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Institutional Solid Waste Management Practices: A Case Study in Jigme Namgyel Engineering College

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Abstract

Solid waste management in Bhutan has become a significant environmental concern with considerable social and economic implications. As the country experiences rapid urbanization and economic development, the generation of solid waste has increased, placing strain on existing waste management systems. This situation necessitates an investigation and response to the challenges faced by institutional solid waste management practices nationwide. Waste management in Bhutan's schools and colleges encounters critical difficulties. Inadequate waste segregation, limited recycling infrastructure, and low awareness among students contribute to poor waste management practices. Furthermore, overflowing bins, improper waste handling, and insufficient institutional policies lead to environmental pollution and health hazards. Therefore, this study was conducted to characterize and quantify solid waste generation at Jigme Namgyel Engineering College (JNEC). The research focused on identifying potential technological and infrastructural interventions to enhance waste management practices within the campus. The study determined a per capita waste generation rate of 170g per day. Waste characterization revealed that organic waste (wet waste) constituted the largest proportion at 35%, followed by paper waste at 19.09% and plastic waste at 24.24%. Over a six-month period, approximately 4.5 metric tons (Mg) of dry waste and 6 metric tons (Mg) of wet waste were collected. Greenhouse Gas (GHG) emissions originating from waste generated within the campus were modeled using LANDGEM. The results indicated total greenhouse gas emissions amounted to 3472 cubic meters per year. This included 1736 cubic meters of methane, 1736 cubic meters of carbon dioxide, and 8.33 cubic meters of non-methane organic compounds (NMOC) emitted annually. Based on an estimated monthly generation of 617.74 kg of dry waste and 838.92 kg of wet waste solely from JNEC, the existing municipal landfill is projected to reach its maximum capacity by the year 2040.

Keywords— Solid waste management, waste characterisation, LANDGEM, green house gas (GHG) emissions, institutional waste

1 Introduction

1.1 General Background on Global Solid Waste Management

Waste Management has been a persisting issue for most developing countries even though there has been strict legislation and policies framed by the government. Most of the developed countries have managed to handle the waste through improved technologies such as waste to energy, recycling facilities, bio-methanation, composting, etc., but due to improved living standard of people and technologies, a proper waste management policy is being challenged every now and then with different waste compositions which are been introduced for the government and people to handle.

As per [24], the annual generation of municipal solid waste in all the countries around the globe is around 2.01 billion tonnes out of which 33 percent is conservative. Simultaneously by the year 2050, global waste is expected to grow up to 3.40 billion tonnes. As per the projection prepared by World Bank, daily per capita waste generation for high income countries is expected to increase by 19 percent by 2050. Similarly, for low-and middle-income countries it is expected to increase up to 40 percent or even more. The waste composition differs across various income levels, indicating diverse consumption patterns across individuals. High income countries tend to generate relatively less food and green waste, which comprises 32 percent of total waste. The dry waste generated constitutes about 51 percent of recyclable waste such as plastic paper, car-board, metals, and glasses. Middle-income and low-income countries generate about 53 percent and 57 percent of food waste and green waste.

1.2 Waste Management Outlook in Hilly Regions

Waste management especially in hilly regions are seen as a problem in most of the developing countries with increase in urban sprawl, change in consumption habits of the people, tourism and illegal open dumping activities due to poor waste collection systems. Due to dispersed settlements in the hilly areas, collection and transportation of the waste can be majorly seen as an issue. Subsequently, identifying a proper landfill area in these places is also considered a critical factor in proper management of waste generated from these areas.

According to [20], factors such as topography, isolation, socio-economic conditions and its risk factors involved due to natural hazards make waste management difficult and challenging as compared to waste management in plainer areas. The organic and biodegradable fractions from these localities include agricultural waste, leftover food, fruits, vegetables, seeds, paper, etc. These organic wastes degrade naturally in a few weeks or months. However, the non-degradable fraction includes plastics from packaged foods, glass, bottles, metal cans, e-waste in small fractions, etc., which tend to persist in environment for decades or even centuries. It is reported that than nearly 46 percent of total waste comprises of food waste i.e. 0.3 kg of food waste per day per household in Bhutan [14].

