JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 13(1), MARCH, 2025
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

Analysis of the Electricity Generation Potentials of Plastic Wastes on a University Campus

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ABSTRACT

This study analyzes the electricity generation potentials of plastic wastes generated in the Faculty of Engineering Building of Baze University Abuja, Nigeria. The plastics were collected from the waste bins over four weeks from June 12, 2024, to July 11, 2024. The weight of the plastics collected was determined, after which samples were subjected to energy potential analysis. A total of 6,346.67 g of plastics were collected. In June and July, 3,708.33 g and 2,638.34 g of plastics were produced, respectively, which equates to an average of 337.12 g and 329.79 g per day. The net calorific value was found as 15.23 MJ/kg, and the estimated daily energy potential is 1.53 kWh, equivalent to 63.75 W. These findings suggest that plastic waste can be a viable source of electricity generation, highlighting its significance for sustainable waste management and energy production on university campuses.

ARTICLE INFO
Article History
Received: October, 2024
Received in revised form: December, 2024
Accepted: February, 2025
Published online: March, 2025

KEYWORDS
Calorific Value; Incineration; Sustainable Development Goals; Thermochemical; Waste-To-Energy

INTRODUCTION

The United Nations has established 17 sustainable development goals for 2030, which are broken down into three categories: economic, social, and environmental (Dodo & Ashigwuike, 2023a). Goal 12 addresses production and consumption to minimize the negative effects on the environment and human health by reducing waste and chemicals. It emphasizes that plastic is a major source of ocean pollution and that it is one aspect of the waste problem. In recent years, the world's plastic output has grown, rising from 270,000 ktons in 2010 to about 359,000 kton in 2018 (Asare et al., 2022). Nigeria is ranked ninth in the world for marine environment pollution, with reports indicating that up to 0.34 million tonnes of plastic debris were released into the ocean in 2010 (Dodo, 2023; Vuppaladadiyam et al., 2024). The primary reason for this increase is that plastic has become a substance that we use daily. Plastic's remarkable rise can be attributed to its durability, affordability, longevity, and lightweight. Because it is inexpensive to produce in large quantities, the material is accessible to people of all income levels. Furthermore, due to its use in the manufacturing of technically complex materials, such as those for industrial uses, food packaging, and medical delivery, certain plastic is difficult to replace.

Asare et al. (2022) predicted that greenhouse gas emissions linked to the plastic life cycle would rise. Additionally, littering and plastic contamination in marine waters will have detrimental effects. Plastic waste has a detrimental impact on the environment since it can take 500–1000 years for it to completely degrade and can prevent nearby biodegradable materials from breaking down (Vuppaladadiyam et al., 2024). Open dumping is the most popular practice, and only 50–80% of total waste is collected in developing countries (Dodo et al., 2022a; Dodo & Ashigwuike, 2023a). The primary cause of plastic's ecological leakage is the absence of a scientific waste collection system. Thus, there is a need to investigate alternative ways of addressing this life-threatening challenge.

Landfilling is currently the most common scientific way to handle plastic waste worldwide. Landfilling is mostly used in underdeveloped nations due to the high expense of alternative

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garbage disposal methods. Landfills are also linked to leachate, which can contaminate surrounding water supplies, groundwater contamination, and greenhouse gas emissions (Asare et al., 2022; Fereja & Chemeda, 2022). As an alternative to landfilling, incineration is another popular disposal technique. However, plastic wastes comprise a wide range of chemicals, some of which are known to produce carcinogenic compounds such as dioxins, polycyclic aromatic hydrocarbons (PAHs), and nitro-PAHs after burning (Asare et al., 2022). These pollutants are also highly mutagenic. To lower the levels of these pollutants, large-scale combined heat and power facilities are using multistage gas cleaning systems.

