Community Reduce & Reuse Programs* (Toronto, Ontario, Canada). City of Toronto; City of Toronto. <https://www.toronto.ca/services-payments/recycling-organics-garbage/waste-management/waste-reduction/community-reduce-reuse-programs/>

- Delufa Tuz Jerin, Hasna Hena Sara, Marzuka Ahmad Radia, Prianka Sultana Hema, Shahriar Hasan, Salma Akter Urme, Camilla Audia, Md. Tanvir Hasan, & Zahidul Quayyum. (2022). *An overview of progress towards implementation of solid waste management policies in Dhaka, Bangladesh—ScienceDirect*.
<https://www.sciencedirect.com/science/article/pii/S2405844022002067>
- Diaz, Luis, F. (n.d.). *The 3Rs as the Basis for Sustainable Waste Management: Moving Towards Zero Waste*. Retrieved 10 September 2024, from
https://uncrd.un.org/sites/uncrd.un.org/files/3rd-3r_keynote-address_paper.pdf
- Gray, A. (2017, December 18). *Germany recycles more than any other country*. World Economic Forum. <https://www.weforum.org/agenda/2017/12/germany-recycles-more-than-any-other-country/>
- Haggarty, L. (1996). What is content analysis? *Medical Teacher*, 18(2), 99–101.
<https://doi.org/10.3109/0142159960903414134141>
- Hall, D. M., & Steiner, R. (2020). Policy content analysis: Qualitative method for analyzing sub-national insect pollinator legislation. *MethodsX*, 7, 100787.
<https://doi.org/10.1016/j.mex.2020.100787>
- He, Z., Chu, Z., Zhao, M., Zhuang, J., & Liu, F. (2018). Policy-making coordination of municipal solid waste policies in China: A content analysis. *Journal of Material Cycles and Waste Management*, 20(2), 1073–1084. <https://doi.org/10.1007/s10163-017-0668-3>
- Hecker, S., Wicke, N., Haklay, M., & Bonn, A. (2019). How Does Policy Conceptualise Citizen Science? A Qualitative Content Analysis of International Policy Documents. *Citizen Science: Theory and Practice*, 4(1). <https://doi.org/10.5334/cstp.230>
- Hotta, Y., Visvanathan, C., Kojima, M., & Pariatamby, A. (2016). Developing 3R policy indicators for Asia and the Pacific region: Experience from Regional 3R Forum in Asia and the Pacific. *Journal of Material Cycles and Waste Management*, 18(1), 22–37.
<https://doi.org/10.1007/s10163-015-0442-3>
- Kadiri, Folashade. (2019). *Still on the LAWMA Bluebox Initiative*. Lagos State Government.
<https://lagosstate.gov.ng>
- Kashyap, P., & Visvanathan, C. (2014). Formalization of Informal Recycling in Low-Income Countries. In A. Pariatamby & M. Tanaka (Eds.), *Municipal Solid Waste Management in Asia and the Pacific Islands: Challenges and Strategic Solutions* (pp. 41–60). Springer. https://doi.org/10.1007/978-981-4451-73-4_3

- Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648-1329-0. License: Creative Commons Attribution CC BY 3.0 IGO
- Kurniawan, T. A., Liang, X., O’Callaghan, E., Goh, H., Othman, M. H. D., Avtar, R., & Kusworo, T. D. (2022). Transformation of Solid Waste Management in China: Moving towards Sustainability through Digitalization-Based Circular Economy. *Sustainability*, 14(4), Article 4. <https://doi.org/10.3390/su14042374>
- Luckert, M. K., Dosman, D., Adamowicz, W., & Laplante, B. (1996). *Waste Management Legislation in Canada*. ERA. <https://doi.org/10.7939/R3QJ77Z4X>
- Mahartin, T. L. (2023). Waste management plan with reduce, reuse, recycle (3r) method. *Journal of Sustainability, Society, and Eco-Welfare*, 1(1), Article 1. <https://doi.org/10.61511/jssew.v1i1.2023.181>
- Ng, L. S., Tan, L. W., & Seow, T. W. (2017). Current practices of construction waste reduction through 3R practice among contractors in malaysia: Case study in penang. *IOP Conference Series: Materials Science and Engineering*, 271(1), 012039. <https://doi.org/10.1088/1757-899X/271/1/012039>
- Peprah, K., Twumasi Amoah, S., & Thomas Wedam Achana, G. (2015). Assessing ‘3Rs’ Model in Relation to Municipal Solid Waste Management in Wa, Ghana. *World Environment*, 5(3), 112–120. <https://doi.org/10.5923/j.env.20150503.03>
- Sabharwal, M., Levine, H., & D’Agostino, M. (2018). A Conceptual Content Analysis of 75 Years of Diversity Research in Public Administration. *Review of Public Personnel Administration*, 38(2), 248–267. <https://doi.org/10.1177/0734371X16671368>
- Salsabila, L., Purnomo, E. P., & Jovita, H. D. (2021). The Importance of Public Participation in Sustainable Solid Waste Management. *Journal of Governance and Public Policy*, 8(2), Article 2. <https://doi.org/10.18196/jgpp.v8i2.11519>
- Trees & Trees Justice Media. (2018, March 22). *TEAM lawnigeria.com—Law Nigeria*. <https://lawnigeria.com/2018/03/22/about-us-team-lawnigeria-com/>
- Usman, M., Lamangida, T., & Akbar, M. F. (2021). Implementation of Waste Management Policy with 3R Principles (Reduse, Reuse, Recycle) in the Gorontalo City. *Journal of Public Representative and Society Provision*, 1(1), Article 1. <https://doi.org/10.55885/jprsp.v1i1.36>

- Wichai-utcha, N., & Chavalparit, O. (2019). 3Rs Policy and plastic waste management in Thailand. *Journal of Material Cycles and Waste Management*, 21(1), 10–22. <https://doi.org/10.1007/s10163-018-0781-y>
- Widyastutie, M., Kadar, I., & Wahyuni, S. (2022). Evaluation of the 3R (Reduce, Reuse, Recycle) Waste Disposal Site Program in the Context of Reducing Waste in Sukabumi City. *Journal of Science Innovare*, 4(1), Article 1. <https://doi.org/10.33751/jsi.v4i1.6113>
- Yoshida, H., Shimamura, K., & Aizawa, H. (2007). 3R strategies for the establishment of an international sound material-cycle society. *Journal of Material Cycles and Waste Management*, 9(2), 101–111. <https://doi.org/10.1007/s10163-007-0177-x>

CHAPTER FOUR

4.0 GENERAL DISCUSSION

This dissertation investigated the effectiveness of 3Rs policies in SSA cities using the lens of Lagos State, Nigeria. Three studies were conducted to obtain data to answer the research questions.

In chapter one, a systematic review of the literature was carried out to understand the status of municipal solid waste collection in SSA cities regarding waste collection and coverage rates, as well as the constraints impeding rapid progress in this area. To understand the situation in the region, four major cities – Lagos and Abuja (both Nigeria), and Accra and Kumasi (both Ghana) were critically studied to get a good overview of the current trend in MSW collection and the associated challenges. Abuja is Nigeria’s capital city and the seat of government while Lagos, Nigeria’s largest city by population is regarded as the nation’s chief commercial, financial, and marine capital [1]. To obtain an estimate of the findings from the studies reviewed in the article, a meta-analysis of the aggregated data from the studies was carried out to determine the collection and coverage rates for the region. The findings showed that in SSA, which includes Lagos, the average collection rate of MSW is 65% while the average coverage rate is 67% instead of the desired 100 [2]. The implication of this regarding implementing the 3Rs in the region is that, assumably, environmental policies on waste collection appear weak, ultimately limiting the chances of recovering useful materials for reuse and recycling purposes. Specifically, in Lagos, the study further found that, even though the private sector has been involved in waste collection since 1997 (about 27 years as of 2024), many low-income neighbourhoods still lack proper waste collection services due to road accessibility issues, among other factors. Medium and high-income areas on the other hand enjoy better waste collection services. The study concluded with recommendations on how to increase the collection and coverage rates as well as the need to limit scavenging in the city’s unsanitary landfills, in the interest of public health and the well-being of the informal waste workers.



Figure 2. Map of Ghana showing the study areas of chapter one, Accra and Kumasi [4]

In chapter two, an evaluation of the effectiveness of the ongoing LRI was carried out in three of the 20 local government areas (LGAs) in Lagos to understand the programme's impact on the diversion of recyclable wastes from landfills. Machine learning algorithms were then employed to predict the factors that motivate household recycling based on data gathered from the field

survey in Lagos. Field data was collected by administering two sets of questionnaire surveys – the first questionnaire was for the collectors of household recyclables (Appendix I), while the second was for households (Appendix II). Both surveys were conducted in the three selected LGAs. The findings from the field data collected in 2022 indicate that with a low recycling diversion rate (RDR) of 0.37%, only an estimated 2.4% of the total annual recyclables in the MSW stream in Lagos are recoverable in one year compared to the municipal authority’s 2021 target of 50%. This is a significant gap from the target and further reveals the weakness of Lagos State’s policy on the transition to a CE. The study further found that the most significant motivator of recycling in the studied areas is the waste collection time, implying that people will participate more in recycling if their recyclables are picked up in time, to avoid piling up, caused either due to space constraints, or the fact that they prefer to be paid promptly since they make some income from trading in recyclables. To improve the recycling rate above current levels, the study recommended increased public awareness about the programme and emphasized the need to address the challenges faced by the collectors of recyclables, which limit performance below their monthly targets.

A review of the Lagos State Environmental Management and Protection Law 2017 was presented in **chapter three**. Using qualitative content analysis, the paper explored coverage of the 3Rs in the document to get an overview of their proportionate representation. Implementation measures stipulated in the policy were also examined. Findings showed that the least attention is placed on waste reuse, followed by reduction while recycling takes the highest priority of the three. Unfortunately, even the attention placed on recycling does not appear adequate. The study recommended the formulation of a supplementary waste management policy where there is some balance between the 3Rs, with implementation measures incorporated, to ensure the smooth transition to a CE.

4.1 Integration and Synthesis of Results

The three studies complement each other by addressing different aspects of the waste management framework in Lagos. Jointly, they portray the connection of infrastructure, policy, and public participation in achieving the transition to a CE. Some critical findings from the three articles are discussed in the paragraphs that follow.

4.1.1 Waste generation in SSA

The annual volume of MSW generated in SSA has increased from 174 million tonnes per year in 2016 [5] to over 200 million tonnes per year as of the first quarter of 2024 [6]. Chapter one of this dissertation showed that the pace at which MSW is collected far outweighs the rate of generation [2], which continually leads to the loss of useful materials to the waste stream. The

essence of this chapter is to alert waste management authorities and policymakers in SSA on the continued rise in the volume of MSW in the region to help them better formulate policies and best practices aimed at resource recovery from waste. Chapters two and three highlight the need to formulate good policies and better waste management practices in pursuit of a true CE. Moreso, having highlighted some of the critical challenges confronting the providers of waste collection services, which impede the achievement of higher collection rates, this chapter contributes to spurring decision-makers to engage more actively with stakeholders in the waste management industry to address the lingering challenges in the sector.

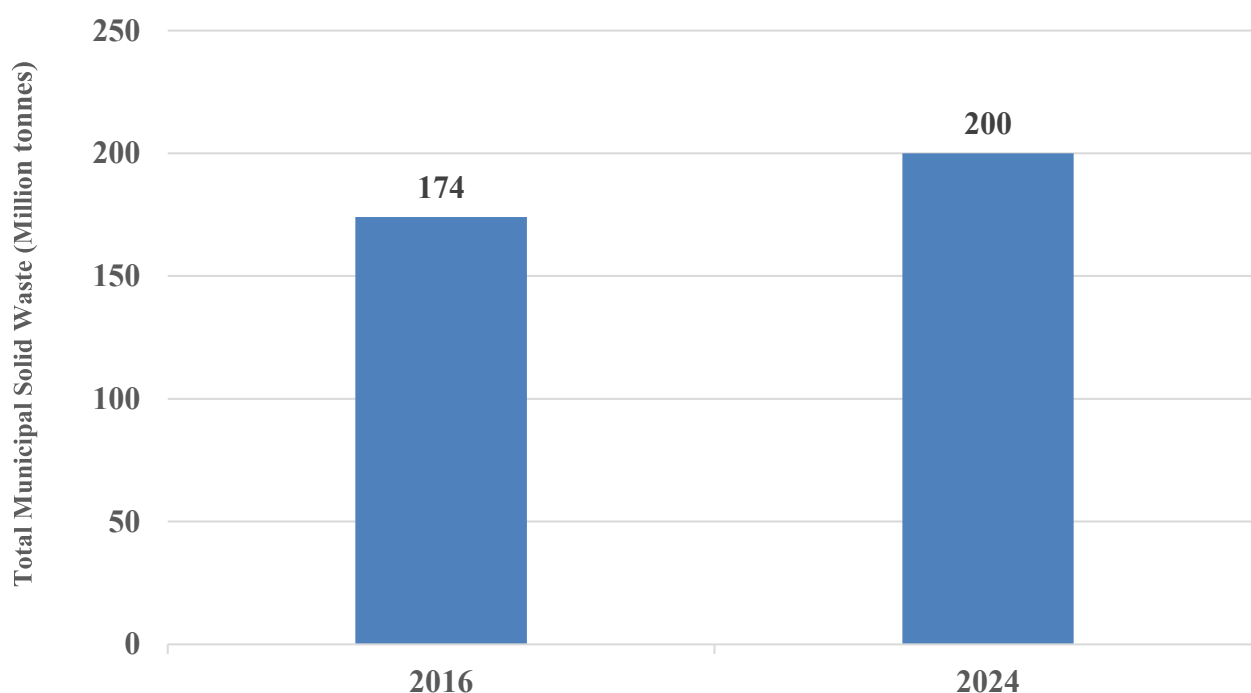


Figure 3. Striking rise in MSW generation in SSA from 2016 until 2024 [5], [6]

4.1.2 Waste collection and coverage rates

A meta-analysis of the studies reviewed in chapter one revealed an average of 65% collection rate and 67% collection coverage rate for SSA as of 2023. While this is far below the desired 100%, it represents an improvement compared to the average of 44.3% collection rate in 2012 [7] and 44% collection coverage rate in 2018 [5]. As elucidated in chapter one, the collection rate refers to the proportion of waste collected for disposal from the volume of waste generated while the collection coverage rate is the number of households with access to waste collection service, both expressed as a percentage. The improvement seen in 2023 implies that some cities in SSA have seen better performance in their waste collection services compared to previous years. However, cities such as Lagos and Abuja are still far below the previous average for SSA. Both

the collection coverage and the collection rate in Lagos and Abuja are below 40% [5], [8], indicating that municipal authorities in these cities have more work to do. As shown in chapter two, an improvement in recycling practices at the household level can contribute to increasing the volume of recyclables collected, thereby improving the collection and coverage rates. Supporting this with good policy implementation of the 3Rs as shown in chapter three can help people to understand their roles in ensuring an improvement in the waste collection system.