1.3 Objectives

- To quantify and characterize the solid waste generated at JNEC
- To assess the existing solid waste management practices and challenges at JNEC
- To evaluate the environmental impacts of institutional solid waste and recommend sustainable waste management strategies

2 Materials and Methods

2.1 Study Area

Jigme Namgyel Engineering College (JNEC) is one of the constituent colleges of the Royal University of Bhutan (RUB). The college is located atop a hill overlooking the small town of Dewathang (26.8602° N, 91.4647° E) at an altitude of approximately 880 m above the mean sea level and is 18 kilometers from Samdrup Jongkhar town, second gateway to Bhutan from Indian state of Assam. It offers a total of twelve undergraduate programmes and has 808 students and 125 staff as of 2024. The campus covers a total area of 56.2 acres, making it the largest contributor to solid waste within Dewathang community. The survey was carried out for seven months from December 2023 to June 2024 within the campus covering the waste generation from both students and staff. Both qualitative and quantitative surveys were conducted to understand the persisting waste management practices within campus. Fig. 1 shows the study area for this research.

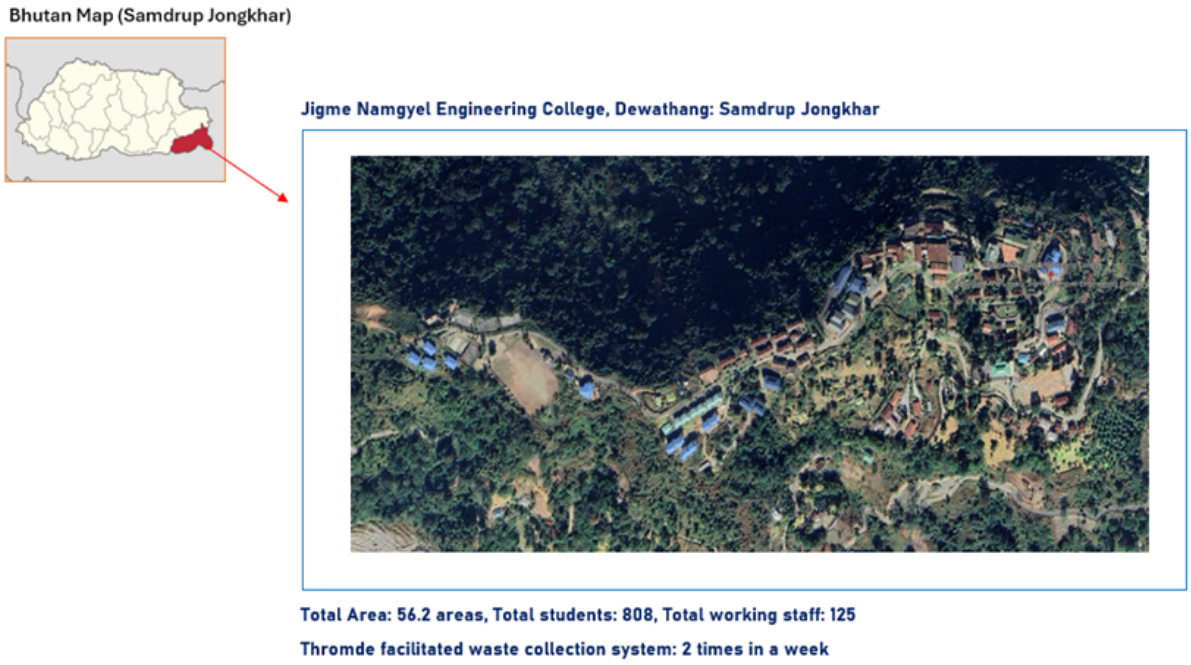


Figure 1: Study Area: Jigme Namgyel Engineering College, Dewathang: Samdrup Jongkhar

2.2 Sample collection

Two sets of questionnaire surveys were prepared by the research team, Department of Civil Engineering Surveying, Jigme Namgyel Engineering College (JNEC) to survey staff and students at college. Among staff, approximately 52 households comprising academics (21 households), academic support staff (17 households), general support staff (8 households), and administrative staff (6 households) were surveyed. Around 232 students were surveyed on the present waste management scenario on campus as shown in Fig. 2. Of 232, 155 students were recorded to be self-catering while 77 were recorded to be dining in student mess. The data obtained were related to quantity of MSW, daily disposal habits, level of satisfaction on the facilities within campus, prior knowledge on MSW management, etc. Similarly, per capita generation rate of MSW (kg/capita/day) was estimated based on quantification data within campus. Finally, based on data collection, possible greenhouse gas emissions were modeled using LANDGEM. The standard procedure of sample collection and MSW

analysis was adopted as defined in [16]. In each of the selected households on campus, garbage bags were provided on a timely basis to manage the separation of their garbage. Garbage bags were then labelled corresponding to the fraction of the waste, i.e., organic and in-organic waste. The frequency of collection was two times a week during the study period (December 2023 – June 2024). Similarly, from student hostels and administrative buildings, the waste quantity was determined from the common drop off points twice a week.

