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Sustainable integrated solid waste management for a university campus – A case study of the Federal University of Technology Akure (FUTA), Nigeria

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A R T I C L E I N F O

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Waste generation
Circular economy
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University waste management

A B S T R A C T

This study provides valuable insights into the waste composition, generation rates, and opportunities for improving the current solid management practices of a university campus in Sub-Saharan Africa. Representative points were selected within the campus to collect solid waste (SW). The SW were sampled following ASTM D5231-92. The quadrant method prescribed by ASTM D 6323 was used to reduce about 150 kg of collected waste to 50 kg. The SW samples were collected in triplicates and sorted manually to determine their composition. QGIS, a geographic information system was utilized to optimize waste collection efficiency, optimal collection points, and the number of waste bins. The average daily solid waste generation at FUTA was 952.3 kg, with polythene and paper waste constituting the largest proportions at 26 % and 24 %, respectively. The waste generation rate per capita was estimated at 0.046 kg per day. Remarkably, 81 % of the waste generated at FUTA has the potential for recycling. This offers a viable potential for promoting sustainable integrated solid waste management (SISWM). The study proposes optimising waste collection points from the initial 42 to 97, considering the proximity to buildings and transportation routes. The study did not consider fluctuations in waste generation rates and composition throughout the seasons, yet the data gathered is considered adequate for this initial survey. Lack of collaboration, adequate policies, funds, infrastructure, and political will are among the impediments to SISWM in FUTA. The introduction of colour-coded waste separation bins, and assigning different colours to specific waste types, can promote proper waste disposal and facilitate recycling. Also, engaging the university community through workshops and seminars can foster such behavioural change. Collaboration with local entrepreneurs and recycling centres is another essential aspect of this paradigm shift. Such partnerships can explore innovative solutions for upcycling polythene waste and create waste-to-wealth pathways. Initial challenges of an insufficient policy framework for university- small scale enterprises (SME) engagement and the lack of business growth models could be addressed by promoting relevant skill development and motivational tasking of the existing entrepreneurship faculty. By implementing the proposed strategies and embracing circular economy (CE) principles, FUTA can reduce its environmental impact, promote recycling, and foster a culture of sustainability and entrepreneurial value creation on campus and beyond.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) promotes comprehensive management principles that couple the waste reduce, reuse, and recycle (3Rs) initiatives in mitigating greenhouse gas emissions. Solid waste management is a grave problem in sub-Saharan Africa and even in their citadels of learning which are supposed to be the model for effective and hygienic solid waste management. Nigeria is one of the emerging nations struggling to control the growing amount of solid waste it generates (Adewumi et al., 2017; Hassan and Oluwafemi, 2017; Okeniyi and Anwan, 2012). According to Owojori et al. (2020), open dumping/landfilling is the primary disposal method because of lax environmental legislation, insufficient funding, unplanned rapid development, and inappropriate industrial waste disposal.

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The principles of SISWM emphasizing reducing, reusing, and recycling of SW, entails an overarching change of community behavioural attitude and waste management framework to an efficient resource recovery and entrepreneurial value creation-based waste management system (Zhan et al., 2023). This is not yet the practice in Nigerian universities.

In the modern world, university communities are miniature cities with expansive geographic ranges and various human activities with varying environmental impacts (Armijo de Vega et al., 2008; Gallardo et al., 2014; Shriberg and Tallent, 2003). There are different types of waste generated by universities because they house a variety of facilities, including hospitals, restaurants, banks, offices, classrooms, and venues for events. These facilities generate waste related to construction and demolition, electronics, office supplies, lamps, furniture, metal, and medical/health care, among other things (Boskovic and Jovicic, 2015; Okeniyi and Anwan, 2012; Zamorano et al., 2009). It is expected that universities such as FUTA adopt sustainable development policies in all their operations, to ensure the social and environmental well-being of their immediate and wider environments. Universities have been identified as potent systems/communities in fostering sustainable development (Adami and Schiavon, 2021; Hoang et al., 2022; Mason et al., 2003). This is because of the potential of universities to contribute to the improvement of the larger society through teaching, research, and outreach (the three core pillars of the University), making the campus a living laboratory for the development of a sustainability culture. Therefore, universities are supposed to be the frontrunners in achieving a safe and sustainable environment. Unfortunately, the waste management systems in Nigerian universities are far below standards (Adeniran et al., 2017; Adewumi et al., 2017; Alshuwaikhat and Abubakar, 2008; Hassan and Oluwafemi, 2017; Okeniyi and Anwan, 2012). This national menace also affects FUTA.

The implementation of responsible waste management regulations toward a CE is expected to be led by universities as the main force in the movement toward clean and friendly surroundings. In the past ten years, researchers from a variety of disciplines have become interested in the CE, as evidenced by the rise in the number of papers available in the Scopus database that contain the term “circular economy” in the title, abstract, or keywords (Fagnani and Guimaraes, 2017; Gallo et al., 2018; Goldenhar, 1991; Mason et al., 2003; Zen et al., 2016). These researchers range from economists to engineers to environmental scientists and sociologists. In the year 2020, there were 2460 publications, up from 121 in 2010. CE approaches were discussed in 1966, and Leontief later examined them in 1991(Adami and Schiavon, 2021). The most recent version of CE, however, was codified in 2013. It focuses on four important areas: it uses renewable energy sources, forgoes harmful substances, and seeks to reduce waste by restructuring production and supply processes.

Over the years, the concept of CE has been defined in many ways and has taken on many hues. The CE proposes an ambitious action program with measures covering the entire cycle, from production and consumption to waste management and the market for secondary raw materials. As such, CE will positively affect the environment and the economy (Alshuwaikhat and Abubakar, 2008; Smyth et al., 2010). The general idea behind the concept of CE is based on the concept that in nature, there is no such thing as waste because everything serves a purpose and contributes to maintaining a balance based on closed cycles (Gallo et al., 2018).