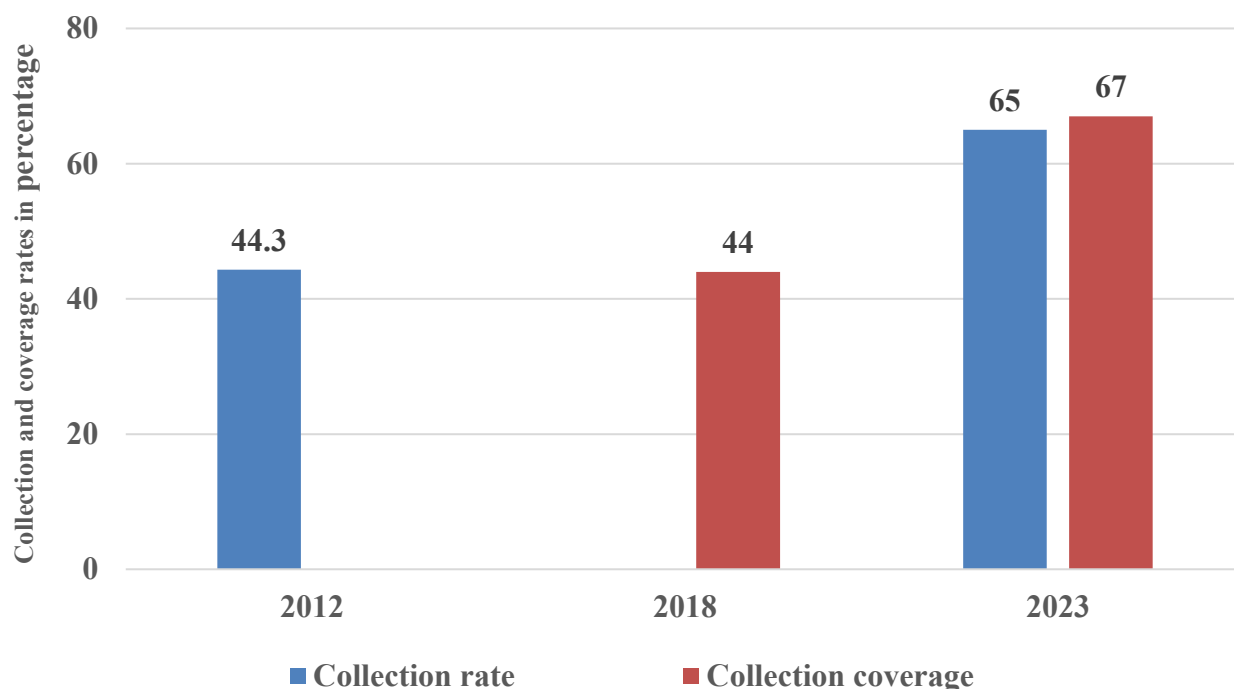


Figure 4. Collection and coverage rates average in SSA in 2012, 2018, and 2023 [2], [5], [7]

4.1.3 Potentials for waste to energy (WTE) in SSA

The organic content of the MSW waste stream in SSA is 57% on average, higher than that of South Asia at 50% and Malaysia at 45% [2]. As highlighted in chapter one, this indicates that the potential for energy generation from waste through the process of anaerobic digestion is high, if properly harnessed. Where this is supported by relevant 3Rs policies, which ensure the separation of organics from other fractions at the household level, energy generation in the region can be boosted, thereby reducing the total reliance on electricity generation from the national grid in Nigeria. Unfortunately, while Malaysia has already made progress in this area, many countries in SSA, including Nigeria are yet to tap into the opportunity, despite the high organic content in the waste stream. The continued commingling of organic waste with other fractions impedes the realisation of this potential.

4.1.4 Established private sector involvement

To ensure speedy progress in the collection and recovery of useful materials from the waste stream, the private sector plays a crucial role as the municipal government alone cannot manage the enormous volume of waste generated daily. While some private sector operators are putting their best towards a reduction in the amount of waste sent to landfills (Figures 5 & 6) by using machines to separate useful materials from mixed waste, the municipal authority can support such operations by offering tax rebates or tax holidays to cushion the high cost of operating plants and machinery with diesel-powered generators, given the epileptic electricity supply in Nigeria. Such companies can also be supported with the acquisition of more machinery that can process more waste volume per day. Additionally, the government in Lagos can equally offer support to existing private support operators (PSPs) to help them navigate through the infrastructure and logistics challenges they face in the collection of MSW from households and commercial premises across the state. Such concerted efforts will boost the collection and coverage rates in the city.



Figure 5. Separation of useful materials from mixed waste at a recycling facility in Lagos. (Researcher's field photo, 2022)



Figure 6. Collected PET plastic bottles undergoing machine compression [9]

4.1.5 Informal sector contribution

Although the Lagos State government has declared zero tolerance for scavenging on the city's mostly unsanitary landfills in the interest of public health [10], the activities of workers in this sector contribute immensely to the recovery of recyclables from the waste stream. Figure 7 shows waste pickers at a dumpsite in Lagos preparing to transport hand-picked recyclables. In many developing country cities, scavengers contribute their quota to the CE by ensuring reusable and recyclable materials are recovered from dumpsites in their contaminated form before being sorted and sold to local industries or junk dealers [11], [12]. However, in the interest of public health, as emphasised in chapter one, their activities can be coordinated and their health protected by setting up material recovery facilities (MRF) across the city where unsorted dry wastes (excluding the organic fraction) are assembled and separated in their clean form before sale to local recycling industries. The success of the MRF can be guaranteed through the formulation of a waste policy that ensures households separate their waste from the source without commingling it with organics. Chapters two and three respectively emphasize the need to improve the recycling process as well as the critical importance of formulating an appropriate supplementary WM policy that requires Lagos residents to fulfil their environmental obligation by sorting clean recyclables at the source.



Figure 7. Informal waste pickers (scavengers) preparing to transport their collections from a dump site in Lagos [13]

4.1.6 Waste diversion rate and recycling diversion rate

In chapter two, the RDR was used to estimate the progress of the LRI. The RDR is a component of the waste diversion rate (WDR) and both are indices for assessing the performance of recycling programmes in relation to landfill diversion [14], [15]. The WDR is more popularly used to estimate how much is being diverted from landfills – the formula for calculating the WDR (stated in chapter two) accounts for materials recovered from the waste stream for recycling, reuse, composting and other forms of recovery like waste to energy. However, in situations where only recycling is emphasized in a city, like the situation in Lagos, the RDR can be calculated to determine the impact of the city’s recycling programme on landfill diversion since that was the only index available during data collection. The result of this calculation in chapter two, as earlier stated in the preamble to this discussion, reveals that current efforts under the ongoing LRI are insufficient to achieve the city’s target of recovering at least 50% of recyclable materials from the MSW stream. The field survey carried out in Lagos in 2022 attests to the fact that the current number of household collectors of recyclable wastes under the current recycling programme may not be adequate to meet the collection demand, given the high volume of recyclables in the daily waste stream in Lagos. Moreover, the collectors are confronted with logistics challenges and inadequate funding for the purchase of equipment for their daily operations. Two critical issues identified are the lack of public awareness about the need to separate waste for recycling, and the inadequate provision of receptacles for waste storage before scheduled pick up. The low public awareness may not be unconnected with the low coverage of the 3Rs as explained in chapter two.

This could imply that the government's reduced policy focus on how to pragmatically implement the 3Rs equally impacts its commitment to publicising the current recycling programme. Subsequently, this affects public participation, resulting in low recovery rates as highlighted in chapter two.

4.2 Official perspectives on the Lagos Recycle Initiative – Interview with LAWMA official

A semi-structured interview was conducted with a senior official (Central Head of Recycling) of the Lagos State Waste Management Authority (LAWMA) at their head office in Lagos during the fieldwork in 2022. The purpose of the interview was to understand the municipal authority's objective of introducing the LRI. The official has been in the authority's employment since 2014 and was therefore in a good position to represent the authority on this issue. The interview analysis is added here as supplementary data since it was not included in chapter three for the reason stated in this discussion section. According to Jennings [16], in a semi-structured interview, a researcher uses a set of themes to discuss specific issues with a participant to get the interviewee's views on a particular subject of discourse. The order of discussing each theme depends on the response from the participant. Although interviews of this nature take time to conduct, they provide an opportunity for conversational exchange between the researcher and the participant.

4.2.1 Interview methodology

The semi-structured interview was divided into six sections comprising a total of 27 questions (Appendix III). The interview was recorded and transcribed verbatim using Restream audio to text transcriber [17] (Appendix IV). The transcript was thereafter compared with the original audio file to correct any errors, thereby ensuring an accurate presentation of the official's views on the questions asked. To standardise the transcript, repeated and redundant words, including pidgin English were deleted, while incorrectly used expressions were rephrased. However, the editing process did not alter the salient information gathered during the interview rather, all thoughts expressed by the participant were well captured. A copy of the edited transcript is available in the appendix (Appendix 4). The transcript was thereafter analysed using thematic analysis. Thematic analysis is a qualitative research methodology which entails identifying and analysing patterns in qualitative data [18]. Subsequently, responses given by the official in the transcript were coded into thematic categories for an easy interpretation of the interview data.

4.2.2 Interview data results and discussion

Analysis of themes developed from the interview transcript are presented and discussed in the paragraphs that follow.

4.2.3 Municipal authority's efforts at waste segregation

Lagos, among other Nigerian cities, has consistently been on the frontline of finding solutions to the challenges of MSW management through its numerous waste programmes (discussed in chapter two). As part of its efforts to improve waste collection, in 2017, the state awarded a contract to Visionscape from Dubai, United Arab Emirates, for the city-wide collection of MSW. [19]. In chapter two, reference was made to the Blue Box Initiative of the Lagos State government, which preceded the LRI. During the interview, the official revealed the reason for rebranding to the LRI. He noted that some people assumed that the non-receipt of a blue box (Figure 8) from the city government excluded them from waste segregation at the source, hence the rebranding to a name that appears to be inclusive of all Lagosians. The official emphasized that, under the LRI, the government intends that all Lagosians must sort their waste at the source to discourage the comingling of recyclable materials with residual (general) waste. While this intention is indicative of something mandatory, the existing policy in the state, as discussed extensively in chapter three points to the contrary. It is imperative to add that, the official's revelation that a mandatory recycling policy will only be put in place by the 1st of April, 2022 (still being awaited) corroborates the findings presented in chapter three that the current WM policy in Lagos (enacted in 2017) lacks the efficacy to enforce the sorting of household waste materials at the point of generation. It is worthy of note that, as of the time of writing this dissertation, the proposed mandatory recycling policy is yet to be signed into law, much less being implemented. Even the official admitted that, while it is one thing to enact a policy, its implementation is another daunting task on its own.



Figure 8. The former Blue Box Initiative [20]

4.2.4 Recycling incentives

According to the official, at the launch of the LRI in a Lagos residential estate, residents were offered the opportunity of getting electricity units provided they separate their recyclables from the general waste stream. He further stated that once mandatory recycling is implemented, Lagos residents who practice waste segregation at the household level will receive a 25% discount on their general waste collection fees. Otherwise, an increase in waste bill of about 25% will be imposed on those who do not participate in the recycling programme. Studies have shown that reward schemes like monetary incentives can motivate recycling motivation. For example, a study in Hong Kong found that the use of rewards can motivate households to increase the volume of recyclables available for collection [21], while in China, monetary incentive was identified as a significant factor motivating households to recycle [22]. In one of the discussions, the official mentioned that waste workers who work with the registered recyclers receive commissions for getting more recyclables collected, in addition to their salaries. Such incentives to recycling workers will motivate them to scout for more recyclables beyond their given targets, ultimately contributing to an overall increase in the collection and coverage rates. However, as good as incentives may appear to households, where awareness of such incentive offers is not well publicised, participation in recycling behaviour may still be limited. It is therefore essential to continually seek ways to get people motivated in recycling.

4.2.5 Waste data capture

In chapter two, it was noted that recyclers who use the Pakam app usually transmit the data of the volume of waste collected via the app to LAWMA's waste database. However, on an enquiry about this data from the LAWMA official during the interview, no such data was made available. As all efforts to get data from the authority's representative proved abortive, weekly data of recyclables collected by the recyclers extrapolated to one-year estimates was used to estimate the RDR presented in chapter two. One would have expected that since the collectors of recyclables engaged by LAWMA transmit data to the authority as they collect and weigh recyclables under the LRI programme, the authority should have been able to build a robust waste database on its website that can be easily accessed by the public. Unfortunately, this data was not available. While online reports suggest that the volume of recyclables in the Lagos waste stream is 3,500 metric tonnes per day [23] (25% of 14,000 metric tonnes per day), the official estimated that the actual volume of recyclables should be in the region of 44%. This further accentuates the incongruency of waste data typical of developing countries. More worrisome is the fact that even the data on monthly waste deposits in landfills across the state, which the authority could easily have obtained from private waste collectors working for the city government were also not made

available. This prevented a more detailed assessment of the impact of the LRI on landfill diversion in Lagos. Although the official promised to release the data of its most recent waste characterisation study, all efforts to get this during the Lagos field trip in 2022 proved abortive. As shown in chapter one, the last available waste characterisation data for Lagos was that of 2009 [24], which many researchers continually reference since no recent data has been made public. The paucity and non-reliability of waste data in many developing countries have been reported in the literature [2], [25]. This was also highlighted in chapter one of this dissertation. The implication of insufficient, or lack of data availability from WM authorities to researchers impedes evidence-based analysis of the current status of WM in developing countries, which is essential for offering appropriate recommendations to the relevant authorities. Moreso, without this data, city governments will not be able to plan adequately for waste collection services and infrastructure, thereby delaying the progression to the sustainable management of MSW.

4.2.6 Processing of collected recyclables

Insights from the interview reveal that there are three categories of players and different processes involved in the management of recyclables collected from households. As shown in Figure 9, the registered recyclers pick up recyclables from households. The planned inclusion of the PSPs (in the proposed mandatory recycling policy) will allow for competition, given the large volume of recyclables in the waste stream. This proactive step, if eventually implemented by the government concurs with one of the recommendations offered in chapter one on the need to open up the market for the collection of MSW. It would turn out to be a good approach to increasing the collection and coverage rates, thereby keeping households continually motivated to recycle their waste. The collected recyclables are thereafter taken to community recycling centres (CRCs) spread across different parts of the city for easy access to households. At the CRCs (referred to in chapter two), the recyclables are preprocessed by cleaning and machine-crushing in preparation for transport to local recycling industries that further use them as raw materials in their manufacturing processes. Findings from the interview indicated that the authority is making efforts to increase the number of CRCs in the state so that households can independently take their accumulated recyclables to government-designated CRCs for direct sale to off-takers. This approach will ensure timely payment to households engaged in the trade of recyclables, further encouraging citizenship participation. As mentioned in chapter two, a critical factor for recycling motivation is timely collection, hence the proposed option for households to sell recyclables directly to off-takers will undoubtedly address the issues of timely collection and prompt payment.