The waste generation rate was determined by combining the collected waste. The collected waste was weighed twice a week, and physical composition of the solid waste was determined. The collected waste was mixed thoroughly, and random sampling was performed. Waste composition in terms of different fractions such as organic waste, papers and cardboards, plastics, textiles, metals, glasses and others such as inert wastes, dirt, etc., was carried out using a quartering method. A density box (30 cm x 30 cm x 30 cm) having a volume of 0.027 m3 was fabricated using plywood to estimate the density of the waste. The samples after the density test were taken to the Environmental Engineering Laboratory of JNEC and analyzed moisture content using guidelines as mentioned in [3].

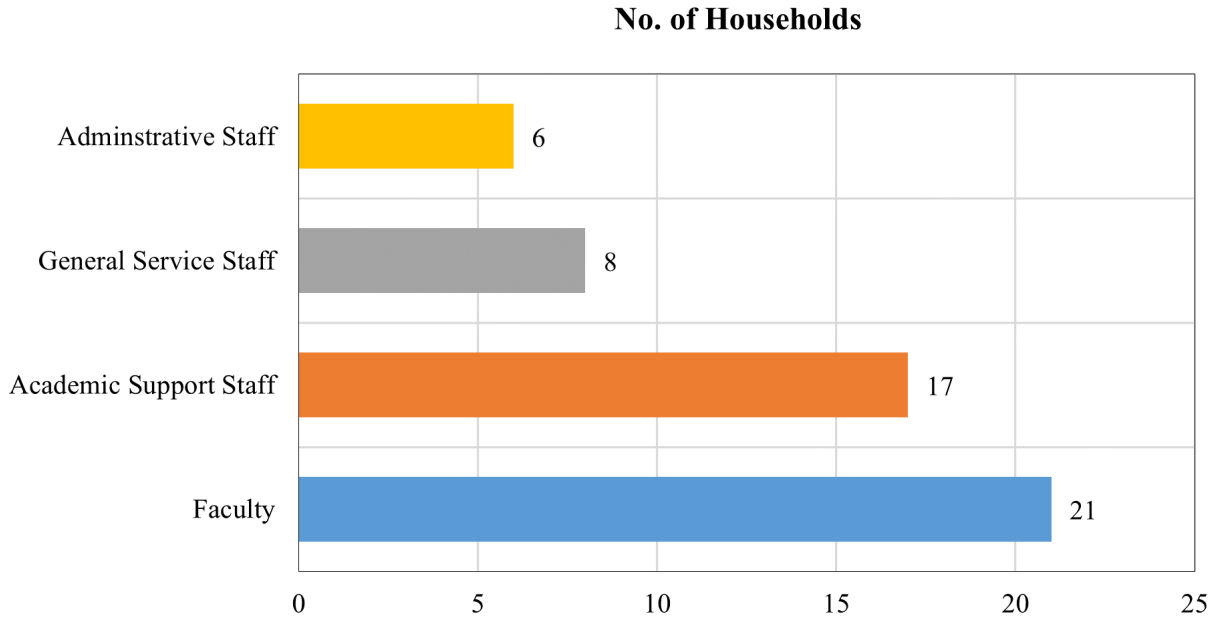


Figure 2: Number of households surveyed

3 Results and Discussion

3.1 Waste Generation

Waste generation rate is a pivotal factor in designing a proper waste management system for any area. It is a significant parameter even to improve the existing waste management practices [6, 7]. A quantitative survey involved waste quantification in which waste was measured 4 weeks in a month from December 2023 to June 2024. The dry waste collected over six months accounts for 4324.22 kg (4.324 tonnes) as shown in Fig. 3. The highest collections were observed to be in February with 947.98 kg of dry waste, with January having the least value over 258.96 kg. Since February and June are the months were students report to the college and breaks for vacation, the collection values are generally noticed to be higher as compared to other months.