Therefore, there is a need for the nature and composition of generated solid waste, campus waste management practices, and management policies of FUTA to be examined holistically to set a baseline or serve as a model for other Nigerian universities to follow. The volume, pattern, and composition of solid waste produced in FUTA have scarcely been studied. Therefore, this study offers the necessary information on better management and treatment options for municipal solid waste (MSW) in FUTA and explores the possibility of developing a CE framework to close the loop of product lifecycles through waste reduction, upcycling, increased recycling, and reuse. The study employed a multifaceted approach to analyse waste generation patterns at the University. This included conducting a comprehensive waste audit and utilizing identified data collection methods. Attention was also given to studying waste generation and collection points across the University, with efforts made to optimize collection points for enhanced efficiency and propose strategies for effective waste management. However, while these strategies offered valuable insights into waste management practices, they were not without potential drawbacks. For example, relying on questionnaires for data collection may have introduced biases or inaccuracies due to respondent subjectivity or incomplete responses. Additionally, while GIS mapping provided spatial analysis capabilities, limitations in data accuracy or resolution could have impacted the reliability of the findings. Furthermore, categorizing the University into different functional groups may have oversimplified the complexities of waste generation dynamics within each group. Despite these potential drawbacks, the waste audit served as a valuable tool for understanding waste generation patterns, optimizing collection points, and proposing strategies for effective waste management at the University. Continued refinement of methodologies and ongoing monitoring will be crucial for ensuring the sustainability and success of waste management efforts in the future.

The findings of FUTA waste characterization research are presented in this paper as a step towards laying the groundwork for developing a campus-wide circular economy/zero waste program to reduce, recover, and recycle waste. The recommendations for waste control at the source are also highlighted.

Materials and methods

Description of the study area

FUTA was founded in 1981 and is rated as one of Nigeria’s top technology universities. It is located at latitude 7° 28′ North of the equator and longitude 5° 13′ East of the Greenwich meridian, in Akure, the capital of Ondo State, Nigeria (Fig. 1). FUTA is located at a height of about 295 m above sea level. It has a tropical, humid climate with two distinct seasons, a slightly dry season from November to March and a wet or rainy season from April to October, with a mean annual temperature of 24–27 °C (Adewumi et al., 2017). Since its establishment in 1981, the university has grown significantly, creating twelve Schools and 58 academic departments to broaden its scope of academic study. As of January 2024, the university records indicated a total enrollment of 23,100 students, including 17,550 undergraduates. It also has about 2767 staff members.

Sampling locations and study block areas

The university campus was partitioned into different research blocks for easy data collection. These divisions include academic spaces (labs, lecture theatres, and computer labs), administrative offices, commercial areas, hostels, and residential structures. These points serve as a good summary of all the activities that take place on campus. Some solid wastes are burnt after being disposed of in the open, while others are gathered at various collection sites. For ease of collection, transportation, and disposal, the university’s waste management department situated waste bins around campus at a few key locations (collection sites).

Sampling procedure and estimation of waste generation rate

Sampling procedure

Following ASTM D5231-92 (Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste), sampling was carried out. The number of sorting samples needed depended on the kind of solid waste that must be sorted. The guideline specifies

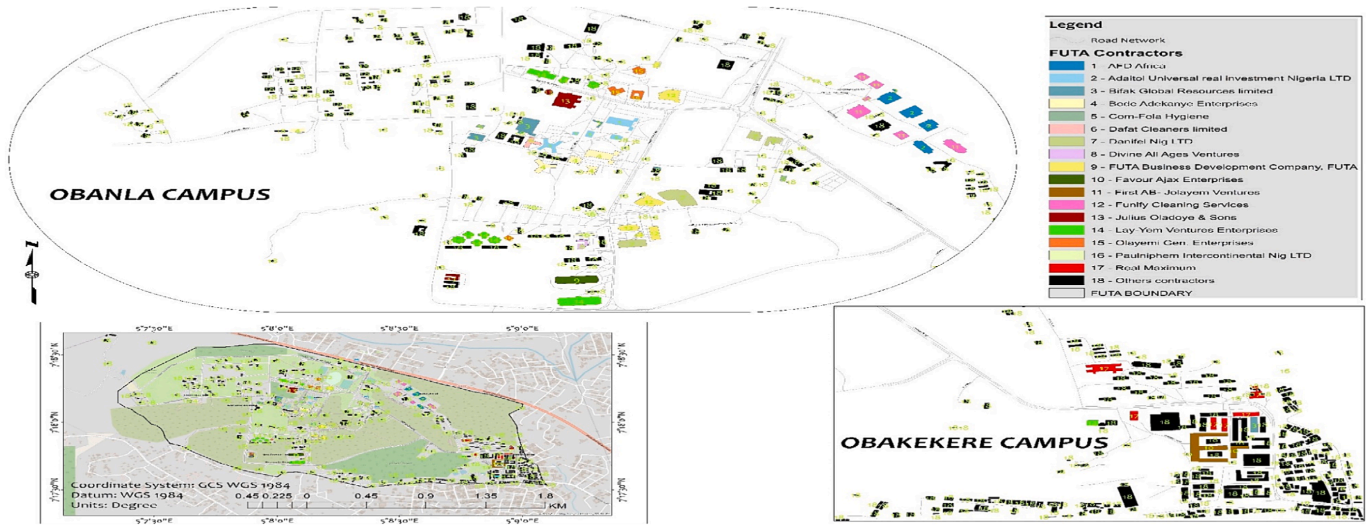

Fig. 1. The layout of the university.

that each sample of unprocessed solid waste for sorting should weigh between 91 and 136 kg; nevertheless, the average sample size for this study ranged from 50 to 130 kg. The conventional calculation approach was utilized to establish the precise number of samples. Using the equation by ASTM D5231-92, the N (number of samples that were sorted), required to give a high level of measurement precision, is given as;

$$N = (\frac{TS}{EX})2 \quad (1)$$

The variables T, S, E, and X represent the value of t Statistics, estimated standard deviation, desired accuracy level, and estimated mean, respectively. The parameters of the following equation were statistically used to determine the number of samples taken. In determining the number of samples to be collected, the method prescribed by ASTM D5231-92 (2003) was used. The method recommends that a waste component be chosen as governing waste composition. For this study, plastic was chosen as the governing waste composition, and a student T value of 1.645 corresponding to $n = \infty$, 90 % confidence level, E of 10 %, S value at 0.03, and X value of 0.09 were first used to obtain a value of 30. The second phase required that the T value obtained for $n = 30$ was used while other parameters were kept constant. The calculation gave a value of 32 which was within 10 % of 30. Therefore, 32 (the highest) number of samples was arrived at.

Between 50 and 130 kg is the typical sample size for the container. The values for each component were calculated manually. The total amount of solid waste in each dumpster was calculated by adding the average weights of each component. The amount of solid waste in a particular dumpster or collection location was then calculated by adding the weights of the constituent components. Throughout the research, samples were obtained at least once a week for four months (March 1 – July 31, 2021) while noting any compositional changes. Waste composition may vary seasonally, influenced by factors like holidays, events, or shifts in consumption habits. It's crucial to recognize that the collected data is deemed representative of the school's waste generation as the audit occurred during peak periods in the academic calendar. This data can be utilized for devising and implementing waste management strategies.