Both industrialized and developing nations face significant challenges in sustainably managing solid waste. The world produces a great deal of garbage, and the most important question is how to manage it effectively and efficiently to preserve the environment for humankind's continued existence. The issue of solid waste management plagues many towns, cities, municipalities, and even university campuses. Universities are the hubs for the development of technology, ideas, and knowledge. Because of these activities, resources like food, water, and energy are consumed, which leads to waste production (Dodo & Ashigwuike, 2023b; Tu et al., 2015). Promoting the concept of sustainability among students, staff, and the general public is one of the goals of many universities across the globe. Plastics can remain in the environment for prolonged periods and do not break down fast, which raises environmental concerns. Therefore, one of the cardinal issues that universities must deal with to meet the campus sustainability goals is the sustainable management of plastic waste. Recycling waste and using it locally to generate electricity is one way to solve the problem (Dodo & Ashigwuike, 2023a).

There are similar studies in the literature on the energy potential analysis of various wastes. For instance, Dodo & Ashigwuike (2023a) examined the power generation potential of municipal solid wastes (MSW) in Abuja, Nigeria. After determining the city's MSW generation rate, waste samples from the dumpsite were subjected to thorough physicochemical and thermal examinations. The energy potential of the waste components is 2,274.42 MWh. Tu et al. (2015) investigated the University of Cincinnati's implementation of three waste-to-energy (WTE) projects: food waste-to-biogas, waste cooking oil-to-biodiesel, and waste paper-to-fuel pellets. The project aimed to improve waste management efforts and lower greenhouse gas emissions through the replacement of fossil fuels. It was found that the three WTE initiatives reduced GHG emissions by 9.37 (biodiesel), 260.49 (fuel pellets), and 11.36 (biogas) tons of CO_2-eq annually, respectively.

Aderoju et al. (2019) focused on the incineration of waste plastics with energy recovery in Nigeria. Using 4.83 million tons of waste plastics, the power production potential was calculated, yielding approximately 29,000MW, respectively. Nugroho et al. (2018) investigated the optimal engineering solution for plastic processing technologies. It attempted to create alternative fuels and energy from renewable sources. Pyrolysis was used for the oil processing. A range of reactor temperatures, including 300, 350, and 400 ^{o}C, were examined. The plastic at 300°C reactor temperature produced more solid residue and less oil with a clearer color than the 400°C reactor temperature, which produced more oil and less solid residue. Kabeyi & Olanrewaju (2021) employed a plastic oil pyrolysis plant to address the issues of plastic pollution and the rising need for fossil fuels. The early assessment demonstrated that the pyrolysis operation is economically viable. The LDPE plastic oil at 300°C used the least amount of fuel. With a load generator of 150 Watts and 75% gasoline and 25% pyrolisis oil, it took 13.5 minutes. Overall, the generator's fuel consumption and lifespan were found to be greatly influenced by the calorific value.

Nandhini et al. (2022) examined how thermochemical processes including gasification, combustion, pyrolysis, and torrefaction are used to turn municipal solid waste into energy. It was established that the composition of the feedstock and operational conditions affect energy yield. For

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example, the co-pyrolysis of cereals and peanut waste produced a heating value of 31.44 MJ/kg at 540 °C, but the torrefaction of municipal wastes at 200 °C produced a heating value of 33.01 MJ/kg. Olusunmade et al. (2019) estimated the amount of energy lost as a result of the current plastic waste disposal procedure in terms of the amount of power and oil that could have been generated had thermochemical approaches been used. It demonstrated that Nigeria's plastic waste could create over 17.3 million barrels of crude oil, valued at almost $1 billion, and 7.1 million MWh of electricity, enough to power 4.4 million households.

From the review of similar studies, there have been research efforts to investigate the energy potential of different waste materials but little has been done to consider plastic wastes on a university campus. This study, therefore, aimed to analyze the electricity generation potentials of plastic waste on the Baze University Abuja campus. Baze University Abuja, Nigeria is not an exception to the continued struggles with solid waste management, particularly, the plastic waste that many university campuses face. The study aim was achieved by collecting the plastics from the waste bins, determining the quantity of plastic waste generated, examining the calorific value of the plastic wastes, and analysis of the electricity generation potential of the plastic wastes. Implementation of this study will improve the aesthetic value of the university. The quantum of the wastes that will be deposited and consequently burnt at dumpsites or openly will reduce significantly. This will further reduce the greenhouse gas emissions and other contaminants associated with open burning of plastic wastes. As a result, there will be a paradigm shift to large-scale electricity production not only from plastic wastes but other biomass substrates in the University.