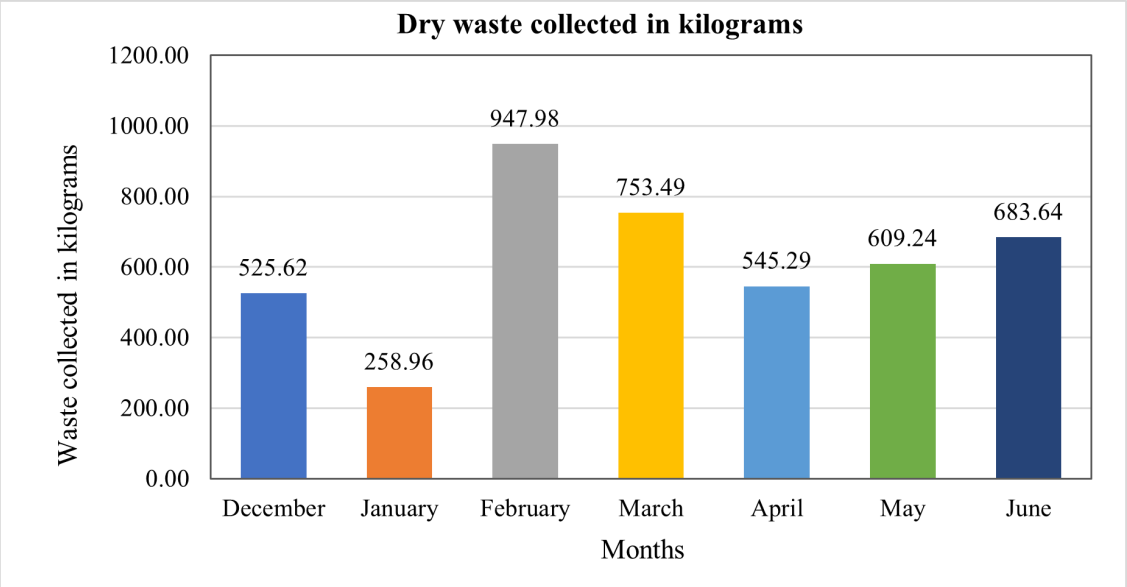


Figure 3: Dry waste collected over 7 months

Similarly, the wet waste collected from upper and lower mess accounts for 5.872 tonnes in seven months in which daily cumulative collection over 4 weeks is shown in Fig. 4. With this level of collection, there is full potential of food waste as an energy source either through biogas plants or through composting.