During the sampling process, difficulties were encountered in collecting fresh samples consistently across all campus areas. This challenge arose from infrastructure issues within the campus, which restricted access to certain locations for waste collection. To overcome this obstacle, the sampling procedure was adjusted to ensure the acquisition of representative samples despite these limitations. The adopted approach involved estimating the average per capita waste generation rate using available data and observations from accessible areas. Although this method offered an estimation, it facilitated the extrapolation of waste generation rates across the entire campus, considering variations in activity levels.

Waste characterisation

The first step was to conduct a reconnaissance tour of the many collecting spots spread throughout the campus. Carrying out the reconnaissance survey provided information on the kind of waste to be anticipated and the characterization strategy to use. The wastes often contain various types, from organic to inorganic substances. Periodically, different solid waste categories were gathered and collected. The collecting points provided samples, which were then collected and analysed in the laboratory (lab). The various wastes considered are; organics (food waste, garden waste (branches, twigs, leaves, grass), paper (notebook, printer paper, textbooks, etc.), plastics (Polyethylene Terephthalate –PET- bottles, High-Density Polyethylene – HDPE- plastics, and other plastics), metals (tins cans, aluminium and non-aluminium cans, iron,), e-waste (electric cables, phone accessories, etc), polythene (polythene packaging bags, sachet water bags, nylons, etc), textile (cloth materials and wigs), medical waste (Health Centre wastes), and others (Wood fragments, ash, foam, leather, etc). The samples were collected at roughly 150 kg and reduced to a practical weight of 50 kg using the quadrant method (coning and quartering) described in ASTM D6323-19. After being transported to the lab in duplicate, the samples were manually classified into various physical components, such as paper, plastics, rubber, wood, glass, metals, textiles, etc. Most information used for this study had to be approximated because there was no existing data on the generation of solid waste on campus, before this investigation. The weight of solid waste collected at regular intervals from all collection locations on campus was used to calculate the estimated daily generation. Questionnaires were also used to gather information about people's consumption patterns to validate the data gathered on-site. The weight of the empty collection tank or the weight of the waste generated on a given day less than the weight recorded the day before was initially observed to calculate the weight of the solid waste generated on campus. The waste generated each day was determined by the weight differential. Then the total number of students and employees in the university is then multiplied by the total waste produced per capita daily.

Optimization of waste collection points within the university

For optimization, this work used a model that had already been adopted by Boskovic and Jovicic (2015). The most effective location for waste collection sites and the right number of waste bins were identified using a GIS (Geographic Information Technology) system, which was used to increase the efficiency of waste collection. For this, the QGIS software suite was used. It is an all-encompassing system for generating, controlling, integrating, and studying geographic data. This methodology is structured in three different phases:

determination of the current situation (data collection and design of geodatabase in GIS environment)
defining the optimal collection point locations;
defining the required number of waste bins.

Evaluating the solid waste collection system's existing condition, the location of the research area, and its precise position are the first steps toward optimizing solid waste collection. Critical input parameters for the design and optimization of waste collection systems and transportation include the morphological composition of solid waste and the volume of waste produced in the area under investigation. This objective was achieved by completing a reconnaissance study of the university's collection points. GPS coordinates were used during the survey to record the locations of the primary and secondary collection points and the number of collection containers.

Experience typically determines the number of bins, the spatial distribution of the collection places, and the frequency of collection. This technique leads to developing a good system that meets user needs and creates a favourable impression of the organisation in the form of a tidy university. Despite this, collection stations are frequently not placed in the best locations because calculations considering low energy requirements are lacking. They may occasionally be close to one another, which unnecessarily raises collection costs because of the need for numerous vehicle pauses, especially when waste is collected daily. Outsourcing the university waste management system and the related supply chain would resolve industrial action and ineptitude related challenges in keeping up with the designed waste collection schedules within the university.

Placement of collection points is critical in optimising collection points. This includes identifying the maximum distance from the entryway to the waste bin to provide a decent service to all users while lowering collection expenses. This distance is usually not strictly defined and is determined by the expectations of the users. For example, Zamorano et al. (2009) set a maximum distance to the waste container of 75 m, while Gallardo et al. (2014) recommended 30–40 m for curbside pickup.

The final step was determining the optimal number of collection containers/bins to include in the waste generation rate to prevent overflowing at the collection points. The number of collection containers can also help segregate the waste generated at the collection point (e.g., separating recyclables from the general waste stream by providing a separate container), which will help manage the waste.

Results and discussion

Waste generation rate and waste management systems in FUTA

The results of the solid waste management and optimization studies carried out in 2021 are as follows:

$$\text{FUTA campus population} = 20{,}487 \quad (3.1)$$

$$\text{Average waste generation per day} = 950\ \text{kg/day} \quad (3.2)$$

$$\text{Average waste generation per capita per day} = 0.046\ \text{kg/capita/day} \quad (3.3)$$

The waste generation per capita is approximately 0.05 kg/capita/day. This is close to the per capita waste of 0.06 kg/day reported for the University of Nigeria, Nsukka (UNN) and Covenant University (Okeniyi and Anwan, 2012; Ugwu et al., 2020). Although the population of the university campuses varies, disposal and consumption habits and socio-economic factors may have contributed to the results pattern. However, the volume of waste generated daily on the FUTA campus is 30 times less than that generated at the University of Lagos Akoka (Adeniran et al., 2017). This can be attributed to the fact that the university's total population at the time of the study was 55,000, significantly higher than the population of FUTA. This daily waste generation rate for FUTA is relatively close to the volume generated daily on Campus Mexicali I of the Autonomous University of Baja California (UABC) with 1000 kg per day (Armijo de Vega et al., 2008) and Covenant University, Ota, Ogun State, Nigeria with an average daily waste generation of 560 kg (Okeniyi and Anwan, 2012). FUTA waste management scheme comprises the University unit and over 18 private contractors who are allotted different areas of the school to clean based on contract. The contractors service the different buildings and stockpile the waste at the designated collection points. Then the university waste collection vehicles transport the waste to the FUTA dumpsite.

Waste characterisation

Fig. 2 shows the waste composition by weight of MSW generated at the Federal University of Technology, Akure. Polythene comprises most of the MSW generated on campus, accounting for 26 %. Paper comes second with 24 %, followed by plastics and organic material with 19 % and 10 %, respectively. Generally, 1 % is glass/bottle, 4 % is textiles/leather, 4 % is E-waste, 4 % is medical, and 3 % is metal waste.