MATERIALS AND METHODS

This study principally focused on assessing the energy potential of plastic bottles generated at the Faculty of Engineering Building of Baze University Abuja, Nigeria via incineration. The plastic bottles were collected daily from the waste bins stationed within the building for four weeks commencing from 12th June 2024 to 11th July 2024. However, the collection excluded Saturdays and Sundays because of a lack of academic activities taking place on those days. The quantity of the plastics collected was determined using a weighing balance, before taking the samples to the laboratory for determination of calorific value. The study methodology chart is shown in Fig.1. The materials employed included a hand glove, face masks, polythene bags, hand sanitizer, nichrome wire, a lighter, crucible, digital weighing scale, plastic waste samples, a bomb calorimeter, benzoic acid, thread, oxygen, thermometer, bomb cylinder, and fuse wire.

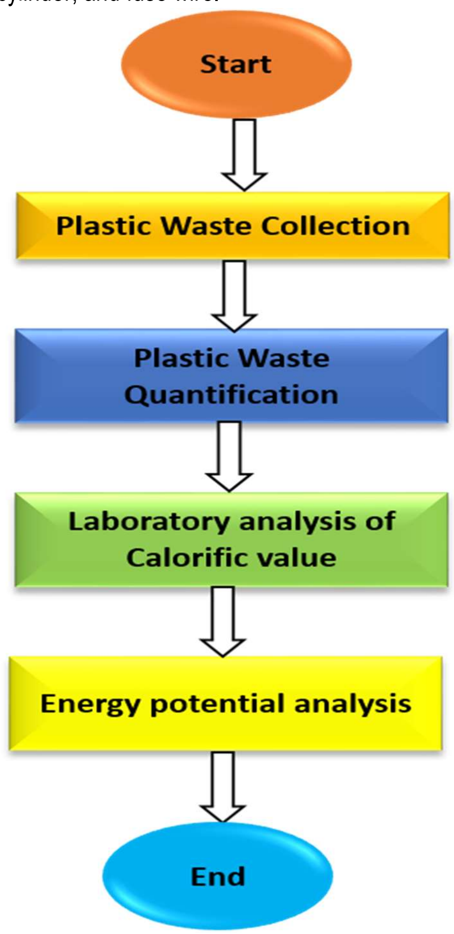

Fig. 1: Study methodology chart

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Collection of Plastic Wastes

Plastic wastes were collected daily for four weeks commencing from 12th June 2024 to 11th July 2024. The wastes were collected from the Faculty of Engineering Building, Baze University Abuja. Wastes were collected from Mondays to Fridays, being the days' academic activities take place in the Faculty. The building has a total of 13 waste bins, 7 downstairs and 6 upstairs, as of the time this study was conducted. The plastic wastes were collected in polyethylene bags from the bins around 5:30 pm to ensure sufficient deposit by the staff and students. The collection of the plastics from the bins is shown in Fig. 2.

Fig. 2: Collection of plastic wastes from the dustbins

Determination of plastic waste quantity

The weights of the plastic wastes were determined daily at the Petroleum and Gas Engineering Laboratory using a digital weighing scale as shown in Fig. 3. While measuring the weights, attention was given to the plastics collected from the trash bins placed upstairs and downstairs respectively.

Fig. 3: Measurement of the weights of the plastic wastes

Calorific value of the plastic wastes

Samples that represented the parent stream of the plastic wastes were taken to the Thermodynamics Laboratory of the Faculty for determination of the calorific values. The methods outlined in BS EN 14918:2009 were used to calculate the GCV (Dodo et al., 2022b; Ivanova et al., 2018). The samples were crushed to a 4 mm particle size after being air-dried. Thereafter, they were packaged in tablet form to facilitate combustion in the bomb calorimeter.