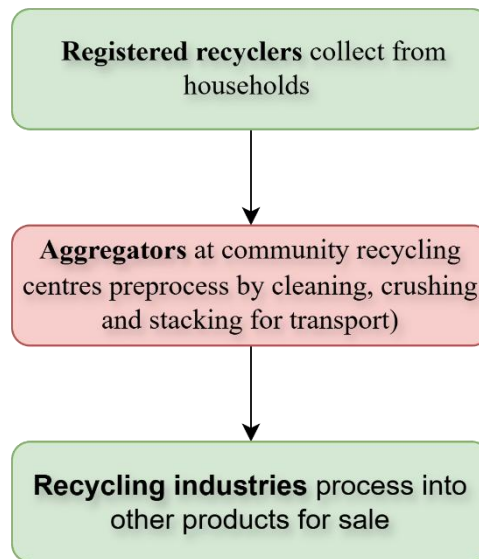


Figure 9. Actors in the management of recyclables

4.2.7 Pricing of recyclables

In response to the question on pricing, the interviewee confirmed that the collectors of recyclables determine the prices at which they are willing to buy recyclables from households. Usually, those prices are indicated in the Pakam app at the time a recycler is being onboarded on the app by LAWMA. Given the competition in the current market for recyclables in Lagos, households would normally prefer to sell to buyers who will pay them higher. This was confirmed by the researcher during the field survey of households in 2022 where some respondents complained that current buyers of their recyclables do not price them fairly, hence they prefer to patronise buyers who will offer them better value for their collections. This further affirms that financial motivation plays a crucial role in participation in recycling behaviour, as earlier mentioned. Table 1 below shows that aluminium cans and plastics (comprising PET bottles and nylon) are mostly traded on the market due to the high demand for these materials by the local recycling industries.

Table 1. Traded recyclables and their prices

Recyclables	Price per Kg (Naira)	**Price per Kg (USD equivalent)
PET plastic bottles	40	0.02
Aluminium cans	100	0.06
Cartons	30	0.02
Nylons	40	0.02
**Glass	40	0.02

Source: Field interview [26], ** added by the researcher

4.2.8 LAWMA's opinion on landfill diversion under the LRI

In a bid to compare the findings from registered recyclers (as highlighted in chapter two) with the authority's figures on landfill diversion rate, the researcher sought to know from the authority whether there had been any quantified impact of the LRI on the diversion of waste from landfills in the city since the commencement of the programme. Surprisingly, no such assessment had been carried out by the authority as of the time the interview was conducted in 2022. Rather, the authority's representative merely stated that he had heard reports from a scavenger (informal waste worker) that there has been a reduction in the number of recyclable materials in the landfills compared to the situation before the launch of the LRI. As claimed by the scavenger, it appears that workers who work with the PSPs for the collection of general waste from households separate the recyclables before loading waste to be transported to landfills into their trucks. As such, they earn some extra income in addition to their salaries. This demonstrates the rising interest in the trade in recyclables in the state and such interests could be leveraged by the city government by investing more resources and infrastructure in the LRI to enhance its performance. The net effect of such investments will be increased waste diversion from the limited landfills in the state. However, given that LAWMA has a research and development department, conducting the quantitative impact of the LRI on landfill diversion should be considered rather than relying on mere statements from informal waste workers in place of empirical evidence. Data from an assessment like this will help the authority to see the progress made with the programme, and where improvements are necessary.

4.2.9 Market for recyclables

The availability of the market for recyclables and the products made through recycling is crucial to the success of the recycling system in any society [27], [28]. Recycling industries that buy recyclables usually specify the kinds of materials in the waste stream that are useful for their manufacturing operations. This, in turn, determines the kinds of materials that traders in recyclables look out for in the waste stream. For example, in Lagos, the interview provided insights into the types of materials that are mostly traded on the market. These are polyethylene terephthalate (PET plastic bottles), polypropylene (PP), low-density polyethylene (LDPE), polyvinyl chloride (PVC), cartons, aluminium cans, and glass (Figures 10a-f). However, as stated by the official, currently in Nigeria there is no market for polystyrene even though it is recyclable. The non-availability of this market continues to pose threats to human health and the environment in Lagos as these materials end up in drainages and canals (Figure 11), resulting in blockages that eventually cause flooding of homes during the rainy season [29]. To mitigate this problem, the Lagos State government, as of January 2024, announced a ban on the use of styrofoam and single-use plastics in Lagos [30]. Styrofoam, mostly used for food packaging is manufactured from polystyrene plastic [31]. This lingering problem occasions the need for the government to attract foreign investors with expertise in this area to close the gap in polystyrene management, given this open window of opportunity in Nigeria.



Figure 10 (a-f). Types of materials collected under the LRI [32], [33], [34], [35]



Figure 10. Loads of polypropylene and single-use plastics in a drainage canal in Lagos [29]

4.3.0 Collection vehicles and household collection bins

In Lagos, poor road infrastructure in many places impedes access to low-income neighbourhoods as highlighted in chapter one. As a result, LAWMA recommends that collectors of recyclables use trucks with a capacity of one to two tons so that they can easily navigate through narrow streets to areas with low waste collection coverage. Some of the collectors make use of tricycles (Figures 12a & b) as this is faster for navigation, easy to manoeuvre between streets, irrespective of potholes, and they do not need fuel. The use of tricycles proves that challenges can motivate people to think of innovative ways of running their businesses to reduce overhead costs to a bearable minimum, while achieving their business objectives. This situation is similar to the scenario in some other developing countries where accessibility to poor residential areas poses a challenge [36], [37]. When these tricycles are well utilized, they help to improve the collection and coverage rates addressed in chapter one. It is interesting to note that although some Lagos residents did not receive the purple bags, they resorted to self-help by storing their recyclables in sacks. This demonstrates the people's commitment to participating in recycling even in the face of challenges. More results can be achieved when the necessary recycling facilities are provided.



a



b

Figures 12a & b. Tricycles for collecting recyclable wastes in Lagos [38], [39]

4.3.1 LAWMA's operational challenges

Discussions with the LAWMA representative opened up issues of critical importance that could in one way, or another affect the performance of the LRI. For example, the official confirmed that residents of some neighbourhoods in Mushin, one of the city's LGAs do not pay for waste collection instead, they prefer to dump their commingled waste along the road median (Figure 13), leaving the authority with no option than to evacuate them at its own cost. This appears to be a recurring issue across SSA [40], [41] and constitutes a stumbling block to raising the necessary funds for MSW management since the government cannot bear the huge cost alone. As noted in chapter three, an effective policy provision can address this challenge. Such a policy could mandate landlords to include the cost of waste bills in the rents paid by tenants, while the landlords remit the payments to the city government. This ensures that no tenant evades the payment of waste bills at any time.



Figure 13. LAWMA truck picking up waste lining a road median in Mushin, Lagos [42]

Another challenge is the researcher's observation of low awareness about the LRI in Lagos, even among the educated and working-class people. For example, some people in the working class who live in mainland and Island Lagos affirmed their non-awareness of the LRI. In what appears to be the official's agreement with this low awareness, he stated that the authority could not yet commence extensive media announcements when there are no adequate plans in place for the efficient collection and storage of recyclables. He further admitted that when people are mandated to sort their waste at the source and there are no collectors to pick them up in time, they could be discouraged. This sheds light on the findings from the machine learning analysis in chapter two that collection time is a significant factor in recycling motivation. A further issue of concern is the low number of registered recyclers in the state. As of 2022 when the interview was conducted, there were about 40 registered recyclers in the city. Weighing this number against Lagos' population of 26 million as of 2020 [43] implies that one recycler serves about 650,000 residents. This is unachievable, given the current challenges these recyclers are confronted with as detailed in chapter two. There is therefore an urgent need for the city government in Lagos to register more recyclers under the LRI as quickly as possible to prevent further loss of valuable waste resources to the waste stream.

4.3.2 Integration of Informal Waste Pickers into the LRI

Several studies have been conducted on the need to integrate informal waste pickers into the formal MSW system of developing countries. [12], [44], [45]. While these workers do it mostly for their daily survival, they nonetheless contribute to the active recovery of potentially recyclable materials from the waste stream. However, this activity has its associated risks, particularly due to exposure to landfill fire hazards, injuries while scouting the site, and the possibility of exposure to health hazards on the dumpsites [46], [47], [48]. To ensure the safety of informal waste pickers and the security of their income, LAWMA plans to integrate them into its Pakam recycling app in the not-too-distant future, as confirmed during the interview. When this is done, the informal waste workers will equally be able to respond to requests placed by households for the collection of recyclables much as the registered collectors of recyclables do. Given the aggressive search for recyclables by these workers, it is believed that their onboarding on the app would result in an increased collection rate of household recyclables. As recommended in chapter one, co-opting informal waste workers into the formal WM system, which was demonstrated at a revamped dumpsite in Ibadan, Nigeria [2] is not only beneficial to their health but ensures they continue to earn income for their survival. Obviously, this proposed plan by LAWMA will step up its collection drive and improve public health in the medium to long term.

4.4 Innovative recycling technology – drawbacks

To drive public engagement with the LRI, the municipal waste authority in Lagos introduced the Pakam app (Figure 14), an innovative technology that households can use to place requests for the collection of their recyclables. While this was expected to increase participation in the LRI, the machine learning analysis presented in chapter two revealed that the introduction of the app did not positively impact people’s recycling behaviour. Comparing this result with the findings from a previous study on the use of green apps to motivate recycling behaviour [49] led to the conclusion that the authority in Lagos needs to conduct a city-wide survey to understand the factors that motivate Lagos residents to use the recycling app. The outcome of such a survey could help the authority to review the app use history and find ways to better engage the public with it. It is pertinent to add that, analysis of the data obtained during the field study in Lagos in 2022 showed that 70% of the households surveyed confessed to their non-awareness of the recycling app (Figure 15), while 30% confirmed awareness of it. The non-popularity of the app could account for why its usage is low. A study has shown that sometimes, people are motivated to recycle because of the expectations from family members, friends, or neighbours. [50]. Building on the article in chapter one, a green app like the Pakam app could contribute to an increased collection rate since, as people become aware of its usage, it becomes easier for them to place more requests for the collection of their recyclables through it, thereby facilitating the government’s efforts towards increasing the volume of waste collected. This, in turn, brings the government closer to the realisation of its CE goals.

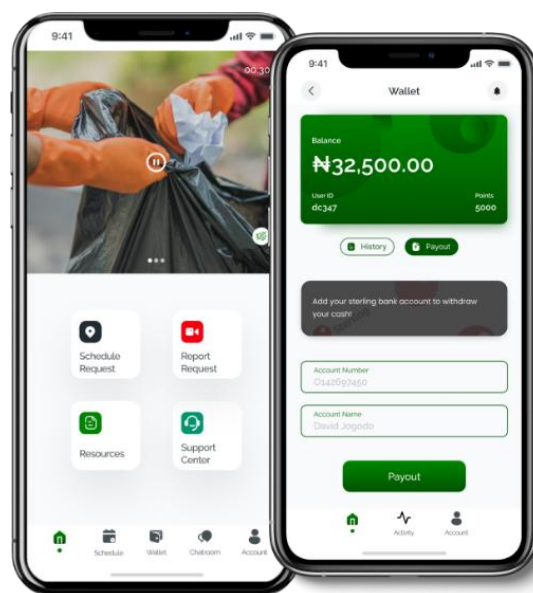


Figure 14. The Pakam App shows request buttons and payout in naira [51]

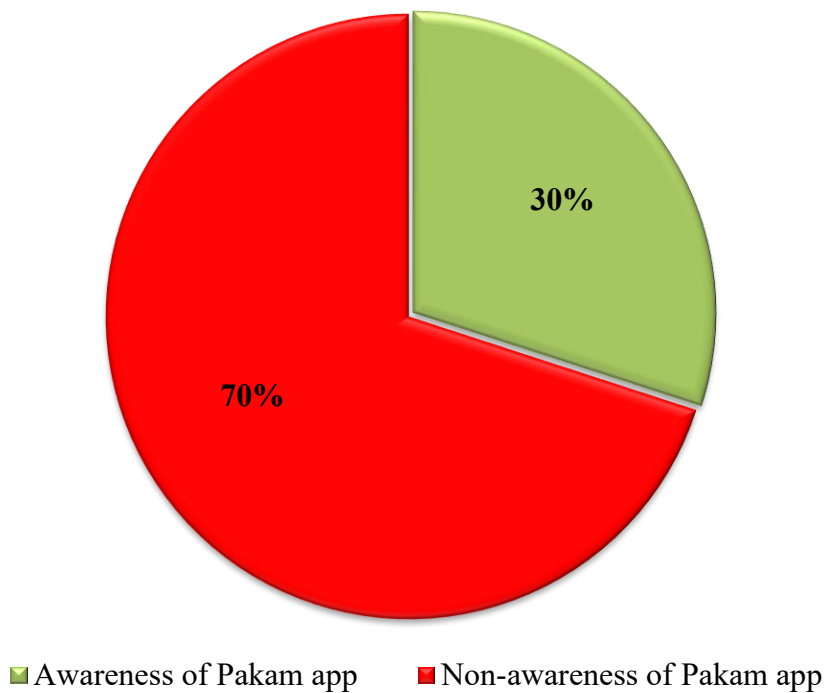


Figure 15. Respondent's awareness of the Pakam app (Researcher's field data)

4.4.1 Waste collection time and public motivation

The insights from the studies in chapters two and three reveal that recycling is a focal point in the Lagos State's policy on the environment. However, practical outcomes on the ground remain limited. In chapter two, the machine learning analysis showed that the most significant factor that motivates household recycling among the respondents surveyed is the collection time of their recyclable wastes. This has been corroborated by some studies [52], [53], and it is particularly true because interactions with some respondents during the field survey in Lagos revealed that many of those involved in the trade of recyclables either do it to earn daily income for their survival, or as a side income to substantiate their income from other sources. Given the downturn in the Nigerian economy, which has highly impacted the cost of living, these traders prefer timely collection, coupled with instant payment to enable them to meet up with the increased cost of living, worsened by galloping inflation. This eagerness to sell recyclables can be advantageous to the waste collectors provided they are well-staffed and equipped to meet the public's demand for their services. However, because they are also beset with logistics challenges, collection time is delayed and irregular. Delays can deter households from engaging in this beneficial recycling behaviour, thereby impeding the progress of the recycling initiative. Findings in chapter one suggests that when collection time is more regular, more waste will be collected, thus increasing the collection and coverage rates over time. The results presented in chapter two show that current efforts at collecting recyclables from households are insufficient to meet the city's recycling target in the face of rising waste volume. Additionally, as identified in chapter three, despite the

law's emphasis on recycling, on-the-ground efforts to increase recycling rates are currently lacking. The disconnect between the legislative intent of the Lagos government and public action underscores the need to align policies with robust public awareness campaigns, actionable guidelines for implementation, and the introduction of incentives to drive participation in recycling behaviours.