Recyclable potential of waste

A reasonable proportion of the MSW generated in the FUTA campus is recyclable or is potentially recyclable. This study revealed that 81 % of the waste streams are potentially recyclable. The FUTA campus has a lower non-recyclable potential at 19 % when matched with some reported university studies by Adeniran et al. (2017), Armijo de Vega et al. (2008), and Smyth et al. (2010) at 25, 34, and 28 % respectively. The findings of the present study indicate a notable upswing in the proportion of recyclable waste when compared to Smyth et al. (2010) and Adeniran et al. (2017). The considerable surge from 49.34 % (Smyth et al., 2010) and 11.00 % (Adeniran et al., 2017) to 81 % in the current study suggests an increased potential for intensified recycling endeavors within the FUTA campus. This favorable trajectory implies that the university is progressing in the right direction toward cultivating a more sustainable waste management system. This implies substantial opportunities for expanding recycling initiatives, contributing not only to waste reduction but also fostering the development of a CE within the university. Conversely, the percentage of non-recyclable waste in the present study is notably lower (19 %) compared to Smyth et al. (2010) at 28 % and Adeniran et al. (2017) at 34 %. This indicates commendable progress by the university in reducing non-recyclable waste, presenting a positive signal for environmental sustainability. The marked increase in percentages of recyclable and potential recyclable waste aligns with the overarching objective of establishing a SISWM at FUTA. This data emphasizes the significance of sustaining and expanding initiatives promoting recycling, waste separation, and sustainable practices. Furthermore, this demonstrates the potential for collaborative efforts with local recycling industries to enhance the circularity of the waste management system. At present, FUTA does not recycle, reuse, or recover energy from any of its waste categories. The recycling potential rating for waste generated in the university is 81 %. Generally, 57 % of the recyclables have an existing market for recycling in Nigeria, and 43 % do not have.. Although, a large percentage of the waste stream can be recycled if proper channels are implemented to segregate waste at the source. Factors such as lack of collaboration, adequate policies, funds, infrastructure, and administrative willingness are impediments to viable recycling of FUTA waste streams.

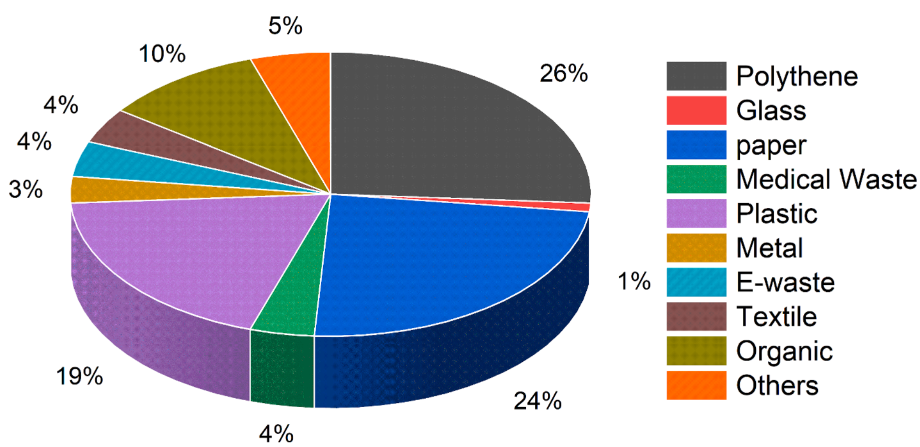

Fig. 2. Chart Showing the General Distribution of Waste in FUTA Community.

Optimisation of collection points

The reconnaissance study conducted to count the primary and secondary collection points currently in FUTA revealed that the number of primary collection points currently in place are insufficient to handle the volume of waste generated in the university. The outcome revealed that FUTA now has 42 primary collection points (as shown in Fig. 3). However, it was also discovered that these primary collection points were unevenly placed around the university region, causing waste to be overlooked in some areas. This would have the unintended consequence of encouraging open burning and careless waste disposal, both of which are harmful to the environment.

With the addition of 55 more collection points to the existing number currently in the institution, the number of primary collection points was increased to an optimal value of 97 (Fig. 4). The proximity of the primary collection points to other buildings and a lot of activity—as well as the route for transportation to the secondary collection points—were taken into account during optimization. The distance between the primary collection points and other buildings was kept to a maximum of 15 m.

The preliminary survey's findings indicated that there are seven secondary collection points in total, which are insufficient as evidenced by the university's numerous overflowing secondary collection points. The collection route was crucial in making secondary collection stations more effective since it determines how long it will take the collection truck to deliver waste from secondary collection points to the final disposal site.

Nineteen collection stations were found to be the optimal amount. This is a 37 % increase from the number already present on campus. For ease of access from the principal collection point and the collecting truck, the other collection stations were positioned at strategic locations across the university's main routes. Fig. 5 and Fig. 6 show the current and optimized secondary collection points in FUTA. The amount of solid waste that has to be collected, as well as the weather, cost, and demand