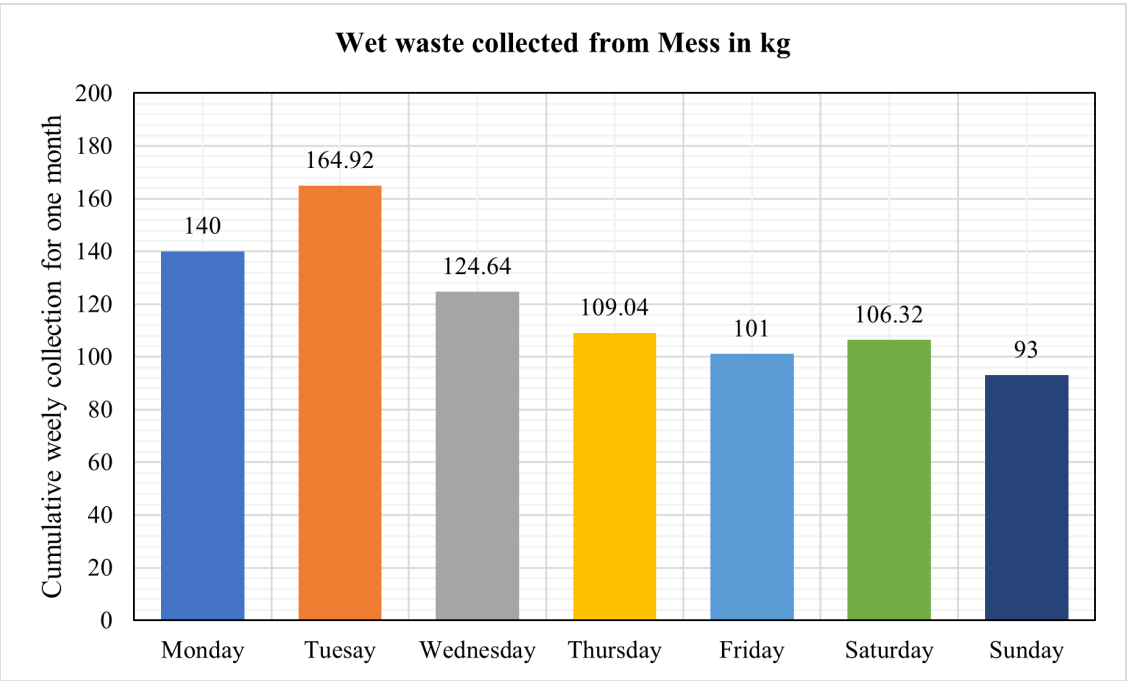


Figure 4: Wet waste collected over 7 months

To understand the waste characterization and waste generation rate within campus, waste samples were collected from selected households for 8 consecutive days and analyzed. Per capita waste generated per day was evaluated to be 170 g per person per day as shown in Table 1.

Institutional waste generation in Bhutan, arising from schools, hospitals, government offices, and religious institutions contributes significantly to the country's overall waste stream, though

Table 1: Waste generation rate for Jigme Namgyel Engineering College

Household No.	Family Size	Amounts (kg)							Total Weight (kg)
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	
Household 1	7	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 2	3	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 3	2	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 4	5	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 5	1	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 6	4	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 7	6	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 8	2	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Household 9	1	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.13
Total Waste		**5.31**	**5.31**	**5.31**	**5.31**	**5.31**	**5.31**	**5.31**	**37.17**
Total People	**31**	31	31	31	31	31	31	31	
Per Capita Generation Rate (kg/capita/day)		0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.170

comprehensive nationwide data remains limited. Available studies indicate that institutions in urban areas, particularly in Thimphu and Phuentsholing, generate 0.2 to 0.4 kg per capita per day, with higher rates observed in healthcare facilities due to biomedical waste [11]. However, there are no official data records suggesting per capita waste generate rate from any academic institutions within the country.

3.2 Waste Composition

Analyzing the composition of solid waste is a critical step in waste management, as it provides the necessary data to implement strategies for minimizing waste generation, enhancing recycling efforts, selecting appropriate processing methods, and ensuring environmentally sound disposal [2, 1]. Similarly, the density and moisture content of solid waste are critical parameters in waste management, influencing storage, transportation, processing, and disposal efficiency. Density affects the design of waste collection systems, landfill capacity, and the economic feasibility of waste transport, with higher density reducing volume and associated costs [21]. Meanwhile, moisture content impacts waste decomposition rates, calorific value in waste-to-energy processes, and leachate generation in landfills [9]. High moisture content can increase biodegradability in composting but reduce efficiency in incineration, while low moisture content may lead to dust and fire hazards [18]. Accurate measurement of these properties ensures optimal waste treatment selection, cost-effective logistics, and compliance with environmental regulations [4]. Recent studies on Bhutan's municipal solid waste highlight important characteristics regarding density and moisture content that significantly influence waste management strategies.

According to the National Environment Commission [12], Bhutan's MSW exhibits an average bulk density ranging between 280-400 kg/m^3 in urban areas, with higher densities observed in Thimphu (350-400 kg/m^3) due to greater amounts of non-organic waste like plastics and packaging materials. In contrast, rural areas show lower density values (250-300 kg/m^3) because waste streams are dominated by loose organic matter [22]. Increasing urbanization and consumption of packaged goods are also contributing to gradual rises in waste density nationwide [12]. Moisture content in Bhutan's waste remains notably high at 45-65% [13], primarily attributed to three key factors: the predominance of organic waste (comprising 60-70% of MSW), seasonal monsoon rains that increase wetness in uncovered waste storage, and inadequate waste segregation practices that keep moisture trapped in mixed waste streams [5, 19]. These characteristics have important implications for waste treatment, the high moisture content makes waste unsuitable for incineration due to low calorific value [25], while creating ideal conditions for composting (though requiring careful moisture monitoring to maintain optimal 50-60% levels). The elevated moisture also increases leachate production in landfills, necessitating improved lining systems [8]. Based on the quartering method deployed, Table 2 represents the composition in the campus collected from different locations

and Fig. 5 presents the overall composition of waste generated from campus.