4.4.2 Waste collection infrastructure and policy

Chapter one revealed that most low-income areas in SSA, including Lagos, suffer from poor waste collection coverage, often leading to public health risks and environmental issues. In many SSA cities, when people do not receive the expected waste collection service, they often resort to self-help like waste burning and indiscriminate dumping, to get rid of the uncollected waste as quickly as possible [54], [55]. These practices have their associated environmental impacts like damage to air quality and land contamination, among others. [56], [57]. Chapter three provides context to these findings by showing that, although the Lagos State Environmental Law has good provisions for managing solid waste, the lack of actionable guidelines on waste reduction, reuse and recycling could also result in an oversight in the legislative provision for required infrastructure that can improve waste collection services. The provision of basic infrastructure like good road access, especially in areas with low coverage can potentially improve the collection system [58]. Poor road infrastructure, exacerbated by annual flooding (Figures 16a & b) can impede access to waste collection in low-income areas. This highlights how inadequate legislative frameworks can worsen infrastructure deficiencies and best waste management practices, thereby dampening the vision of sustainable WM.



Figures 16a & b. The deplorable state of roads in two of the local governments surveyed [59], [60]

4.4.3 Legislative support and policy gaps

The findings from chapter three show that the Lagos legislation emphasizes recycling far more than reduction and reuse. This imbalance in the coverage of the 3Rs can create unintended consequences, such as over-reliance on recycling as a primary waste diversion strategy, without addressing the root causes of waste generation and how to achieve waste reuse. Similar cases have been reported in some developing countries where emphasis is placed on reduction without adequately addressing recycling and reuse strategies [61], [62]. A proportionate representation of the 3Rs in environmental policies is a reflection of the government's efforts to holistically adopt CE approaches for the sustainable management of MSW. This is because each R has its distinct function. For example, waste reduction strategies help to minimize waste generation at the source, thereby cutting the cost of WM [63], [64], while also reducing the volume of landfilled waste, especially considering that space for landfilling is limited in supply in a place like Lagos [65]. Both reuse and recycling help to manage already generated waste by first ensuring they are collected in clean conditions and recirculated in the economy, thus limiting the extraction of virgin resources from the earth's finite supply. [66], [67]. When this situation is compared with the findings presented in chapter one on infrastructure gaps and the findings in chapter two on the need for household engagement in recycling participation, it becomes apparent that comprehensive MSW management requires a balanced legislative approach that gives equal representation to all components of the 3Rs. A major policy gap identified in the Lagos law is the absence of a clear provision for the implementation of the 3Rs. Like in similar climes, this is a recurring issue [68]. The Lagos law merely makes general statements about the enforcement of the entire policy and its enforcement agencies – there are no specific statements on how the public will understand the importance of each of the Rs to the sustainable management of waste in the state. Such a lack of an implementation plan weakens the policy's potency and narrows the pathway to a CE [69].

4.4.4 Cooperation between academia and government

All three studies emphasized the need for cooperation between academic researchers and the government in pursuing sustainable WM goals. For example, study one noted that there is limited research in SSA on MSW collection. Study two highlighted the need for collaboration between researchers and municipal WM authorities regarding access to critical data that researchers need for a better assessment of ongoing WM programmes of the government. Study three found that the Lagos policy includes a provision for research and development - the insertion of this provision in the Lagos law is a testament to the city government's appreciation of the role of research in shaping better WM practices in the state. Moreover, the repeated reference to this in

the three articles reveals the indispensability of research in the transition to a CE [70]. This is because researchers are mostly up to date with current issues in the field and can rely on historical data, combined with data provided by the municipal authorities, to understand the status of WM per time. Researchers can also project what the situation might likely be in the future using modern analytical tools. Researchers who work on WM issues in developing countries have continually expressed disappointment with the lack of data from the authorities [71]. This paucity of critical WM data prevents evidence-based research work and limits the progress on MSW in the region because researchers lack the data needed to understand the real issues on the ground. During study two fieldwork (chapter two), for example, LAWMA was unwilling to release historical data on landfill deposits needed for comparing the impact of its current recycling initiative on landfill diversion with the situation before the initiative was introduced. This would have shown a more vivid picture of the LRI's impact in Lagos.

4.4.5 Private sector challenges in waste management

Study one highlighted that, despite the private sector's involvement in MSW management since 1997, the companies engaged in waste collection are still confronted with challenges that limit their performance below the desired 100% collection and coverage rates. Study two also noted that the collectors of recyclables under the LRI are also beset with challenges that make them perform below their monthly targets. While some of the private sector operators face well-known similar challenges, some of them do have challenges peculiar to their businesses. The municipal waste authority in Lagos could plan a regular stakeholders' meeting where all such challenges are laid out for discussion to find lasting solutions that can enhance the performance of the private sector in MSW management. Addressing the challenges raised in such meetings will go a long way in helping the municipal government to increase the coverage of waste collection in the state.

Research limitations

This research encountered some limitations. One limitation of the first study is the geographical focus on four cities in SSA, which, while representative of the situation in the region, may not entirely capture the diversity of WM challenges across SSA. It was not feasible to include more cities because the research did not benefit from any form of external funding other than the University of Kiel's payment for the publication. Future studies could be conducted on a much larger scale where funding is available. Additionally, study two's focus on three local government areas (LGAs) in Lagos and the use of the convenience sampling technique may not necessarily reflect the situation across all the 20 LGAs. Again, this could be attributed to the lack of funding for large-scale research that incorporates at least about 10 to 15 of the 20 LGAs in Lagos. Finally,

the content analysis in study three could be expanded with interviews from key stakeholders for a more comprehensive understanding of legislative intent and enforcement challenges.

Conclusion and outlook

This dissertation's cumulative approach demonstrates that combining the quantitative methods of meta-analysis and machine learning with qualitative content analysis allows a more comprehensive understanding of WM issues concerning the relationship between policy and practice in Lagos. The studies carried out reveal that, in Lagos, the state government, in collaboration with the private sector, has indeed made concerted efforts to manage waste more sustainably in achieving a CE. However, a juxtaposition of these efforts with the reality on the ground shows that there are wide gaps between policy statements and actual performance. In essence, a continuation of business-as-usual as it is now could consistently impede the city's ability to meet its targeted 50% recovery of recyclables from the MSW stream and further exacerbate the possibility of achieving yet-to-be-set goals for waste reduction and reuse in the long-term.

The lingering challenge with the provision of a critical WM service like waste collection at the desired 100% level of efficiency attests to the fact that the city is currently not well positioned to meet the requirements of SDG (Sustainable Development Goal) target 11.6.1 which measures the tonnage of MSW collected and managed in controlled facilities against the total volume generated per day, and SDG target 12.5 on the reduction of waste generation through prevention, reduction, reuse, and recycling. Lagos largely falls short of these goals as the rate of MSW generation per day far outweighs the collection pace, leaving tonnes of waste uncollected. The resultant effects are threats to public health and the environment. Furthermore, the poor collection rate limits the chances of recovering valuable resources from the waste stream for reuse, or supply to local recycling facilities. The lopsided balance between the 3Rs in the city's environmental policy, as well as the glaring absence of actionable guidelines on their implementation, poses a challenge to the realisation of a CE in the medium to long term. The emphasis on recycling without adequate support for reduction and reuse reflects a linear waste approach rather than a truly CE model, suggesting an area for expansion in policy-driven waste minimization.

The combined findings from this research contribute to the literature on sustainable WM and CE economy models in developing urban settings. There is a need for balanced 3Rs-focused legislation to effectively support CE frameworks, particularly in developing countries where WM resources are limited. The insights from this research carry practical relevance for policymakers and WM authorities in Lagos and comparable cities in SSA. The work adds significant value to WM policy by highlighting legislative gaps and operational challenges. By providing actionable insights that target these areas, the doctoral dissertation makes meaningful contributions to

sustainable waste policy formulation in SSA. Future research could investigate why waste collection and coverage rates in Lagos are still below 70%, despite private sector involvement for more than two decades. A comparison could be carried out between Lagos and other cities where private sector efforts have yielded 100% within a shorter time frame. Alternatively, a comparative analysis of the waste collection system in Lagos and a city in the Global North where collection and coverages are at the 100% mark can be carried out to adapt lessons learnt to Lagos. However, this should be done in consideration of differences in technological advancement, level of infrastructure development, legislative differences, and the socio-economic situation in the city being compared. The findings from such research could be used to offer useful recommendations that can help to raise the collection and coverage rates beyond current levels.

References

- [1] Lagos State Government, 'About Lagos', Lagos State Government. Accessed: Jul. 11, 2024. [Online]. Available: <https://lagosstate.gov.ng/about-lagos/>
- [2] M. L. Adedara, R. Taiwo, and H.-R. Bork, 'Municipal Solid Waste Collection and Coverage Rates in Sub-Saharan African Countries: A Comprehensive Systematic Review and Meta-Analysis', *Waste*, vol. 1, no. 2, Art. no. 2, Jun. 2023, doi: 10.3390/waste1020024.
- [3] Global Administrative Areas, 'Download GADM data (version 4.1) - Nigeria', 2022 2018. Accessed: Nov. 30, 2024. [Online]. Available: https://gadm.org/download_country.html
- [4] The Permanent Mission of Ghana to the United Nations, 'Map & Regions in Ghana', Ghana Permanent Mission to the United Nations. Accessed: Nov. 30, 2024. [Online]. Available: <https://www.ghanamissionun.org/map-regions-in-ghana/>
- [5] Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648-1329-0. License: Creative Commons Attribution CC BY 3.0 IGO
- [6] UNEP, 'Global Waste Management Outlook 2024 | UNEP - UN Environment Programme'. Accessed: Aug. 19, 2024. [Online]. Available: <https://www.unep.org/resources/global-waste-management-outlook-2024>
- [7] N. Scarlat, V. Motola, J. F. Dallemand, F. Monforti-Ferrario, and L. Mofor, 'Evaluation of energy potential of Municipal Solid Waste from African urban areas', *Renewable and Sustainable Energy Reviews*, vol. 50, pp. 1269–1286, Oct. 2015, doi: 10.1016/j.rser.2015.05.067.
- [8] N. C. Anyaegbunam, 'Environmentally Friendly and Sustainable Municipal Solid Waste Management in Abuja.', *International Journal of Engineering Science Invention*, vol. 2, pp. 42–50, 2013, [Online]. Available: www.ijesi.org
- [9] Wecyclers, 'Wecyclers - Recycling! Environmental awareness Waste management!... | Facebook'. Accessed: Nov. 29, 2024. [Online]. Available: <https://www.facebook.com/Wecyclers/posts/recyclingenvironmental-awarenesswaste-managementempowermentjob-creationwe-are-pa/1588898541197503/>
- [10] Kadiri, Folashade, 'Still on the LAWMA Bluebox Initiative', Lagos State Government. Accessed: May 20, 2024. [Online]. Available: <https://lagosstate.gov.ng>
- [11] M. Medina, 'Scavenger cooperatives in Asia and Latin America', *Resources, Conservation and Recycling*, vol. 31, no. 1, pp. 51–69, Dec. 2000, doi: 10.1016/S0921-3449(00)00071-9.
- [12] M. Asim, S. A. Batool, and M. N. Chaudhry, 'Scavengers and their role in the recycling of waste in Southwestern Lahore', *Resources, Conservation and Recycling*, vol. 58, pp. 152–162, Jan. 2012, doi: 10.1016/j.resconrec.2011.10.013.

- [13] O. Dada, 'Waste pickers in Lagos tell their stories about a dangerous existence', Down To Earth. Accessed: Nov. 29, 2024. [Online]. Available: <https://www.downtoearth.org.in/africa/waste-pickers-in-lagos-tell-their-stories-about-a-dangerous-existence-84678>
- [14] S. R. Smith and S. Jasim, 'Small-scale home composting of biodegradable household waste: overview of key results from a 3-year research programme in West London', *Waste Manag Res*, vol. 27, no. 10, pp. 941–950, Dec. 2009, doi: 10.1177/0734242X09103828.
- [15] M. J. Clarke and J. A. Maantay, 'Optimizing recycling in all of New York City's neighborhoods: Using GIS to develop the REAP index for improved recycling education, awareness, and participation', *Resources, Conservation and Recycling*, vol. 46, no. 2, pp. 128–148, Feb. 2006, doi: 10.1016/j.resconrec.2005.06.008.
- [16] G. R. Jennings, 'Semistructured Interviews', in *Encyclopedia of Social Measurement*, Science Direct, 2005. Accessed: Nov. 25, 2024. [Online]. Available: <https://www.sciencedirect.com/topics/psychology/semistructured-interview>
- [17] Restream Inc., 'Transcribe Audio to Text - AI Transcription Software | Restream', Transcribe Audio to Text - AI Transcription Software | Restream. Accessed: Nov. 25, 2024. [Online]. Available: <https://restream.io/tools/transcribe-audio-to-text>
- [18] V. Clarke and V. Braun, 'Teaching thematic analysis: Overcoming challenges and developing strategies for effective learning'. Accessed: Nov. 25, 2024. [Online]. Available: <https://uwe-repository.worktribe.com/preview/937606/Teaching%20>
- [19] PR Newswire, 'Visionscape Wins Municipal Waste Management Contract for the City of Lagos'. Accessed: Dec. 01, 2024. [Online]. Available: <https://www.prnewswire.co.uk/news-releases/visionscape-wins-municipal-waste-management-contract-for-the-city-of-lagos-633838703.html>
- [20] Lagos State Government, 'The Blue Box Recycling Initiative'. Accessed: Nov. 29, 2024. [Online]. Available: https://www.facebook.com/photo.php?fbid=2754981581189757&id=492378324116772&set=a.676862885668314&checkpoint_src=any
- [21] Y. Yau, 'Domestic waste recycling, collective action and economic incentive: The case in Hong Kong', *Waste Management*, vol. 30, no. 12, pp. 2440–2447, Dec. 2010, doi: 10.1016/j.wasman.2010.06.009.
- [22] B. Lu and J. Wang, 'How can residents be motivated to participate in waste recycling? An analysis based on two survey experiments in China', *Waste Management*, vol. 143, pp. 206–214, Apr. 2022, doi: 10.1016/j.wasman.2022.02.034.
- [23] B. Oghifo, 'LAWMA Seeks Collaboration to Recycle Plastics – THISDAYLIVE'. Accessed: Jul. 04, 2024. [Online]. Available: <https://www.thisdaylive.com/index.php/2021/02/16/lawma-seeks-collaboration-to-recycle-plastics/>