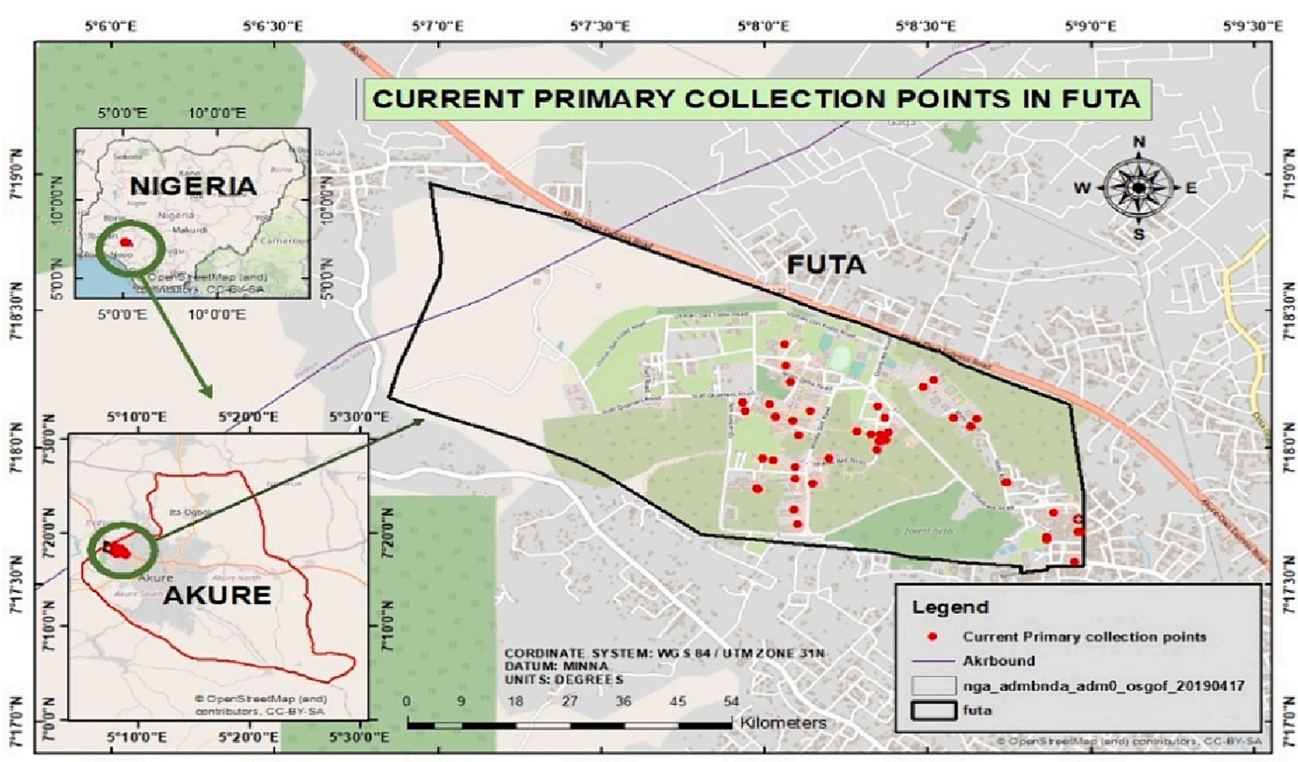

Fig. 3. Current Number of Primary Collection Points.

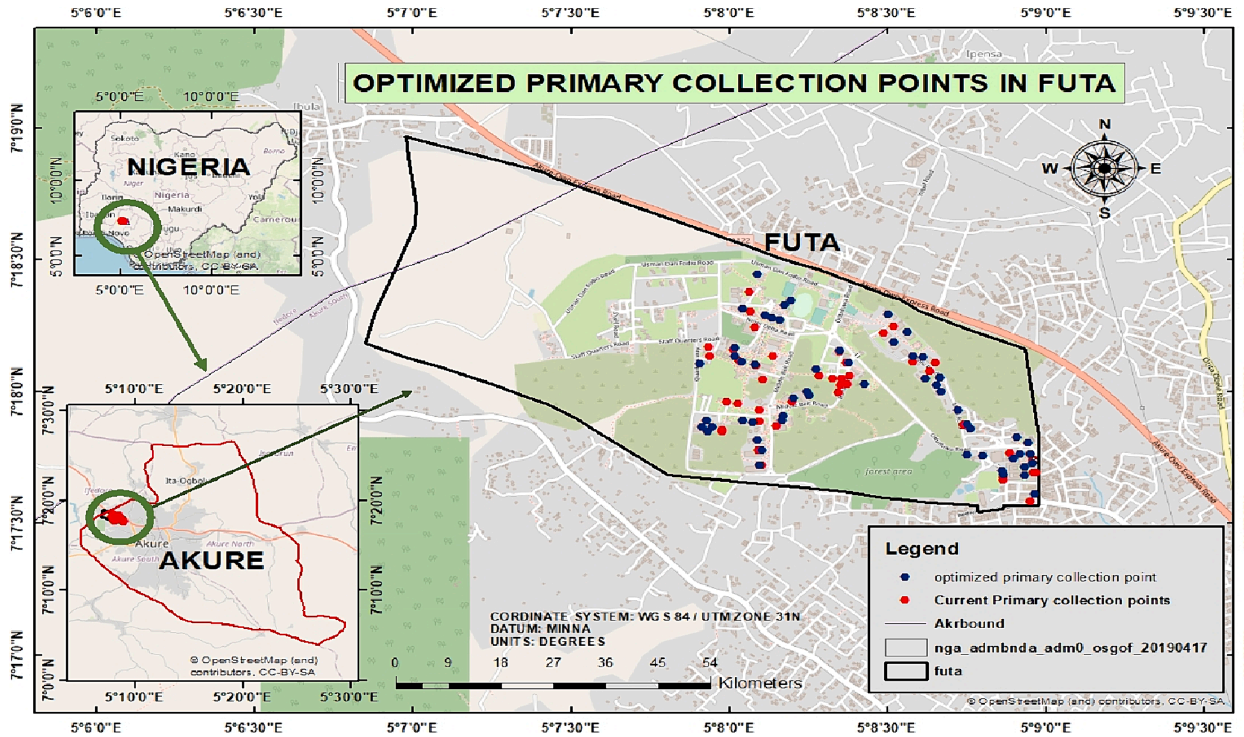

Fig. 4. Optimized Primary Collection Points in FUTA.