Table 2: Waste fraction composition over seven days

Waste Fraction	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Total (kg)	Percentage (%)
Organic waste	2.21	2.82	2.24	2.55	2.26	2.88	2.32	17.28	34.99
Paper and Cardboard	0.86	1.51	0.97	2.19	1.06	1.07	1.77	9.43	19.09
Plastic	0.99	2.67	0.98	0.63	2.93	1.88	1.89	11.97	24.24
Textile	0.67	0.00	0.56	0.87	1.47	0.00	0.00	3.57	7.23
Metals	0.66	0.87	0.00	0.00	1.12	0.00	0.00	2.65	5.37
Glass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.45	0.55	0.48	0.65	0.36	0.80	1.20	4.49	9.09
Total								**49.39**	**100.00**

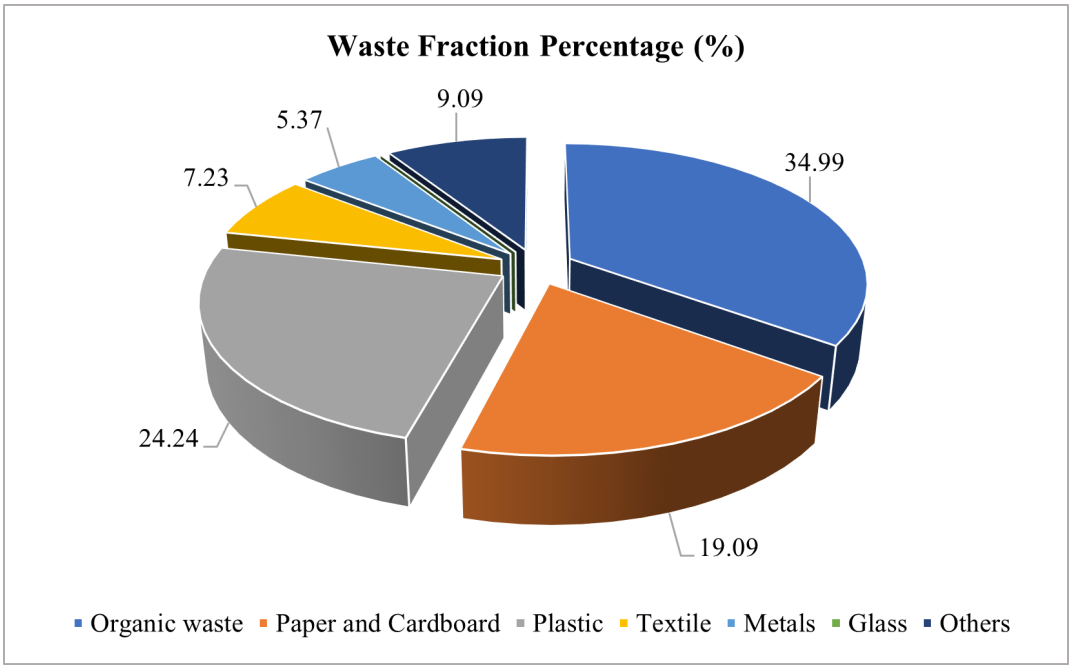


Figure 5: Waste fraction percentage (%)

Organic waste or wet waste was found to be highest with 35% followed by 19.09% comprising paper and 24.24% of plastic waste respectively. The density and moisture content of the waste from the institute ranged from 30 – 38 kg/m3, and 74 – 80%. Observations reported that there is high recycling potential of waste, particularly paper and cardboard (19.09%), and plastics (24.27%). Additionally, a high fraction of organic waste can be used for composting or biogas generation. Thus, for successful implementation of integrated waste management system within the campus, the waste should be properly segregated at the source, followed by implementing proper sorting and reusing programmes at the source to reduce the waste generation at source.

3.3 Estimation of GHG emissions from total waste generated from JNEC

The increasing accumulation of organic fraction of municipal solid waste (OFMSW) from municipalities, communities, and educational institutions presents significant environmental and economic challenges particularly at disposal sites [11]. Bhutan faces growing waste management difficulties

due to urbanization, population expansion, and shifting consumption habits and the country generates 172.16 metric tons of waste daily with food waste accounting for 46% and plastics and paper making up 33% [11]. Urban centers beyond the capital also contribute substantially to organic waste generation. Academic institutions are major contributors discarding large quantities of food waste per student per meal. Currently, most organic waste is landfilled, emitting harmful methane while wasting energy potential that could be harnessed as biogas [23]. Since most of the waste composition is dominated by food waste, possible GHG emissions from the total waste generated from JNEC were modelled using LANDGEM.