- [24] T. Chibueze Ogwueleka, 'Municipal solid waste characteristics and management in Nigeria Production of biodiesel fuel from waste cooking oil View project', 2009. [Online]. Available: <https://www.researchgate.net/publication/40542918>
- [25] M. Iqbal *et al.*, 'Emerging issue of e-waste in Pakistan: A review of status, research needs and data gaps', *Environmental Pollution*, vol. 207, pp. 308–318, Dec. 2015, doi: 10.1016/j.envpol.2015.09.002.
- [26] A. Aryee and S. Rehoboth, 'Waste Resource Mapping Study for Circular Economy in Lagos, Nigeria', 2023. Accessed: Nov. 29, 2024. [Online]. Available: <https://www.dihk-service-gmbh.de/resource/blob/109332/ecfb64871f2186978aec2a1ba29523ed/2023-nigeria-umfeldanalyse-data.pdf>
- [27] D. Loughlin and M. Barlaz, '(PDF) Policies for Strengthening Markets for Recyclables: A Worldwide Perspective', *ResearchGate*, Oct. 2024, doi: 10.1080/10643380600566952.
- [28] H. Leverenz and F. Kreith, 'Markets and Products for Recycled Material', in *Handbook of solid waste management*, 2nd ed., in McGraw-Hill handbooks. , New York: McGraw-Hill, 2002.
- [29] Okayafrica, 'Lagos Government Says "No Going Back" on Styrofoam Ban - Okayplayer'. Accessed: Nov. 28, 2024. [Online]. Available: <https://www.okayafrica.com/lagos-styrofoam-ban/>
- [30] Lagos State Government, 'Lagos announces ban on usage of Styrofoams, single-use plastics'. Accessed: Nov. 28, 2024. [Online]. Available: <https://lagosstate.gov.ng/lagos-announces-ban-on-usage-of-styrofoams-single-use-plastics/>
- [31] P. Plotts, 'Extruded Polystyrene | Discover the Differences Between Extruded Polystyrene Foam & Styrofoam - Foam Equipment & Consulting'. Accessed: Nov. 28, 2024. [Online]. Available: <https://www.foamequipment.com/blog/bid/33863/what-is-styrofoam>
- [32] S. Salunke, 'Where To Buy Carton Boxes In Nigeria: Moving Boxes For Sale'. Accessed: Nov. 28, 2024. [Online]. Available: <https://expressmovers.com.ng/where-to-buy-cartoon-boxes-in-nigeria-moving-boxes-for-sale/>
- [33] P. S. Admin, 'All About Plastics: What is PVC?', *Plastics SA*. Accessed: Nov. 28, 2024. [Online]. Available: <https://www.plasticsinfo.co.za/2021/01/11/all-about-plastics-what-is-pvc/>
- [34] Distrupol, 'Riblene® LDPE'. Accessed: Nov. 28, 2024. [Online]. Available: <https://www.distrupol.com/riblene-ldpe.html>
- [35] Primex, 'Polypropylene | Extruded Plastic Sheet & Roll Stock | Primex', *Primex Plastics*. Accessed: Nov. 28, 2024. [Online]. Available: <https://www.primexplastics.com/polypropylene/>
- [36] C. J. Fagariba and S. Song, 'Assessment of Impediments and Factors Affecting Waste Management: A Case of Accra Metropolis - [v2]', 2016090012. Accessed: Nov. 30, 2024. [Online]. Available: <https://www.preprints.org/manuscript/201609.0012>

- [37] R. K. Henry, Z. Yongsheng, and D. Jun, 'Municipal solid waste management challenges in developing countries – Kenyan case study', *Waste Management*, vol. 26, no. 1, pp. 92–100, Jan. 2006, doi: 10.1016/j.wasman.2005.03.007.
- [38] J. M. Takouleu, 'Nigeria: Start-up Recycle Points wins \$30,000 at Open Mic Africa Summit', Afrik 21. Accessed: Nov. 28, 2024. [Online]. Available: <https://www.afrik21.africa/en/nigeria-start-up-recycle-points-wins-30000-at-open-mic-africa-summit/>
- [39] Copenhagenize Index, 'A community-driven, cargo bike solution to Lagos' garbage crisis.' Accessed: Nov. 28, 2024. [Online]. Available: <https://copenhagenizeindex.eu/success-stories/community-cargo-bike-solution-lagos-garbage-crisis/>
- [40] X. S. Grangxabe *et al.*, 'The Escalation of Informal Settlement and the High Levels of Illegal Dumping Post-Apartheid: Systematic Review', *Challenges*, vol. 14, no. 3, Art. no. 3, Sep. 2023, doi: 10.3390/challe14030038.
- [41] L. Parrot, J. Sotamenou, and B. K. Dia, 'Municipal solid waste management in Africa: Strategies and livelihoods in Yaoundé, Cameroon', *Waste Management*, vol. 29, no. 2, pp. 986–995, Feb. 2009, doi: 10.1016/j.wasman.2008.05.005.
- [42] Olufemi Adebimpe, 'How do normal people see nothing wrong in turning the median & the roadsides into a dumping site for their refuse because they want free disposal of their waste? All densely populated parts pf Lere and Mushin do this now. This is road going to Yaba today. <https://t.co/g2vCvwIz3d>', Twitter. Accessed: Nov. 28, 2024. [Online]. Available: <https://x.com/femiadebimpe/status/1678061049247875072>
- [43] Lagos State Resilience Office, 'Lagos_Resilience_Strategy.pdf'. Accessed: Aug. 21, 2024. [Online]. Available: https://www.lagosresilience.net/Downloads/Lagos_Resilience_Strategy.pdf
- [44] Masood M, Barlow CY. Framework for integration of informal waste management sector with the formal sector in Pakistan. *Waste Management & Research*. 2013;31(10_suppl):93-105. doi:10.1177/0734242X13499811
- [45] E. Sembiring and V. Nitivattananon, 'Sustainable solid waste management toward an inclusive society: Integration of the informal sector', *Resources, Conservation and Recycling*, vol. 54, no. 11, pp. 802–809, Sep. 2010, doi: 10.1016/j.resconrec.2009.12.010.
- [46] R. Mogul, 'New Delhi chokes as trash mountain fire spreads hazardous fumes', CNN. Accessed: Nov. 30, 2024. [Online]. Available: <https://www.cnn.com/2024/04/23/india/ghazipur-delhi-landfill-fire-intl-hnk/index.html>
- [47] E. Owusu-Sekyere, 'Scavenging for wealth or death? Exploring the health risk associated with waste scavenging in Kumasi, Ghana', *Ghana Journal of Geography*, vol. 6, pp. 63–80, 2014.

- [48] S. Nyathi, J. O. Olowoyo, and A. Oludare, 'Perception of Scavengers and Occupational Health Hazards Associated with Scavenging from a Waste Dumpsite in Pretoria, South Africa', *Journal of Environmental and Public Health*, vol. 2018, no. 1, p. 9458156, 2018, doi: 10.1155/2018/9458156.
- [49] K. K. de Wildt and M. H. C. Meijers, 'Time spent on separating waste is never wasted: Fostering people's recycling behavior through the use of a mobile application', *Computers in Human Behavior*, vol. 139, p. 107541, Feb. 2023, doi: 10.1016/j.chb.2022.107541.
- [50] A. Bruvoll, B. Halvorsen, and K. Nyborg, 'Households' recycling efforts', *Resources, Conservation and Recycling*, vol. 36, no. 4, pp. 337–354, Nov. 2002, doi: 10.1016/S0921-3449(02)00055-1.
- [51] Pakam, 'Earn-as-you-waste (Pakam Household)'. Accessed: Nov. 30, 2024. [Online]. Available: <https://www.pakam.ng/products/earn>
- [52] F. Barbariol and H. Baid, 'Introduction to an intensive care recycling program', *Intensive Care Med*, vol. 49, no. 3, pp. 327–329, 2023, doi: 10.1007/s00134-023-06983-3.
- [53] C. Tabernero, B. Hernández, E. Cuadrado, B. Luque, and C. R. Pereira, 'A multilevel perspective to explain recycling behaviour in communities', *Journal of Environmental Management*, vol. 159, pp. 192–201, Aug. 2015, doi: 10.1016/j.jenvman.2015.05.024.
- [54] K. Anokye, A. S. Mohammed, P. Agyemang, B. A. Agya, E. E. Y. Amuah, and S. Sodoke, 'A systematic review of the impacts of open burning and open dumping of waste in Ghana: A way forward for sustainable waste management', *Cleaner Waste Systems*, vol. 8, p. 100152, Aug. 2024, doi: 10.1016/j.clwas.2024.100152.
- [55] UNEP (2018). Africa Waste Management Outlook. United Nations Environment Programme, Nairobi, Kenya. ISBN No: 978-92-807-3704-2.
- [56] K. Kumari, S. Kumar, V. Rajagopal, A. Khare, and R. Kumar, 'Emission from open burning of municipal solid waste in India', *Environmental Technology*, vol. 40, no. 17, pp. 2201–2214, Jul. 2019, doi: 10.1080/09593330.2017.1351489.
- [57] S. Pillai, A. E. Peter, Sunil B.M., and Shrihari S., 'Soil Pollution near a Municipal Solid Waste Disposal Site in India', in *International Conference on Biological, Civil and Environmental Engineering (BCEE-2014) March 17-18, 2014 Dubai (UAE)*, International Institute of Chemical, Biological & Environmental Engineering, Mar. 2014. doi: 10.15242/IICBE.C0314080.
- [58] S. M. Hina, J. Szmerekovsky, E. Lee, M. Amin, and S. Arooj, 'Effective municipal solid waste collection using geospatial information systems for transportation: A case study of two metropolitan cities in Pakistan', *Research in Transportation Economics*, vol. 84, p. 100950, Dec. 2020, doi: 10.1016/j.retrec.2020.100950.
- [59] AGEGETV, 'Deplorable Roads and Streets in Agege'. Accessed: Nov. 30, 2024. [Online]. Available: <https://www.facebook.com/AGEGETV/posts/pfbid027hP9ZMieo6D9y88AEG4RAvxgrJmQmsL2fqnhRg6SX9Ybw5sz88WXrULxvMwxzHVml>

- [60] A. Daniel, 'Lagos tracker: Three bad roads in Surulere LGA that needs immediate attention', YMonitor. Accessed: Nov. 30, 2024. [Online]. Available: <https://ymonitor.org/lagos-tracker-three-bad-roads-surulere-lga-needs-immediate-attention/>
- [61] L. C. Antonio, *et al.*, '3R Policies for Southeast and East Asia', ERIA Research Project Report 2008 No. 6-1, 2009. Accessed: Oct. 12, 2024. [Online]. Available: <https://www.eria.org/research/3r-policies-for-southeast-and-east-asia/>
- [62] M. Widyastutie, I. Kadar, and S. Wahyuni, 'Evaluation of the 3R (Reduce, Reuse, Recycle) waste disposal site program in the context of reducing waste in Sukabumi city', *Journal of Science Innovare*, vol. 4, no. 1, Art. no. 1, Feb. 2022, doi: 10.33751/jsi.v4i1.6113.
- [63] S. Bandyopadhyay, 'Source composite curve for waste reduction', *Chemical Engineering Journal*, vol. 125, no. 2, pp. 99–110, Dec. 2006, doi: 10.1016/j.cej.2006.08.007.
- [64] M. Murray, 'Reducing Waste in the Supply Chain', LiveAbout. Accessed: Nov. 09, 2024. [Online]. Available: <https://www.liveabout.com/reducing-waste-in-the-supply-chain-2221088>
- [65] G. O. Ojo and D. M. Bowen, 'Environmental And Economic Analysis Of Solid Waste Management Alternatives For Lagos Municipality, Nigeria', 2014. *Journal of Sustainable Development in Africa*, Vol. 16, no.1, 2014, <https://jsd-africa.com/Jsda/Vol16No1-Spring2014A/PDF/Environmental%20and%20Economic%20Analysis%20Waste%20Mngt.pdf>
- [66] J.-P. Birat, 'Life-cycle assessment, resource efficiency and recycling', *Metall. Res. Technol.*, vol. 112, no. 2, Art. no. 2, 2015, doi: 10.1051/metal/2015009.
- [67] L. Reijnders, 'A normative strategy for sustainable resource choice and recycling', *Resources, Conservation and Recycling*, vol. 28, no. 1, pp. 121–133, Jan. 2000, doi: 10.1016/S0921-3449(99)00037-3.
- [68] Jerin, D. T., Sara, H. H., Radia, M. A., Hema, P. S., Hasan, S., Urme, S. A., ... & Quayyum, Z. (2022). An overview of progress towards implementation of solid waste management policies in Dhaka, Bangladesh. *Heliyon*, 8(2).
- [69] United Nations, 'THE 17 GOALS | Sustainable Development'. Accessed: Jan. 24, 2025. [Online]. Available: <https://sdgs.un.org/goals>
- [70] A. Genovese, B. Ponte, S. Cannella, and R. Dominguez, 'Empowering the transition towards a circular economy through empirically-driven research: Past, present, and future', *International Journal of Production Economics*, vol. 258, p. 108765, Apr. 2023, doi: 10.1016/j.ijpe.2022.108765.
- [71] A. K. Jha, S. K. Singh, G. P. Singh, and P. K. Gupta, 'Sustainable municipal solid waste management in low income group of cities: a review', *Municipal Solid Waste Management*, 2011.

GENERAL SUMMARY

This dissertation presents a cumulative analysis of challenges impeding the smooth transition to a CE in Lagos, Nigeria, with a focus on the implementation of the 3Rs (reduce, reuse, and recycle) across three interconnected studies. The three studies carried out collectively reveal the multi-dimensional challenges as well as opportunities for WM in SSA.

Chapter one gives a comprehensive overview of the status of MSW collection in SSA, revealing significant service gaps and low coverage, especially in low-income areas. These gaps contribute to indiscriminate waste dumping and open burning, posing significant public health and environmental risks. Conducting a meta-analysis of previous studies indicated that waste collection and coverage rates in the sub-Sahara are below 70%. To raise these rates to the desired 100% in line with international best practices in sustainable WM, chapter one highlighted the need to enact policies that allow for direct investments in waste treatment technologies for better management of the massive waste volume. The licence of such companies should permit them to collect the waste materials needed for their plants directly from households. This will complement the efforts of private waste collectors engaged by the government, speed up the collection pace and increase the collection and coverage rates above current levels.

Chapter two examines the effectiveness of the Lagos Recycle Initiative in the recovery of household recyclables, which contributes to landfill diversion. Using machine learning algorithms, this chapter showed that the most significant factor for participation in recycling behaviour is the timeliness of collection from households. The results highlight the need for waste collectors to address operational challenges that deter them from meeting their monthly collection targets. It also emphasized the imperativeness of public awareness campaigns, to drive participation in recycling behaviours, which can make the realisation of recycling targets easy to meet.