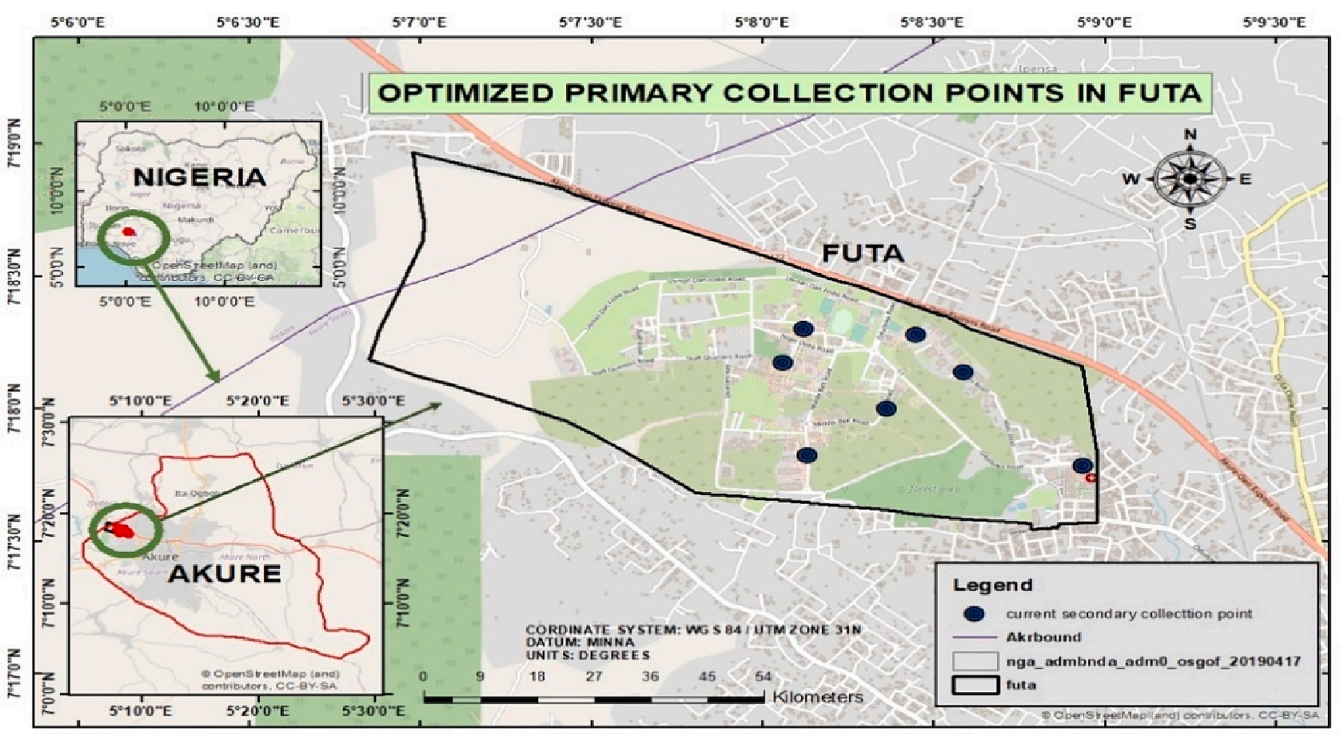

Fig. 5. Current Secondary Collection Points in FUTA.

from the general public, all influence the best frequency of service. Based on the optimal circumstances, a master schedule should be created for each collecting route.

Waste generated by research blocks

This section covers the description and measurement of waste from laboratories, computer centres, faculties, and lecture halls. Paper made up a significant portion of the total waste produced, accounting for 34.83 % of the 200 kg of waste that was characterized across the

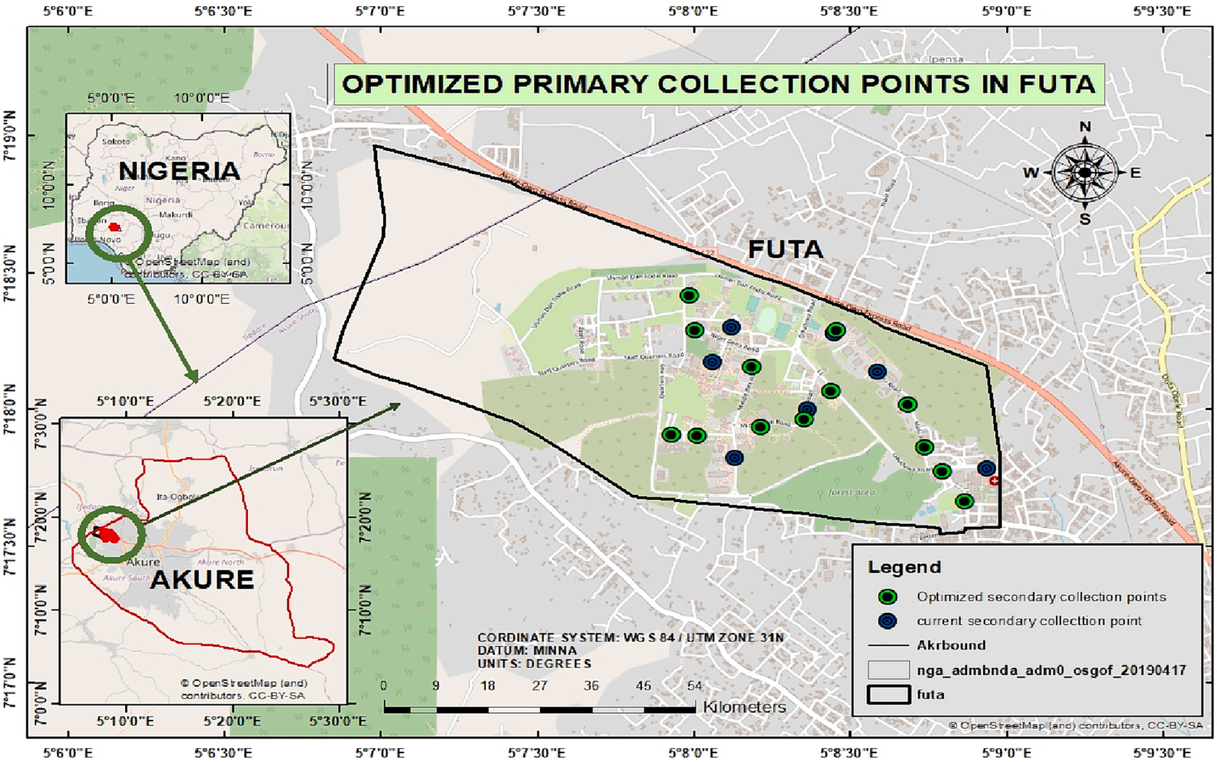

Fig. 6. Optimised Secondary Collection Points in FUTA.

academic areas. This is understandable, given that the majority of academic activities—taking notes, completing assignments, writing exams, etc.—involve the use of paper. Most lecture halls contain shops for snacks and other delicacies often packed in polythene bags, therefore polythene is second in terms of volume at 22.51 % (45.01 kg). There is also a sizable amount of plastics and rubber in the waste stream produced in educational settings, mostly in the form of water and fizzy drink bottles as well as various writing and drawing supplies. About 56.03 % of the waste produced in academic settings can be recycled, demonstrating the potential for recycling these materials. Unfortunately, this waste is disposed off in dumpsites, though outsiders occasionally collect mostly the plastic bottles that are used as containers for selling homemade drinks to the students.