A sample weighing about 5 mg was placed in the crucible before transferring to a chamber known as the bomb. The sample was ignited electrically, and a compressed pellet of pure benzoic acid was weighed and placed in a crucible. Then a nichrome wire of 5 cm and cotton thread of 10 cm were attached to the ignition rods with the capsule just touching the bottom of the crucible. An oxygen sample was coupled to the bomb calorimeter till the pressure in the bomb rose to 25 kg/cm^2 with the release valve in the closed position. A drop of water was put into the bomb and left to burn slowly with oxygen to a pressure of 25kg/cm^2 without displacing the original air. The bomb was then placed in the inner calorimeter vessel which contained a weighted quantity of water sufficient to cover the bomb (2 liters). Thereafter, the inner vessel was lowered into the outer jacket, the firing lid was connected to the lid, and the stirrer unit was fitted to enable the commencement of the stirring. Probes (red and black wires) were fixed to the two ports of the calorimeter and a control box was connected to it. The initial water temperature was recorded by pressing the temperature indicator (thermometer). The final reading was taken from the thermometer when the bomb and the contents attained steady-state temperatures.

If T_1 stands for the initial temperature, after combustion, the calorimeter temperature increased and stabilized at T_2. The heat produced by the reaction is denoted by Q (Joule). The entire calorimeter and reaction products inside the bomb absorbed this heat. Disregarding how these items affected the calorimeter and the water in it. The calorific value was computed using the equation (1) (Kamran, 2021). The experimental set for

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determining the calorific value is shown in Fig. 4.

$$Gross\,calorific\,value = \frac{heat\,produced}{amount\,of\ fuel} \quad (1)$$

The heat produced; Q was computed using the equation (2).

$$Q = nC_p \Delta T \quad (2)$$

where Q is heat produced, n is the number of moles of fuel, C_P is heat capacity at constant pressure (1 bar), and ΔT is the initial and final temperature difference.

Fig. 4: Experimental setup

Plastic waste electricity generation potential analysis

To estimate the plastic's energy potentials, the NCV was calculated using equation (3), (Dodo, 2023; Dodo & Ashigwuike, 2023a).

$$NCV = GCV \times PW \quad (3)$$

Where GCV is the gross calorific value obtained from the calorimeter, and PW represents the weight of the plastic waste sample. Equation (4) was used to calculate the energy potential recovery in kWh, electricity generation potential in kW, and power to grid potential in MW from plastic waste.

$$EP_{plastic} = NCV_{plastic} \times W_{plastic} \times \frac{1000}{3.6} \quad (4)$$

$W_{plastic}$ represents the weight of the plastic wastes (tons), $NCV_{plastic}$ is the net calorific value of the plastic waste (MJ/kg), while the energy conversion ratio is 1 kWh=3.6 MJ.

RESULTS AND DISCUSSION

Plastic waste collection

The results of the plastic wastes in terms of their weight are presented in Table 1. A total of 6,346.67 g of the plastics was collected during the study period with the lowest of 191.22 g and highest collection of 632.34 g made on Friday 13th June, 2024 and Thursday 14th June 2024 respectively. There was no collection of waste on the 17th and 18th of June 2024 due to the Islamic Sallah Festivity.

Table 1: Daily Plastic Waste Collected

Date	Quantity (g)	Date	Quantity (g)
Wednesday 12th June	287.00	Friday 28th June	208.43
Thursday 13th June	632.34	Monday 1st July	223.95
Friday 14th June	191.22	Tuesday 2nd July	219.13
Wednesday 19th June	343.71	Wednesday 3rd July	356.00
Thursday 20th June	202.62	Thursday 4th July	237.59
Friday 21st June	282.94	Friday 5th July	352.87
Monday 24th June	442.29	Monday 8th July	216.60
Tuesday 25th June	302.48	Tuesday 9th July	552.74
Wednesday 26th June	442.35	Wednesday 10th July	378.14
Thursday 27th June	372.95	Thursday 11th July	320.45

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The rates of plastic waste generation are not uniform throughout the study period due to different consumption patterns. The results show that, on average, approximately 317.33 g of plastic waste is generated at the Faculty of Engineering building per day. Fig. 5 shows the monthly plastic waste distribution. A total of 3,708.33 g and 2,638.34 g of plastic waste were generated in June and July amounting to an average daily generation of 337.12 g and 329.79 g respectively. The lower quantum generation in July can be attributed to lower academic activities compared to June. In June, as shown in Fig. 5(a), the largest share of the plastics (623.34 g) was generated on the 3rd while the lowest share of 191.22 g was generated on the 14th. As depicted in Fig. 5(b), in July, approximately 216.6 g of 8th and 552.74 g of 9th are the lowest and highest plastic generation respectively.