Chapter three employs content analysis to analyse the Lagos State Environmental Management and Protection Law 2017, focusing on the coverage and legislative support for the 3Rs. A strong legislative emphasis on recycling was found, while waste reduction and reuse are comparatively underrepresented. This imbalance in coverage suggests a need for more comprehensive policy frameworks that proportionately prioritize all components of the 3Rs in line with CE principles.

ZUSAMMENFASSUNG

Diese Dissertation analysiert die Herausforderungen, die einen reibungslosen Übergang in eine funktionierende Kreislaufwirtschaft in Lagos (Nigeria) behindern. Der Schwerpunkt der Arbeit liegt auf der Prüfung der Umsetzung des 3R-Prinzips (Reduzieren, Wiederverwenden und Recyceln) in drei miteinander verbundenen Studien. Sie belegen die mehrdimensionalen Herausforderungen sowie die Chancen für die Abfallwirtschaft in Subsahara-Afrika.

Das erste Kapitel gibt einen umfassenden Überblick über den Stand der Sammlung von Siedlungsabfällen in Subsahara-Afrika. Es zeigt die erheblichen Lücken und die geringe Abdeckung bei der Sammlung von Siedlungsabfällen auf, insbesondere in einkommensschwachen Gebieten. Diese Lücken tragen zur wahllosen Ablagerung von Abfall und offenen Verbrennung in der Stadtlandschaft bei, was erhebliche Risiken für die öffentliche Gesundheit und die Umwelt mit sich bringt. Eine Meta-Analyse zeigt, dass die Abfallsammelraten und die Abfallerfassungsraten in Subsahara-Afrika unter 70% liegen. Um diese Quote auf die gewünschten 100% zu erhöhen, die mit den internationalen Best Practices der nachhaltigen Abfallwirtschaft in Einklang stehen, sind politische Maßnahmen notwendig, die Direktinvestitionen in Abfallbehandlungstechnologien zur besseren Bewirtschaftung der riesigen Abfallmengen fördern. Lizenzen für solche Unternehmen sollten es ermöglichen, die für ihre Anlagen benötigten Abfälle direkt bei den Haushalten zu sammeln. Dies wird die Bemühungen der von der Regierung beauftragten privaten Abfallsammler ergänzen, die Sammlung beschleunigen und die Sammel- und Erfassungsraten deutlich über das derzeitige Niveau hinaus erhöhen.

Im zweiten Kapitel wird die Wirksamkeit der Lagos Recycle Initiative bei der Verwertung von Wertstoffen aus Haushalten untersucht, die zur Minderung des Müllanfalls beiträgt. Unter Verwendung von Algorithmen des maschinellen Lernens zeigt dieses Kapitel, dass der wichtigste Faktor für die Beteiligung am Recyclingverhalten die Pünktlichkeit der Abholung ist. Die Ergebnisse verdeutlichen, dass die Abfallsammler die betrieblichen Herausforderungen angehen müssen, die sie davon abhalten, ihre monatlichen Sammelziele zu erreichen. Außerdem sind Kampagnen zur Sensibilisierung der Öffentlichkeit erforderlich, um die Mitwirkung am Recycling zu fördern, was die Erreichung der Recyclingziele erleichtern kann.

Im dritten Kapitel wird das Umweltmanagement- und Umweltschutzgesetz des Bundesstaates Lagos von 2017 analysiert, wobei der Schwerpunkt auf dem Geltungsbereich und der gesetzlichen Unterstützung der 3R liegt. Die Ausführungen belegen, dass der Schwerpunkt des Gesetzes auf dem Recycling liegt, während Abfallverringerung und Wiederverwendung unterrepräsentiert sind. Dieses Ungleichgewicht in der Abdeckung weist auf die Notwendigkeit

einer Erweiterung der politischen Rahmenbedingungen hin, die allen Komponenten von 3R im Einklang mit den CE-Prinzipien eine angemessene Priorität einräumen.

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EDUCATION

- Nov. 2018 – 2025 **Doctoral Researcher in Environmental Management & Sustainability**
Christian Albrechts Universität, Kiel, Germany
Dissertation Title: Evaluating the Effectiveness of 3R (Reduce, Reuse, and Recycle) Policies in Sub-Saharan African Cities: A Case Study of Lagos, Nigeria.
- Oct. 2015 – Aug. 2018 **Master of Science in Environmental Management**
Christian Albrechts Universität, Kiel, Germany
Thesis Title: Assessment of the Source Separation of Household Solid Waste in Nigeria: A Case Study of Alimosho Local Government Area, Lagos.
- Jan. 2001 – Mar. 2005 **Bachelor of Science in Real Estate Management**
University of Lagos, Lagos, Nigeria
Thesis Title: Effects of Solid Waste Management on Environmental Quality: A Case Study of Itire & Ijesha Local Government Areas, Lagos:

WORK EXPERIENCE

- Nov. 2018 to date **Doctoral Researcher**
Christian Albrechts Universität, Kiel, Germany
- Published a peer-reviewed article.
 - Conducted comprehensive literature reviews to inform research direction and hypotheses development.
 - Utilized statistical packages to analyze data and create visualizations.
 - Collaborated with external researchers to create a network of knowledge-sharing opportunities.
- Nov. 2012 – Sept. 2015 **Retail Leasing Consultant**
Broll Property Group, Lagos, Nigeria
- Collaborated with cross-functional team members to streamline and expedite the leasing process for shopping mall spaces.
 - Demonstrated acute understanding of market trends and customer preferences to inform leasing strategies.
 - Leased about 15, 702 square meters of shop space.
 - Conducted market research to stay informed of current trends and competitor offerings.
 - Prepared weekly mall leasing report.

PUBLICATIONS

- Municipal Solid Waste Collection and Coverage Rates in Sub-Saharan African Countries: A Comprehensive Systematic Review and Meta-Analysis.
<https://doi.org/10.3390/waste1020024> (published in *Waste*, 2023).
- Evaluating Recycling Initiatives for Landfill Diversion in Developing Economies Using Integrated machine learning techniques.
<https://doi.org/10.3390/recycling10030100> (published in *Recycling*, 2025).
- 3Rs (Reduce, Reuse, and Recycle) Coverage in Lagos Environmental Law: A Content Analysis (*manuscript submitted to the Journal of Discover Environment*).

APPENDIX II

QUESTIONNAIRE FOR COLLECTORS OF HOUSEHOLD RECYCLABLES

Dear Sir / Madam,

My name is Muiyiwa Adedara. I am a doctoral candidate of Environmental Management at the University of Kiel, Germany. My research is on the assessment of 3R- related policies for sustainable solid waste management in sub-Saharan African cities using Lagos as a case study. I would appreciate your kind support in making out about 20 minutes of your time to fill out this questionnaire as it would help me to gather some data for a research article. The analysis of your responses would form part of the recommendations towards achieving sustainable solid waste management in Lagos state. Thank you.

1. What is your assigned local government area of operation?
.....
2. When did you commence the collection of recyclables in your area of operation? Please indicate the year and month.....
3. Have you been involved in the distribution of waste bins for the storage of recyclable waste in your area of operation? Yes ☐ No ☐
4. If you answered 'yes' to question 3 above, please quantify the coverage level of distributed waste bins for the collection of recyclable waste in your area of operation
☐ Less than 49% ☐ Between 50% & 79% ☐ 80% and above ☐ I have no idea
☐ Others (please specify)
5. Please indicate the frequency of the collection of recyclable wastes in your area of operation.
☐ Once a week ☐ Twice in a week ☐ Once in two weeks ☐ Once in 3 week
☐ Others (please specify)
6. What do you do with the collected recyclables?
.....
.....
7. How many trucks do you have in your fleet for collecting recyclable wastes from households?
.....
8. What is the capacity of each truck that you use for collecting recyclable wastes from households?
.....
9. Did LAWMA specify the minimum tonnage of your collection truck? ☐ Yes ☐ No
10. How many workers are attached to a waste collection truck apart from the driver?

.....
11. Do you weigh the recyclables from each household at the point of collection?

☐ Yes ☐ No ☐ Not at all times ☐ We don't have a weighing equipment

12. If you answered 'yes' to question 11 above, please give an estimate of the total volume of recyclables collected directly from households in a week in metric tonnes.

.....
13. What are the types of recyclable materials you collect from households? Please list them here.

.....
.....
.....
14. At what point in the collection chain does your operation ends?

☐ After the transfer of sorted recyclables to community recycling centres
☐ After collection from households
☐ Others (please specify)

15. Did LAWMA give you a monthly target of the volume of recyclables to be collected?

☐ Yes ☐ No

16. If you answered "yes" to question 15 above, please indicate the target volume in metric tonnes.

.....
17. Does your company have its own monthly target of recyclables to be collected?

☐ Yes ☐ No

18. If you answered "yes" to question 17 above, please indicate what this target is

.....
19. Are there challenges preventing you from achieving your weekly or monthly collection target?
Please list them below.

.....
.....
.....
.....
.....

APPENDIX III

QUESTIONNAIRE FOR HOUSEHOLDS

Dear Sir / Madam,

My name is Muiyiwa Adedara. I am a PhD candidate of Environmental Management at the University of Kiel, Germany. My research is on the assessment of 3R- related policies for sustainable solid waste management in sub-Saharan African cities using Lagos as a case study. I would appreciate your kind support in making out about 20 minutes of your time to fill out this questionnaire as it would help me to gather some data for a research article. The analysis of your responses would form part of the recommendations towards achieving sustainable solid waste management in Lagos state. Thank you.

1. Please indicate your age group

- ☐ 18 – 29 ☐ 30 – 49 ☐ 50 – 64 ☐ 65 and above

2. Please indicate your working status

- ☐ Full time worker ☐ Part time worker ☐ I'm not working (housewife, student, or retired)
☐ I have my own business ☐ I'm searching for a job

3. What is your level of education?

- ☐ Primary school certificate ☐ Secondary school certificate
☐ University / Polytechnic / College of Education certificate ☐ Others (please specify)

.....

4. Have you heard about the Lagos "Recycling Initiative?"

- ☐ Yes ☐ No

5. If you answered 'yes' to question 4 above, how did you hear about the "Recycling Initiative?"

- ☐ Roadshow in your area by popular artistes, actors or actresses ☐ Radio
☐ Television ☐ From a friend or neighbour ☐ I heard from 'Woli Arole' on social media ☐ others
(please specify).....

6. If you answered 'yes' to question 4 above, does it mean you have received the waste bin for the collection of recyclables in your neighbourhood? ☐ True ☐ False

7. If you answered 'no' to question 4 above, do you separate your waste into recyclable and non-recyclable waste? ☐ Never ☐ Occasionally ☐ Sometimes ☐ Often ☐ Always

8. What are the types of recyclable materials you separate for collection? Please list them here.

.....
.....

9. Who takes responsibility for recycling in your home? ☐ No one ☐ I am

☐ Someone else ☐ I am and sometimes someone else

10. If you have a waste bin for recyclable waste, how often is the waste collected?

☐ Once a week ☐ Twice a week ☐ One in two weeks ☐ Once in 3 weeks

☐ Others (please specify).....

11. The waste in my recyclable bin does not overflow before it is collected. ☐ Strongly agree

☐ Agree ☐ Neither agree nor disagree ☐ Disagree ☐ Strongly Disagree

12. My recyclable bin collection is **(please indicate by ticking the shape under one of the numbers below)**.

	1	2	3	4	5	
Regular	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Irregular

13. Is the recyclable waste bin given to you enough for all your recyclable wastes?

☐ Yes ☐ No

14. If I get an additional recyclable bin, I will be able to sort more recyclable waste.

☐ True ☐ False ☐ It makes no difference

15. How would you rate the recyclable bin waste collector in your area?

	Excellent	Fair	Poor
Service quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Communication	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

16. Do you use the "Pakam App" for recycling your waste?

☐ Yes ☐ No ☐ I have not heard about it ☐ I don't know how to use it

17. Does the company collecting your recyclable waste weigh the waste before loading into their truck?

☐ Yes ☐ No

18. How does your household rate recycling?

	1	2	3	4	5	6	7	
Good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Bad
Desirable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	undesirable
Productive	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	waste of time

19. How does society influence your recycling habit?

	1	2	3	4	5	6	7	
your household enjoys recycling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Your household does not enjoy recycling
people around you think it is important	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	people around you don't think it is important
people important to you like to recycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	people important to you don't like to recycle

20. What makes you feel you have control over recycling your waste?

	1	2	3	4	5	6	7	
if it easy to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	if it is difficult to do
I am motivated by the money	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	I am not motivated by the money
recycling bins are easily available	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	recycling bins are not easily available

21. What makes you more likely to recycle or not?

	1	2	3	4	5	6	7	
if the waste is collected in time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	if the waste is not collected in time
if where to drop the waste is near my home	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	if where to drop the waste is not near my home

APPENDIX IV

SEMI-STRUCTURED INTERVIEW GUIDE WITH A SENIOR OFFICIAL OF THE LAGOS STATE WASTEMANAGEMENT AUTHORITY (LAWMA)

Section 1 – The interviewee

Q.1 Please could you briefly describe your role as a LAWMA staff?

Q.2 How long have you been working with the authority?

Section 2 – Commencement of the Lagos Recycling Initiative

Q.1 Exactly when did the Lagos recycling initiative commence?

Q.2 In which of the LGAs did you run the pilot scheme?

Section 3 – Operations of the Initiative

Q.1 Please could you describe the process chain of the initiative from the collection at households?

Q.2 How much is paid to those whose recyclable wastes are collected?

Q.3 How is this payment determined?

Q.4 What are the recyclable materials collected from homes?

Section 4 – Performance assessment

Q.1 Can you provide a datasheet of the monthly aggregate volume of recyclables collected directly by household collectors of recyclable wastes from each of these LGAs: **Eti-Osa, Surulere, and Alimosho** LGAs from **January 2021 to December, 2021**?

Q.2 Can we have monthly figures of the total volume of recyclables collected by aggregators via the 'Pakam' app, or any other means in each of **Eti-Osa, Surulere, and Alimosho LGAs** from **January, 2021 to December, 2021**?

Q.3 Based on your observation, has there been a decrease in the volume of waste diverted from landfills serving **Eti-Osa, Surulere, and Alimosho LGAs** since the commencement of the Lagos recycling initiative?

Q.4 Given that landfills are receiving municipal solid wastes from **Eti-Osa, Surulere, and Alimosho LGAs**, please can we have the data of waste deposits at each of the landfills serving these LGAs from **January, 2021 to December, 2021**?

Q.5 Please can you also provide a datasheet of the volume of waste deposited at landfills serving Eti-Osa, Surulere, and Alimosho LGAs prior to the introduction of the Lagos Recycling Initiative?

Q.6 Online information shows that the Lagos waste stream is composed of **3,500 metric tonnes** of recyclables of the **14,000 metric tonnes generated daily**. This implies that **25%** of the daily Lagos waste stream is composed of recyclable waste materials. How authentic is this online information?