From modelling as shown in Fig. 6 it was noticed that total greenhouse emission was 3472 cubic meters per year, methane emission to be 1736 cubic meters per year, carbon dioxide emission to be 1736 cubic meters per year and NMOC (non-methane organic compounds) emission to be 8.33 cubic meters per year. With a monthly generation of 617.74 kg of dry waste and 838.92 kg of wet waste, the existing landfill is expected to be reaching its maximum capacity by the year 2040, just from the waste collected from JNEC. All these emissions are from the assumption that total waste from JNEC is disposed of completely into the landfill. However, with sustainable initiatives such as composting and waste to energy, academic institutions can greatly reap the benefits from generated waste. The benefits can be foreseen in using biogas as cooking fuel as well as using compost for landscaping or gardening purposes within the campus.

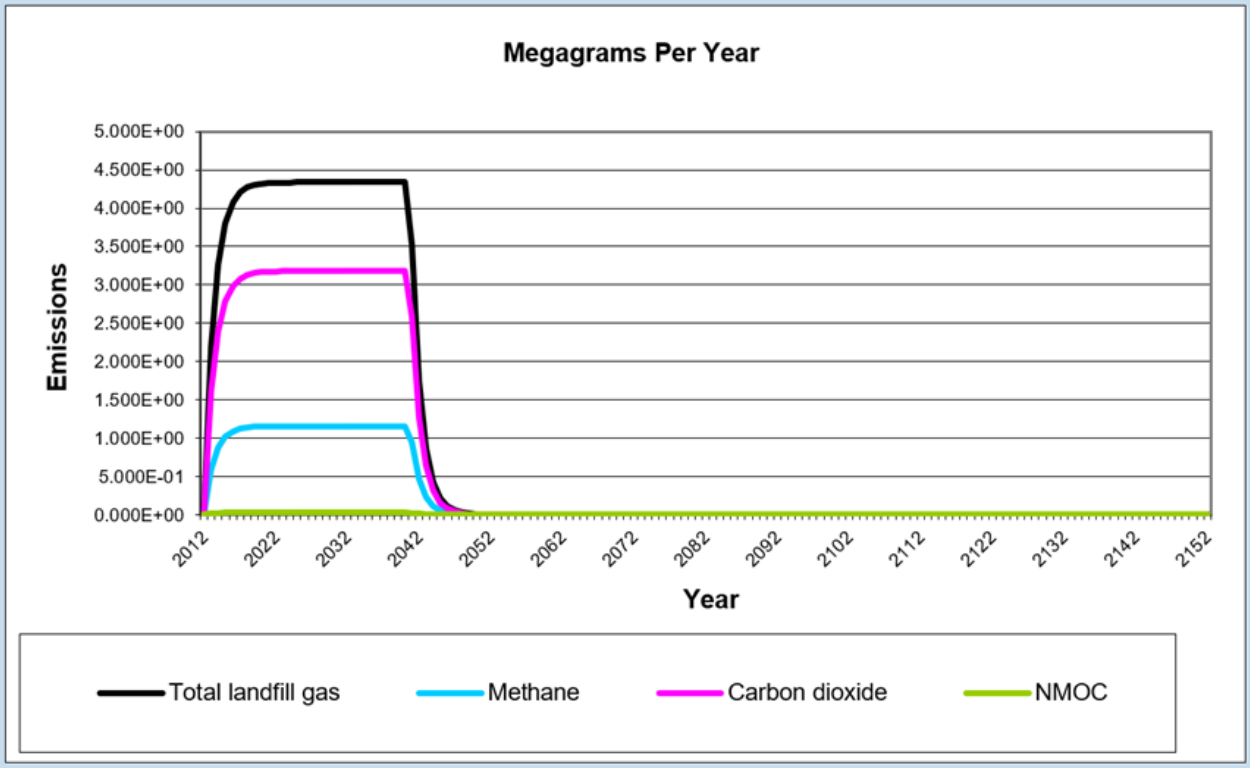


Figure 6: GHG Emissions

3.4 Questionnaire Survey on Solid Waste Management in Campus

A researcher administered a questionnaire survey was conducted to assess the understanding of solid waste management, along with identifying problems, solutions, and recommendations for improving the existing waste management systems within the campus. The survey consisted of a combination of closed- and open-ended questions. Closed-ended questions were designed to be easily comprehensible and quickly answered, while open-ended questions allowed a broader range of responses without being constrained by predefined options. The study employed purposive sampling, focusing on

students and staff residing on campus. The survey was divided into two parts: the first targeted staff members (including 21 academic households, 17 academic support staff households, 8 general support staff households, and 6 administrative staff households living on campus), while the second part focused on students, comprising both self-catering individuals (155 students) and those using the mess dining facilities (77 students).