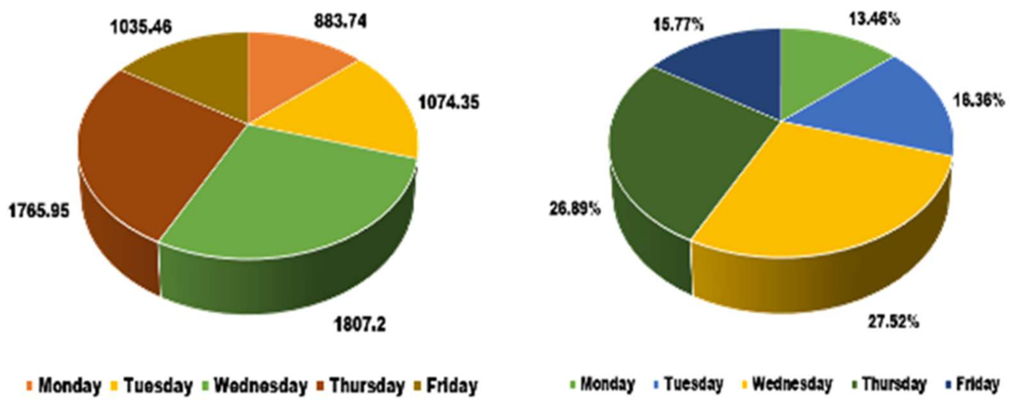

Fig. 5: Monthly plastic waste collection

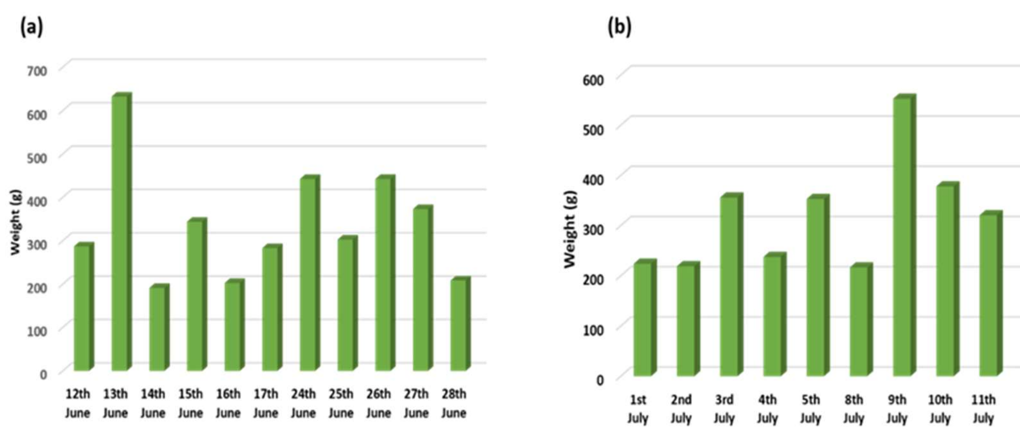

Fig. 6: Work-days Plastic wastes distribution

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Fig. 6 (a) depicts the quantity of plastic waste generated on work days with 883.74 g, 1035.46 g, 1074.35 g, 1765.95 g, and 1807.2 g on Mondays, Fridays, Tuesdays, Thursdays, and Wednesdays respectively in ascending order of quantity. This implies that plastic generation is lowest on Mondays and Fridays being the last and first days of academic activities in the Faculty. While more plastics generated on Wednesdays and Thursdays portrayed more booming activities compared to other days.