The waste generated in the administrative areas of the school includes waste generated at the Senate buildings, admission offices, student affairs buildings, etc. Paper made the bulk of the waste stream at (45.14 %). This is expected, as a lot of paper is used in dealing with student and staff records, and communication between the central administration, departments, and students. This gives room for a waste reduction technique to be employed in reducing the volume of waste generated and landfilled. The use of information and communication technology (ICT) is one sure way to reduce the volume of paper needed for the smooth running of the university's administration. The low volume of organic waste(4.75 kg) can also be explained as most administrative buildings do not have shops for purchasing foods and drinks. The waste audit carried out in the residential areas of the school includes the waste generated at the school hostels (undergraduate and postgraduate) as well as the staff quarters. The waste composition shows that both polythene, plastics, and food waste are generated the most in terms of kilograms (33.02 kg), (19.09 kg) and (18.38 kg) respectively, while glass and bottles are the least at (1.41 kg). Given that students typically cook in their hostels and those who cannot cook tend to get packaged food, it is not unexpected that polythene, plastics, and food waste make up the majority of the waste produced in the hostels and residential areas. The waste audit results show that recyclable waste makes up over 64.30 % of the waste stream, which indicates that if the potential for recycling waste is maximized, there will be a notable reduction in waste transported to landfills. Relative to what was observed in other areas of the university, the volume of paper waste generated was low with only (7.11 %) comprising mainly of packaging for food and other items like soap. This is most likely because the need for paper is not as high and diverse as that of the academic and administrative areas.

The commercial areas refer to specific areas in the school like the various cafeterias in the school as well as the various shopping malls in existence. The waste generated from the audit is shown in the results in Table 1, and it reveals that 13.76 % of it may be composted. This includes all pre-consumer organic food waste, including tomatoes and other perishable items. Polythene waste was the highest waste fraction observed in these areas, taking up 34.59 % of the volume of waste in this waste stream. This points to the fact that a lot of people purchase goods and food items with these polythene bags and dispose of them after consumption of the edibles. Papers, food packaging, plastic bottles, and glass bottles make up 38.02 % of the waste stream that is recyclable. The cafeteria and kitchen waste include many biodegradable items that may be recycled and used as fertilizers. Unfortunately, this is not being utilized properly and instead ends up in the dumpsite.

The waste audit at the University Health Centre is peculiar because, unlike other groups in the research block, this waste stream contained a large proportion of medical waste as to be expected. This includes syringes, needles, cotton wool, gloves, and other medical waste. The medical waste fraction was handled with care due to the hazardous nature of the waste. The medical waste fraction accounted for (41.52 %) of the waste stream. The next waste fraction of waste generated in terms of volume is that of polythene waste. This is not surprising as the majority of the drugs used are packaged in polythene bags. In addition, nurses, doctors, and other working staff in the health centre might be contributing to the volume of polythene waste in the waste stream. It was also observed that the potential for recycling the waste generated is low as only 25.82 % of the waste stream can be recycled.

Table 1
Categorization and Proportion of Wastes Generated at Different Collection Points.

Academic Areas										
Waste Categories	Glass	Medical Waste	Metal	Polythene	Organic	Paper	E-waste	Plastic/Rubber	Textile	Others
Weight(kg)	3.50	0.00	4.92	45.01	10.65	69.66	13.38	33.98	9.05	9.85
Percent Distribution (%)	1.75	2.46	2.46	22.51	5.33	34.83	6.69	16.99	4.53	4.93
Administrative Areas										
Waste Categories	Glass	Medical Waste	Metal	Polythene	Organic	Paper	E-waste	Plastic/Rubber	Textile	Others
Weight(kg)	0.00	0.00	0.57	7.24	4.75	22.57	0.35	11.81	0.56	2.15
Percent Distribution (%)	0.00	0.00	1.14	14.48	9.5	45.14	0.7	23.62	1.12	4.3
Hostels and Residential Areas										
Waste Categories	Glass	Medical Waste	Metal	Polythene	Organic	Paper	E-waste	Plastic/Rubber	Textile	Others
Weight(kg)	1.41	0.00	4.54	33.02	18.38	7.11	3.8	19.09	6.99	5.66
Percent Distribution (%)	1.41	0.00	4.54	33.02	18.38	7.11	3.8	19.09	6.99	5.66
Commercial Areas										
Waste Categories	Glass	Medical Waste	Metal	Polythene	Organic	Paper	E-waste	Plastic/Rubber	Textile	Others
Weight(kg)	0.00	0.00	5.61	34.59	13.76	13.07	0.85	23.19	1.79	7.14
Percent Distribution (%)	0.00	0.00	5.61	34.59	13.76	13.07	0.85	23.19	1.79	7.14
Health Centre										
Waste Categories	Glass	Medical Waste	Metal	Polythene	Organic	Paper	E-waste	Plastic/Rubber	Textile	Others
Weight(kg)	0.00	20.76	0.65	11.31	0.50	6.40	0.00	5.95	2.95	1.48
Percent Distribution (%)	0.00	41.52	1.3	22.62	0.10	12.8	0.00	11.9	5.9	2.96

Implementing a sustainable integrated solid waste management programme in FUTA

FUTA campus generated an average of 952.30 kg of solid waste per day. Interestingly, 81 % of the waste generated has the potential for recycling with polythene and paper wastes accounting for the largest proportions. However, FUTA currently does not practice recycling, reusing, or energy recovery for any waste categories, thereby all wastes end up in apportioned areas within and in the university area outskirt where they are burnt openly after drying. The results obtained from the waste characterization indicated a promising potential for a sustainable integrated solid waste management programme that promotes circular economy (CE) principles due to the higher percentage of recyclables. The waste reduction can be achieved in FUTA by upgrading awareness and education of the university population, encouraging reusable alternatives, enhancing waste segregation and recycling. Also, collaboration with entrepreneurs, viable research and development drive, and partnership/engagement with stakeholders are vital in achieving sustainable waste management practices in FUTA.

Awareness and education

Creating awareness and educating the university community about the importance of waste reduction and recycling is crucial. Based on the findings of this research, the incorporation of environmental awareness and responsibility content in the first-year undergraduate curriculum that is aligned with the SISWM concept will be a transformational move in the right direction. In addition, FUTA can conduct awareness campaigns, workshops, and seminars on sustainable waste management practices. Engaging students through environmental clubs or associations can also foster a culture of responsible waste management and encourage behavioural change (Owojori et al., 2020; Vargas and Campos, 2020).

Encouraging reusable alternatives

To reduce the usage of polythene, FUTA can promote the use of reusable alternatives. This can involve adopting the policy of reusable bags for grocery and consumer products sale on campus and encouraging students and staff to utilize reusable shopping bags, durable water bottles, and food containers. Additionally, the university can collaborate with local business entrepreneurs to explore alternatives to polythene packaging and promote eco-friendly materials (Adewumi et al., 2017; Fagnani and Guimaraes, 2017).