- Q.7** In your opinion, what impact has the incentives provided under this initiative had on the recovery of recyclables from households in Lagos?
- Q.8** How do you confirm whether all the recyclables collected from households are sold to off-takers to ensure that nothing collected is lost to the waste stream again?
- Q.9** Do you have instances when off-takers do not buy all the recyclables collected from households? If this is the case, is there any reason for this?

Section 5 – Waste collection apparatus

- Q.1** How many collectors of household recyclables are actively engaged in Lagos?
- Q.2** Can you provide information of the names and locations where these collectors are assigned?
- Q.3** can you give an estimate, in percentage, of the **coverage level of the distribution of waste bins** for the collection of recyclables in each of these LGAs: **Eti-Osa, Surulere and Alimosho**?
- Q.4** In your assessment, do you know whether the recyclable waste bins in circulation are enough to meet the volume of recyclables generated across the city, based on feedback from household collectors?
- Q.5** Has there been a demand for the supply of more recyclable waste bins from households since the initiative commenced?
- Q.6** Is there a minimum truck capacity that should be in the fleet of household collectors of recyclables?

Section 6 – Operational challenges

- Q.1** In an online report, the Lagos state commissioner for the environment mentioned that the volume of waste generated daily in Lagos is more than what LAWMA collects. Are there any operational challenges responsible for this?
- Q.2** What are the challenges you face in the discharge of your duties as an official of the authority?

Section 7 – Potentials for increased waste collection coverage

- Q.1** If the Lagos state government should allow recycling and waste treatment companies to collect the materials they need directly from households to feed their plants, thereby complementing the efforts of the PSPs and collectors of recyclables, in your opinion, what impact will this have on waste collection in the city?

Section 8 – Scavenging

- Q.1** I read online that one of the objectives of the Lagos Recycling Initiatives is zero tolerance to scavenging. Given that scavengers rely on income from landfill scouting for their survival, how does LAWMA intend to integrate them into the new initiative to protect their income base?

APPENDIX V

STANDARDISED TRANSCRIPT OF LAWMA INTERVIEW

Researcher:

Sir, please could you, briefly describe your role as a LAWMA staff?

LAWMA Official:

My name is Engineer Akimwulo Ayobami. I'm the head of recycling central for LAWMA.

Researcher:

Okay. How long have you been working for the authority, sir?

LAWMA Official

I joined LAWMA in 2014, and I've been in recycling unit since 2014.

Researcher:

Okay. Since we are assessing the Lagos recycling initiative, we want to look at the section which concerns the commencement of the Lagos recycling initiative. So exactly when did the Lagos recycling initiative commence sir?

LAWMA Official:

Now the Lagos recycle initiative, when it was launched, it didn't start as Lagos recycling initiative. It started as blue box, and that started on 5th September 2019. The program was launched by the present governor, mister Babajide Sanwolu.

The idea behind the blue box that time was that every resident in Lagos state should sort their waste from source and put it in a blue box. Anyone that doesn't have blue box at that time, we introduced a purple bag where they can put their recyclables. If you can sort your waste into multiple streams of recyclables, sort it, and you get value for the waste. Then you put it in the blue box. You then put the organic waste in the general waste bin, or you sort all the non-organic into different blue boxes for each material like cans, etc. They boxes should be well labelled. So the program was launched that time as blue box. Later on, we noticed that some people did not recycle because they didn't have blue box as they thought without the blue box, they can't recycle. Hence the name was changed and upgraded to Lagos recycle in 2020. I said upgraded. That time, when we renamed it as Lagos recycle initiative, the idea was everybody in Lagos state must sort their waste. Even as you are entering Lagos, what you think about is sorting your waste, all Lagosians. Because once you enter Lagos, you are a Lagosian. Once you leave Lagos, you are not a Lagosian.

Once you are in Lagos, you must sort your waste. That's the idea behind Lagos recycle, and that when you generate plastic waste, you recycle it. Like now, when I finish taking bottled water, I don't throw the bottle away. I keep it. That's what we want people to emulate. We want people to change their mindset from the fixed mindset of dumping their recyclables and commingling it with the general waste. We want them to change it to a growth mindset of sorting their waste from source. So which means whether you

have blue box, or not, you recycle. That's the reason for the name, Lagos recycle, which simply means everybody in Lagos should recycle. We upgraded the program by introducing an app that works in form of Uber. That's the Pakam app. We are now in the computer age, we are now in the digital this thing and you can stay in the comfort of your home and request for people to come and pick up your recyclables. You have a your wallet on your app. On that app, whenever they come to pick, they wait and input it on the app. The app automatically calculates the value of your recyclables in your app wallet. Anytime you want to collect your money, whether it has accumulated to 5000 naira, 10,000 naira, you click on it. The app will request for your account number and you submit it. Then we get the information from our back end and the recycler will pay the person.

Researcher:

Okay. That was quite comprehensive enough.

LAWMA Official:

Yeah.

Researcher:

Sir, in which of the LGAs in Lagos did you run the pilot scheme?

LAWMA Official:

We ran a pilot scheme with the bluebox at the LSDPC Estate, Adeola Odeku, Victoria Island. At the time we ran the pilot, the app had not been introduced. What we did that time was once people sort their waste for a certain period, the people that sorted their waste most were given electricity unit as an incentive just to see the response of people. Later, we launched the initiative with 5 different recyclers. As of now the number has increased to over 50 recyclers collecting the recyclables. But the pilot was done at Adeola Odeku with just a recycler.

Researcher:

Okay. Because I also read online that, there was a pilot done in Surulere.

LAWMA Official:

Yes, after that, we moved to Surulere. We ran another pilot at the LSDPC Estate. We ran the pilots in the organized estates because we believe they are more organized. So we ran this in Surulere, LSDPC Estate, Akerele.

Researcher:

Okay.

LAWMA Official:

Yes.

Researcher:

That's quite beautiful. So, sir, we move to section 3, operations of the initiative. Please, could you describe the process chain of the initiative from the collection at households?

LAWMA Official:

The process of the initiative from the collection at household. Now this is how it's done. The household sort their waste from source. At the launch of the programme, we had a lot of recyclers who showed interest. They submitted their application based on the location where they want to operate. Now let me use Surulere as an example. In Surulere, we have 3 different companies, recyclers, that go from door to door. Once the recyclables are sorted from homes - the household. We advice them to use two approaches - the first one is to download the pakam app. Once they have download the pakam app, the recyclers, the 3 recyclers within that location, will see the request of that person that is around Surulere. Anyone that accepts first will go there to collect.

Another thing we did as a backup for the recycler, LAWMA is also a recycler on the Pakam app, and we are open to all local governments. So if the person in Surulere is not picking up, we have an intervention program to go and pick up because one thing is, the recycler could have a tight schedule, and he won't be able to go there on time. Hence LAWMA moves in, pick up and hand them over to the recycler.... So it's collection request through Pakam. The resident requests through Pakam after they might have sorted their waste. The recycler accepts the request. The address will be there. They go there to pick it up and input the weight. The recyclers have their own app, their own Pakam collector's app. The households also have their own Pakam household app. Immediately the recycler collects they input it in their own collector's app. Then the weight, the value in naira is reflected in the person's wallet on the app.

Researcher:

Okay. So what now happens when the aggregators collect from the households? Where do they now take the recyclables.

LAWMA Official:

Now when the aggregator collects from the household. The aggregator is working for a recycler, like the Weecycler or the Mondo4africa or the Sweep Foundation that is in Surulere. Then let's say the collector from Sweep go to the households to collect. After collecting from the household, they take it to Sweep facility within Surulere area. We call something community recycling center, which belong to Sweep. Mondo4africa have their own. It belongs to Mondo4africa. Weecyclers have their own. So If any of their collector collects, they take to their facility where they now crush. After crushing, they take it to a recycling company. Recycling is a value chain. We have people that collect, under which Sweep Foundation and all these people are categorised. We have people that preprocess the recyclables, which Mondo4africa fall under. But we have company that processes into finished product. That's the 3rd category. So the Mondo4Africa after crushing them, they now take to the company, the likes of Alkem, the likes of Lexis, the likes of Lucky Fibre that process them into finished products. Do you know that Lucky Fiber in Lagos processes the recyclables into human hair and all those things?

Researcher:

Okay. That is fantastic. That's a lot of use is being put to the recyclables. Okay, sir. Let's look at this next question. How much is paid to those whose recyclable waste are collected from the households?

LAWMA Official:

From the household. One thing in Nigeria is that the prices of recyclables fluctuate, and I believe it will be like that throughout the world. The prices fluctuates. So presently, what they pay to them, even let me use last year. As of December last year, per kg for PET bottles, they pay them 40 naira per kg. When the recyclers go there to collect, not that they pay the households immediately, except they have that volume. But somebody will just give you 5 KG. So that value for 5 KG will be in their wallet. As they are doing this, the money is accumulating in their wallet. Once they have aggregated up to 500 KG, you multiply that by 40 naira, which is the value of 1 KG. They then pay them 20,000 naira.

Researcher:

Okay.

LAWMA Official:

Do you get it? Based on whatever volume they have accumulated over a period of time. Do you get my point?

Researcher:

Yes. very clear.

LAWMA Official:

So over a period of time. For example, for carton now, they do pay them 30 naira. For cans, they do pay them 100 naira.

Researcher:

Per KG?

LAWMA Official:

Per KG. So on the app, the value for each material and for each recycler varies. Let's say for Sweep Foundation that is in Surulere. When Sweep is onboarded on the Pakam app, as it's registering on Pakam app as a collector, he's inputting his own value, the amount he will buy those materials from the household. The system automatically enters it for Sweep. So when the collector aggregator from Sweep goes to collect, the value the Sweep foundation has inputted for those things, that's what the system will use to calculate it. So it could be 40 naira for PET, 30 naira for carton. 100 naira for aluminium can. So, like the nylon, it could be 40 naira as well.

Researcher:

Okay. Now your explanation has answered question 3, which is how is this price determined? From that explanation, it's clear. So the next question will now be, what are the recyclable materials collected from homes?

LAWMA Official:

The recyclable materials collected from homes: plastic, the the PET. And You know?, when you talk about plastic, we have 7 types of plastics. So mostly, all collected from home, out of the 7 plastics is PET, pure water sachets, which is LDPE, the regular household plastic, which is, PP, polypropylene. Then another plastic, PVC pipe is also collected. HDPE is also collected from homes. So aside the plastics, another material collected is carton. Carton is collected, glass is collected. Aluminium cans are also collected. Those are the major household materials.

Researcher:

Okay. Beautiful. That is clear enough sir. We now move to section 4, sir, performance assessment. We are referring basically to how the initiative has performed working with LAWMA and the aggregators, the collectors, the likes of waste city, and all of that. So our first question sir is, can you provide a data sheet of the monthly aggregate volume of recyclables collected directly by household collectors of recyclable waste from each of the LGs we are looking at, which is, Eti-Osa, Surulere, and Agege local governments from January 2021 to December 2021.

LAWMA Official:

January, that was for last year. Now, as regards this, you know, LAWMA has an admin part of the Pakam app that we can get this, but we will not get for the whole Lagos State. But for you to get this, I believe the recyclers, the recyclers you are working with, like, the ones in Surulere. If you ask each of them for their data from January to December last year, they will give you, you can now sum them.

Researcher:

Sum everything up. Okay. They gave some data, but, I wanted to wait for LAWMA values from January 2021. So maybe I'll go back to them and see if they can.

LAWMA Official:

Yes. On our end if I open Pakam app for you, we monitor their activities for whole state.

Researcher:

Okay.

LAWMA Official:

Do you get it? For the whole state.

Researcher:

Okay. So question 2. Can we have monthly figures of the total volume of recyclables collected by aggregators via the app?

LAWMA Official:

Yeah. That's what I just said. You will get but it won't be for these 3 local governments alone. It will be for the all the local governments.

Researcher:

Then we can extract the ones for these 3 local governments.

LAWMA Official:

Hmm..I don't think so. It would have summed up all the volume.

Researcher:

Okay.

LAWMA Official:

You know it will be cumbersome when you are saying for local governments.

Researcher:

Okay. We'll work around it when we are doing the study. So question 3. Based on your observation, has there been a decrease in the volume of waste diverted from landfills serving these 3 local government or let's say in the whole of Lagos state because the essence of our study is to see the impact of the initiative on landfill diversion.

LAWMA Official:

Yes. You know, first and foremost, you know, this initiative, to an extent, it is new. You know LAWMA was established in 1977. What people have been doing since 1977 till 2019. You know it will be a bit difficult to change their mindset. And it's when you change their mindset totally that you can feel that impact. Fine, there is impact. It's because we have some people at the landfill called scavengers.

Researchers:

Yes, I'm aware of these people.

LAWMA Official:

So from my interaction with one of the scavengers 2 weeks ago, he now said, ah, sir - the recyclable materials don't get to the site like before.

Researcher:

Okay

LAWMA Official:

People are now getting the materials from home, even the people working with the PSP. All those workers working with the PSP companies, they would have scavenged those materials, they would have picked those materials even from homes. Do you get it? So even someone still called me yesterday that they want to register their association - PET – people that are doing PET they want to register it as an NGO so that anybody that is doing PET they will be able to fight them. So it means the material is not going to the landfill. They are not getting that much material again. They now see that everybody is now doing PET. Do you get my point? So the effect is showing gradually on the landfill, what goes to the landfill in terms of recyclables. But, one thing is, it will still take some time to get that, let's say, 70% diversion. Diversion because it's a process. Like, you are starting a process, and you need to change people's culture. You need to change their mindset and everything.

Researcher:

Okay. Now given that there are landfills receiving municipal solid waste from Eti-Osa, Surulere and Agege LGAs, is it possible to have data of waste deposit at each of these landfills? For example, I know

you have landfills, that may not serve this LGAs separately, but let's say, okay, in the whole of Lagos state. So maybe from PSP deposit, that will be able to tell us what is going on at the landfill site? This is what is going on.

LAWMA Official:

This is fine. If I have access to those data, I will have to call the MD. Okay. The approval is beyond me.

Researcher:

Okay. I will speak to Mrs Jirinsola and see the possibility if we can. Okay. So, sir, question 5.

Can we also have a datasheet of the volume of waste deposited at landfills in Eti-Osa, Surulere and Agege prior to the introduction of the Lagos Recycling Institute?

LAWMA Official:

Yeah. Yes. All the information is still through the MD.

Researcher:

Okay. Question 6, sir. Online information shows that the Lagos waste stream is composed of 3,500 metric tons of recyclables out of the 14,000 metric tons generated daily. This implies that 25% of the daily Lagos waste stream is composed of recyclable waste materials. How authentic is this online information? I read that online.

LAWMA Official:

Even the volume of recyclables should be more than this because if out of the total waste generated, it's 45% organic, which means the remaining 55%, you have, let's say you have fines. Fines will be, like, 1%. You have, putrescibles let's say like 2%. So out of 55, you have 52. One thing is the value is more than 25%.

Researcher:

Okay.