An attempt was made to visualize the plastic waste distribution in terms of the ground floor and upper floor of the faculty building. A total of 3,626.27 g and 3,082.53 g of plastic waste was generated on the upper floor and ground floor, representing 45.95% and 54.05% respectively. As shown in Fig. 7, rates of plastic waste generation are not uniform across the building due to different consumption patterns. In some cases, the quantity of plastics collected on the ground floor supersedes those collected from the dustbins on the upper floor of the faculty building. This occurred on 7th, 8th, 9th, 16th, and 19th days of collection. The share of waste generation on the upper floor can be due to it having more classes compared to the ground floor.

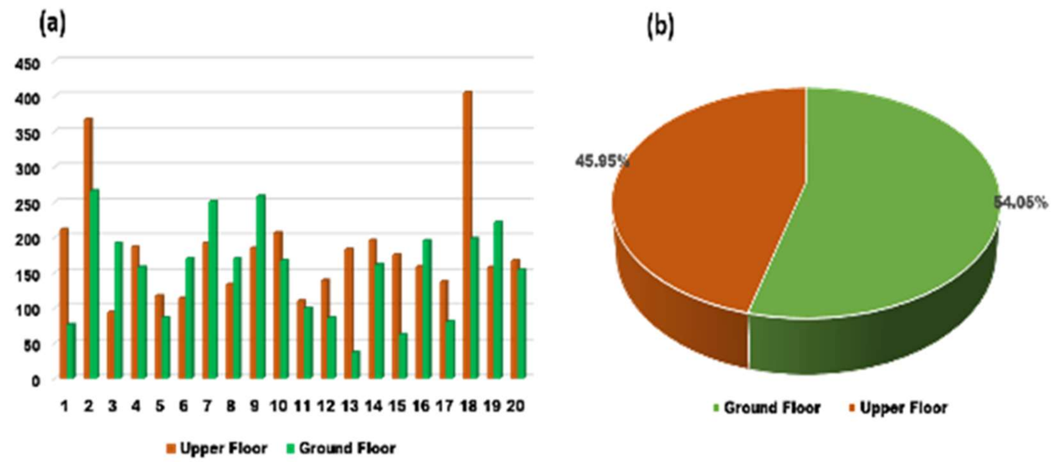

Fig. 7: Ground Floor vs. Upper Floor Plastics Waste Generation

Electricity Generation Potential Analysis

With the specific heat capacity of the plastic as 2.3 J/goC, the temperature change was found as 2869.57 oC. The resulting GCV of the plastic waste was found as 48 MJ/kg. Therefore, the NCV which excludes water vapour is 15.23 MJ/kg. This is about 62%, 41%, and 34% of the NCV of coal, diesel, and natural gas respectively (Dodo & Ashigwuike, 2023a). Therefore, the daily energy potential of the plastic waste generated in the Faculty is 1.53 kWh which is equivalent to 63.75 W.

CONCLUSION

This study presents the energy potential analysis of plastic wastes in the Faculty of Engineering Building of Baze University Abuja, Nigeria. To achieve this target, the plastic wastes were collected for four weeks commencing from 11th June 2024. The quantity of waste collected was analyzed on a daily and monthly basis as well as collection according to the ground floor and upper floors of the building. Samples of the plastics collected were subjected to laboratory analysis to determine their energy potential. A total of 6,346.67 g of plastics were collected; the lowest and highest collections of 191.22 g and 632.34 g, respectively, occurred on Friday, June 13, 2024, and Thursday, June 14, 2024. In June and July, 3,708.33 g and 2,638.34 g of plastic garbage were produced, respectively, which

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equates to an average of 337.12 g and 329.79 g per day.

The energy potential analyses showed that the plastic waste's NCV is 15.23 MJ/kg. Consequently, the Faculty's daily energy potential from the plastic wastes it generates is 1.53 kWh or 63.75 W. Waste conversion into energy reduces the amount of waste that needs to be disposed of on campus while also giving the institution electricity that lowers greenhouse gas emissions by replacing fossil fuels. Using the proposed waste-to-energy options on-site also has the benefit of removing the need for transportation of plastic wastes for final disposal, which lowers fuel usage and related greenhouse gas emissions leading to curtailing climate change. There is a need to explore further the quantity of electricity that can be generated from other biomass materials such as polyethylene (nylons), papers, and food residues found in the dustbins across the universities.

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