Waste segregation and recycling

To ensure efficient waste management at the university, a comprehensive follow-up waste audit is recommended. This audit should take into account seasonal fluctuations and guide infrastructure development. Additionally, implementing composting facilities provides an environmentally friendly solution for managing organic waste, converting it into nutrient-rich compost. The audit also highlighted the necessity to optimize both primary and secondary waste collection points. The spatial analysis resulted in the optimization of the initial 42 primary waste collection points, increasing them to a total of 97. This optimization process considered factors such as proximity to other buildings, high-activity areas, and transportation routes to secondary collection points. Additionally, it is crucial to implement color-coded waste separation bins at these optimized locations (Fig. 7). By assigning different colors to specific types of waste, such as polyethylene, paper, plastics, and organic waste, FUTA can establish an intuitive and clear system for waste segregation. The introduction of color-coded bins not only provides visual cues for waste segregation but also reinforces the importance of proper waste management. This approach significantly boosts participation in recycling efforts and ensures the effective diversion of recyclable materials from general waste streams. By integrating the optimized collection points, color-coded waste separation bins, and effective educational campaigns, FUTA can establish a comprehensive waste management system that aligns with the principles of a CE. Part of this involves students in waste minimization, segregation (source separation), and beneficial reuse as part of the immediate steps towards ingraining the sustainable management waste attitude/behavioural tendency.

Fig. 7. Colour-coded Waste Separation Bins.

Collaboration with entrepreneurs

To address the challenge of polythene waste, FUTA should engage in collaborative efforts, involving the School of Management Technology (SMAT), the Department of Entrepreneurship, and community entrepreneurs/start-ups to explore innovative solutions. These initiatives can focus on upcycling polythene waste into valuable products such as eco-bricks, furniture, or construction materials. By fostering an environment that supports sustainable entrepreneurship, FUTA will not only contribute to local economic development but also tackle the issue of waste management effectively (Adeniran et al., 2017; Adami and Schiavon, 2021; Hoang et al., 2022). The presence of five potential recycling centers in the state where FUTA is located provides a significant opportunity to create alternative waste-to-wealth pathways. Capitalizing on these centres and implementing supportive measures, the university can actively contribute to the principles of a CE and promote sustainable development. One crucial step for FUTA would be to establish formal partnerships with the existing recycling centers. This collaboration would facilitate the exchange of knowledge and expertise between FUTA and the recycling centers (Smyth et al., 2010; Fagnani and Guimaraes, 2017; Owojori et al., 2020). Additionally, it would support FUTA in harnessing the waste streams generated within the university and enabling joint initiatives that focus on creating waste-to-wealth opportunities. Leveraging the infrastructure and resources available at the recycling centers would greatly enhance FUTA's sustainable integrated waste management efforts and support its CE aspirations.

Research and development

As a university, FUTA should invest in research and development initiatives to find sustainable solutions for managing polythene waste. This can include exploring advanced recycling technologies, biodegradable alternatives, and innovative waste-to-energy systems. Research findings can then be shared with the broader community, facilitating knowledge transfer and informing policy decisions.

Partnerships and stakeholder engagement

FUTA should partner with government agencies, non-profit organizations, and industry stakeholders to address the polythene waste issue collectively. Collaboration with waste management authorities can improve waste collection and recycling infrastructure, while partnerships with non-governmental organizations (NGOs) can facilitate awareness campaigns and community engagement programs. Engaging local industries can foster sustainable supply chains and create market demand for recycled materials (Smyth et al., 2010; Adewumi et al., 2017; Khan et al., 2022). Initiating cooperatives of recyclers and upcycling among staff and students in linkage with other campus-city interface settlers will promote vital synergistic entrepreneurship for the enhancement of student learning, the development of employability skills, and the enhancement of the university community's socioeconomic well-being. Students' involvement in waste minimization, segregation (source separation), and beneficial reuse are part of the immediate steps towards ingraining the SISWM attitude and behavioural tendency. Initial challenges of an insufficient policy framework for university-small-scale enterprises (SME) engagement and the lack of business growth models could be addressed by promoting relevant skill development and motivational tasking of the existing entrepreneurship faculty.

Conclusions

This study characterized and examined the waste minimization (reuse, recycle/recovery) potential of MSW generated in the FUTA campus to achieve a sustainable integrated waste management strategy for the University and provided valuable insights. The study revealed that FUTA generates a significant amount of solid waste, primarily consisting of polythene and paper waste. The waste generation rate of 0.046 kg per capita per day underscores the importance of implementing effective waste management strategies. The assessment showed that a considerable portion, around 81 %, of the waste generated at FUTA has the potential for recycling. This finding emphasizes the opportunity to embrace CE principles and establish an integrated waste management system. However, the current solid waste management of FUTA is inefficient and unhygienic. To achieve efficient waste management strategies, the following actions should be implemented.

Optimizing waste collection points and introducing color-coded waste separation bins to enhance waste segregation and facilitate upcycling and recycling. Also, awareness and sensitization must be done to foster an efficient waste management culture within the university community.

Promoting reusable alternatives and collaborating with local entrepreneurs will further reduce the generation of single-use polythene and explore innovative waste-to-wealth solutions. By investing in research and development, forging partnerships with stakeholders, and capitalizing on existing recycling centers, FUTA will actively embrace sustainable waste management practices. These efforts would not only reduce environmental impact but also promote a culture of sustainability within and beyond the university.

Acknowledging the vital importance of infrastructure, FUTA should give precedence to investments in recycling facilities, composting plants, and other necessary infrastructure to facilitate the shift towards sustainable integrated solid waste management. Enacting these strategies, in line with circular economy principles, will not only enhance waste management practices but also foster sustainable development, establishing FUTA as a frontrunner in this domain.

Ultimately, this paradigm shift will engender a transformational boost for a timely global warming mitigation drive that is linked with an educational and socioeconomic framework, in line with the principles of conservation of materials, waste reduction, societal poverty alleviation, and entrepreneurial student development.

By embracing these tailored recommendations, FUTA can lead the way in transforming waste management practices, thereby establishing itself as a pioneer of innovation and sustainability in higher education.

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CRediT authorship contribution statement

Oluwapelumi O. Ojuri: Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization. **Ayodeji S. Olowoselu:** Writing – review & editing, Supervision, Resources. **Joshua Akinrele:** Writing – original draft, Resources, Investigation. **Folahan O. Ayodele:** Validation, Data curation. **Omomomi O. Jayejeje:** Writing – review & editing, Formal analysis.

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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