LAWMA Official:

Because plastic alone is, like 15%. You have metals there. You have paper, which is recyclable. You have tyres. Do you get my point? So it's more than 25% that is recyclable. So maybe that information is not correct, because one thing about waste characterization is when you do it today, you still need to do it after 5 years to see because what people generate, waste generation depends on 2 things, the population and the socioeconomic value.

Researcher:

Yeah.

LAWMA Official:

The socioeconomic value of Lagos state is increasing every day.

Researcher:

Sure.

LAWMA Official:

Do you get it? Like, people...the level of literacy now, you can't compare it to what you had before. The social economic value has increased, and people are spending money on more things. So the characterization changes over time. Maybe when this study was done, that was the case. I believe it might have changed.

Researcher:

Okay. So, how do we get the current figures of, ... daily generation?

LAWMA Official:

I'll help you look for it.

LAWMA Official:

The waste, the last waste characterisation done, I will help you get it.

Researcher:

Okay.

LAWMA Official:

I believe when you see the waste characterization of Lagos State.

Researcher:

I can pick the data from there.

LAWMA Official:

You can pick the data that if organic is 55%, fine is 1%. This so the remaining recyclable is you can calculate percentage and estimate that at least it is 40% of....

LAWMA Official:

Okay. Because what I read online, there was a paper written by one Ogwueleka in 2009. Most, authors refer to that value. There was a waste characterisation done for Lagos, which is far away.

LAWMA Official:

We did another waste characterisation in 2015. We have even done another one recently, but I don't have access to that one. I think they did one last year May, but I don't have access to the data. I don't think it's out yet. So, it depends.

LAWMA Official:

But the one we did in 2015, I can still get it.

Researcher:

Yea. That will be fine if we can get for 2015. we can still work with them.

Okay. So, sir, I think, you have, in a way, answered this question, but just to recap it, in your opinion, what impact has the incentives provided under the initiative had on the recovery of recyclables from households.

LAWMA Official:

That's it now. The incentive. One thing is people, you know, people their mindset, fixed mindset because they commingle their waste. They don't sort it. Now if you say you want them to be sorting it, an incentive must be attached. When you talk about money, they are ready to do whatever you ask them to do.

Researcher:

Okay. Yes. Question 8. How do you confirm whether all the recyclables collected from household are sold to off-takers to ensure that nothing collected is lost again to the waste stream?

LAWMA Official:

The people collecting the recyclables, the aggregators they work with the off-takers now. So whatever they go outside there to collect, that's what they will be paid. They will be paid based on that.

Researcher:

So they will always ensure that nothing is lost?

LAWMA Official:

Yes. Because they'll find they have a fixed salary. Let's say somebody working for Sweep Foundation as a rider, we call them aggregators as well. He gets a fixed amount of 20,000 naira and gets a commission based on whatever he takes to the facility from outside. So there's no way he will want to lose what he collects.

Researcher:

take it back again and lose it?

LAWMA Official:

No. No. No.

Researcher:

Because I even saw the other man I was with yesterday at Agege. One of those referred to me by Gideon Retreasure. The man has a place where he keeps the clean pet bottles, and he guards them so much that nobody should take them.

LAWMA Official:

They are recyclables, you can't take them back to the general waste stream. The only thing that can happen is, if you gather recyclables now, and you keep them here. If care is not taken out, another person will steal them and nd sell them, but it's not going back to the comingled waste stream. No. It could be stolen if care is not taken. For someone to go and steal it, it means people are now seeing value in it.

Researcher:

Okay. I think you have basically answered question 9, which is, do you have instances when off-takers do not buy all the recyclables collected from households? If this is the case, is there any reason for this? Probably maybe they say it's not clean enough. It will cost us money to clean.

LAWMA Official:

Not at all. You know polystyrene can also be recycled. But presently in Nigeria, we don't have people doing polystyrene. It can be converted to electrical board. But presently, you don't have people doing it. So if a recycler collects...they won't even collect it

Researcher:

Because there's no market for it.

LAWMA Official:

There's no market for now. But let's say, someone is selling cans, that's hot cake. They will collect it. I can say it's that polystyrene that is a major challenge. Before, all these black bags, black shopping bags they did pose some challenges in recycling, but people have gotten a solution to that. People now collect and recycle them. All these laminated nylon before, 10, 5 years back. They don't collect them. But now the technology has improved, Nigeria has improved as well. The polystyrene is one of our major challenges, and that's why when you go to our drainages and canals you see that most of the canals are blocked with polystyrene even more than the PETS. Even PETS now you see people take nets into the river as if they want to catch fish from the river to collect them

Researcher:

Beautiful, sir. So section 5, we're almost done. Just a few more sections. Section 5, waste collection apparatus. How many collectors of household recyclables are actively engaged in Lagos officially?

LAWMA Official:

Mhmm. Are actively engaged in Lagos, like 40.

Researcher:

Okay. Can you provide information of the names and locations where these collectors are assigned? I think that has been done because you have given me these contacts. So that's that knocks up that. I thought I would be able to do this interview before I went to the field.

LAWMA Official:

Yeah. Yeah.

Researcher:

Okay. So question 3, sir. Can you give an estimate in percentage of the coverage level of the distribution of waste bins for the collection of recyclables in each of the 3 LGAs, Eti-Osa, Surulere, and Agege?

LAWMA Official:

This is it. The bins. For me, to put the burden of bin distribution on government, bins are expensive. But what government did we to introduce a purple bag, which is reusable. It's thick. So once you put your recyclables in them, the recycler comes to collect it, they empty it and give you the nylon back. And the nylon can be recycled. Again, there was a time we did some biodegradable nylon as well. But we are not using that much, but the synthetic nylon can also be recycled. And if you tell the households to to buy bin, it's expensive and will be too much for them. You want someone to start something, and you're still putting

the burden of buying the bin. So government, what we do presently is we give them purple bags to sort their waste.

Researcher:

Okay.

LAWMA Official:

And some of them normally use sack. Sack is even good. It can be reused several times because it's plastic as well and it's PP.

Researcher: Yes. I saw the receptacles they use, very wide like this. I saw it. Okay, sir. I think that is fine. In your assessment, sir, do you know whether the recyclable waste bins in circulation are enough to meet the volume of recycling we generated? I think this has also been answered. So that knocks off this particular question we asked earlier. So, sir, question 5, has there been a demand for the supply of more recyclable waste bin from households since the initiative commence? That has also been answered by your explanation. So is there a minimum truck capacity that should be in the fleet of household collectors or recyclables in terms of tonnage?

LAWMA Official:

Yes. In terms of tonnage. Fine. What we do to encourage people is, you know when you are collecting from households it's different from when you're into a container.

Researcher:

Yes.

LAWMA Official:

So we normally encourage them to use smaller truck between, let's say, 1 to 2 tons capacity.

Researcher:

1 to 2 tons? For easy navigation.

LAWMA Official:

For easy navigation, and you know, traffic and all those things entering inner roads. Not that you want to be collecting from people on the express. So but when you use one mighty truck, you won't be able to enter the inner streets. So we encourage the mini, all these Dyna 150, LT 40, all these mini trucks.

Researcher:

Okay. I also see the Wecyclers, people, they use, tricycles.

LAWMA Official:

And also the tricycles. You can convert your bicycle and your motorcycles to tricycles, put tyres, put carrier on the back so that you can easily access all these inner streets.

Researcher:

Okay, sir. That's fine. Fair enough, sir. Section c is operational challenges. In an online report, the Lagos state commissioner for the environment mentioned that the volume of waste generated daily in Lagos is more than what LAWMA collects. Are there any operational challenges responsible for this?

LAWMA Official:

Now. The way LAWMA is structured is this. LAWMA is a regulatory body. We have some PSPs working with LAWMA. The PSPs presently are over 400, close to 500 and before you can be a collector for LAWMA you should have a minimum of two trucks. It means we have over 800, close to 1000 trucks in operation. Can you get my point? Now the truck we use for collection, do you get it? Presently govt just acquired 100 trucks, brand new trucks as an intervention so that they will serve as intervention trucks for the company. So in terms of the waste management that time, we didn't have those new trucks. Maybe that was when he gave that statement. And presently now, the PSPs are even investing more. Before the present MD got into the office, the PSPs were 300 plus. After that, we've seen some people investing in the waste collection business. The truck is not one or two naira. To get a new truck It's like 20,000,000 million naira, 15, 20 million, or so.

Researcher:

Yes. I know they are usually imported from, mainly Europe or some other countries. okay, sir. That's fine. What are the challenges you face, sir, in the discharge the of your duties as an official of the authority? This will help us to see okay. Since you are administering....Section 6, that's question 2.

LAWMA Official:

Yeah. Okay. As an official of the authority. First one is the people's mindset. Like, when you tell some people don't do this, they will still do it. You just need to keep training, keep sensitizing them. So that's one of the challenges. And another challenge is, you know how Lagos is, mobility issues. We have cars but for you to move from one place to another can be challenging. But one thing is, those things can never end, you can't run away from them. They are normal. But the major challenge is, for example, I will use Mushin as an example. In Mushin now, LAWMA collects their waste in the morning. They don't pay for waste. Why will someone just not pay for waste? Some areas in Mushin, they put their waste on the road median, and LAWMA cannot just wait without collecting them. Even the educated among them still dump their waste on the road median because they don't want to pay. They see the waste as government's problem. Do you get it? So, changing people's mindset is one of our problems. Let's say this recycling, sorting of waste from source should be what everybody should do voluntarily without forcing them.

Researcher:

Okay, sir. Section 7. We're almost done, sir. Potentials for increased waste collection coverage. If the Lagos state government should allow recycling and waste treatment companies to collect the materials they need directly from households to feed their plants, thereby complementing the effort of the PSPs and collectors of recyclables. In your opinion, what impact will this have on waste collection in the city, sir?

LAWMA Official:

Yeah. Even presently, by 1st of April (2022 when the interview was carried out – researcher's note), there'll be a policy stating that everybody in Lagos must sort their waste. And once you sort your waste, you get, a certain decrease in waste bill.

Researcher:

In waste bill. Okay. Paid to the PSPs collected by LAWMA.

LAWMA Official:

Yes. And once you do not sort your waste, there will be increase, maybe by 25%. So you know, like yesterday I was not around, I went to Agunlejika. Now, one thing is, when you tell people to sort, the idea we want to use is the PSPs will be part of the gospel we want to preach. The PSPs will be collecting from households, the recyclables. They will be collecting general waste as well. They have a separate truck for collecting it. Any household that doesn't comply, we push up their waste bill because we don't have land again for landfill. So if we can solve that problem now, we will protect the future generation from the mess. So the recyclers, the present recyclers as well, they will also be collecting from households. So it's like creating competition.

Researcher:

Exactly. That will step up the collection drive.

LAWMA Official:

You get it. But when the PSPs collect, not all PSPs have where they will take it to. You know, recyclables, when you collect 10 KG today, it's not enough to take to the manufacturer at all. You need to get a place where you store. So we are now trying to work that out. Some of the recyclers that have their own community recycling centers, we have the list. The PSPs can take the collected recyclables there. LAWMA will also have some community recycling centres where you can take it to as a PSP operator. Even as households, when you sort your waste, you can take them to that center and sell them.

Researcher:

If it is not too far away from you.

LAWMA Official:

If it is not too far away from you.

Researcher:

Okay, beautiful:

LAWMA Official:

So the policy, we're working on it. You know, once the policy is there, you now need to find your way around the implementation. So, like, yesterday, I went to identify 2 places. We identified Agunlejika. We've identified Oshodi, a place in Oshodi where we will use for the community recycling for the government. We've identified Olusosun for community recycling. We've identified another one at Agege. We've identified another one at Simpson, Sura. We are just trying to identify as many as possible so that when any PSP collects, they can move the recyclables to the community recycling centres and sell their recyclables.

Researcher:

Okay. I'm aware of some of those places you mentioned like Sura, Simpson, and then, Olusosun. Some of them have waste transfer loading stations.

LAWMA Official:

Yes. The transfer loading stations are there.

Researcher:

But that will just run somewhere by the side.

LAWMA Official:

By the side. That's it.

Researcher:

Okay, sir. Thank you very much. This is the last question now on scavenging. I read online that one of the objectives of the Lagos Recycling Initiative is zero tolerance to scavenging.

LAWMA Official:

Yes.

Researcher:

Given that scavengers rely on income from landfill scouting for their survival, how does LAWMA intend to integrate them into the new initiative to protect their income base? This was done by, the governor of Oyo state. The Awotan dumpsite that was transformed into a modern, landfill where the scavengers who work around on that side were integrated into the new system so that they can now earn money in a neater way instead of scavenging. So what is LAWMA's plan in this regard, sir?

LAWMA Official:

The plan of LAWMA. Firstly, we have started the process as well. But you know, Lagos is big. We're dealing with....The people that are very difficult to control are human beings.

Researcher:

Yes. I agree with you.

LAWMA Official:

Now when the policy starts, the PSPs will need staff for collection. Once the materials are not going to the landfill again, the scavengers will be forced to leave the place and work with the PSPs. And if they decide not to work with the PSP, there is an association – waste pickers association we intend to integrate them – all these scavengers as well – we intend to integrate them into the Pakam app so that they can see requests themselves. Once people sort from homes, people could decide who do they sell to. They may not sell to PSP operators. They may prefer to sell to someone that will pay them more.

Researcher:

Exactly.

LAWMA Official:

So the scavengers also will be on the Pakam app. They accept requests. They go to the household, collect and pay them. Because all these scavengers you see, they also have operational heads they are working for. Those operational heads will be uploaded on the Pakam app as recyclers.

Researcher:

Okay, sir. One question came up just as an after thought. In the course of going out to people on the field, most people don't seem to know the Lagos recycling initiative. Is there any, you know, campaign plan for this to publicize the Lagos Recycling Initiative across board? I've asked people that are corporate people who don't know it. Somebody works in MTN. The other person works. They said they don't know about the Lagos. And they live in Lagos here.

LAWMA Official:

Yeah. Imagine. Yes. There is a plan. But you know what? This thing we want to do, once you say everybody should sort their waste and you don't have plan to collect...

Researcher:

Exactly.

LAWMA Official:

You don't have plan to stock. Why are you campaigning? To campaign is just to pay the radio station now?

Researcher:

Yeah. They'll just collect money, and nothing is achieved yet.

LAWMA Official:

And once people now start sorting, and you now collect it. In fact, when nobody to even go there to collect, they will be discouraged. But once we have put in place those things, okay, this PSP.

Researcher:

The infrastructure.

LAWMA Official:

Yes. The infrastructure. The recyclers are there to collect. The informal sector, the scavengers are there to accept and collect. When they collect, where they will take them to is already on ground, then we can go on the air and say, everybody should sort, If you are not sorting.

Researcher:

Wow. Thank you so much. I estimated 40 minutes and exactly we were able to achieve that.

LAWMA Official:

Yeah.