The questionnaire collected data on participants' prior knowledge of solid waste management, identified issues with the existing waste collection and disposal systems, and assessed their satisfaction levels with municipal services. It also gathered insights on integrated systems for household waste removal, solid waste composition, and related factors. Additionally, as an addendum for students, the survey captured information regarding the need for improved waste disposal and collection systems in hostel areas, ratings of the college's waste management facilities, and the perceived necessity of waste sensitization programs or cleaning campaigns.

3.4.1 Questionnaire Survey for Staffs

- **Serviceability rating on the services rendered by Municipality**

  From the survey amongst staff, approximately 35% expressed to be content with the existing waste collection service offered by the municipality while 65% expressed to be unhappy. Fig. 7 shows the detailed stats of the rating.

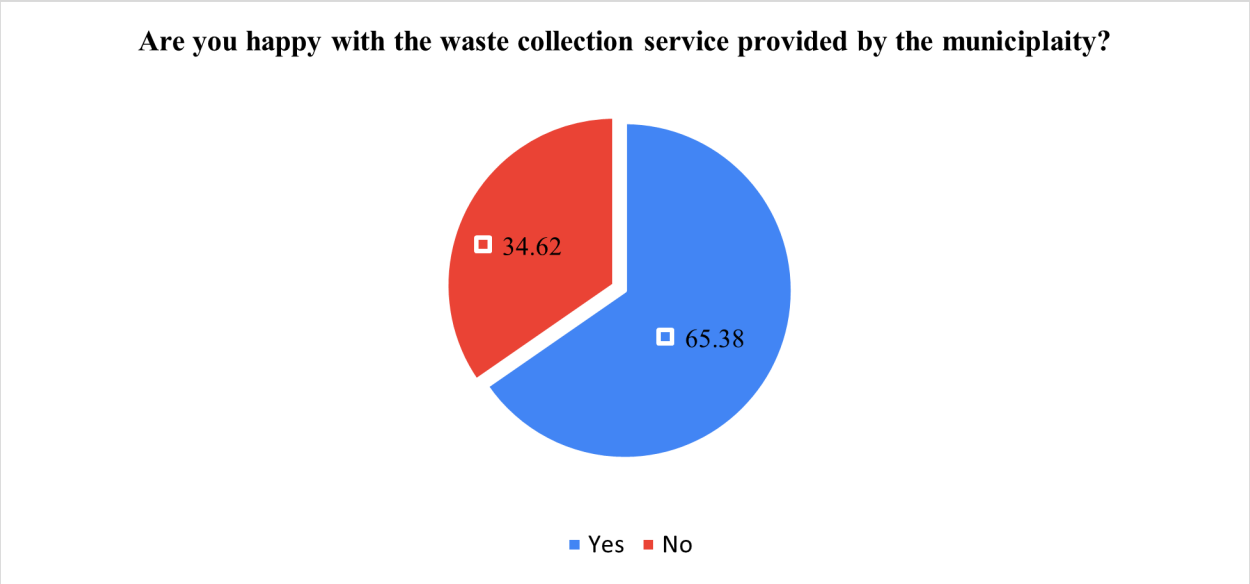


Figure 7: Serviceability rating

According to the municipality's service schedule, waste is collected only on Mondays and Thursdays. Since these collection hours fall on working days, staff members find it inconvenient to dispose of their waste during that time. Additionally, other factors such as the limited frequency of collection and inadequate waste drop-off points are likely contributing to their dissatisfaction.

- **Causes of Solid Waste problems on campus**

  As shown in Fig. 8, the survey indicates that the absence of dustbins in designated areas is the leading cause of littering on campus, with academics reporting this issue most frequently. Unattended waste along roads and drains was also identified as a significant concern, particularly among academic and general service staff. Additional problems include waste left around

dustbins, overflowing containers, and irregular waste collection services, which were noted by academic support staff and other respondents.

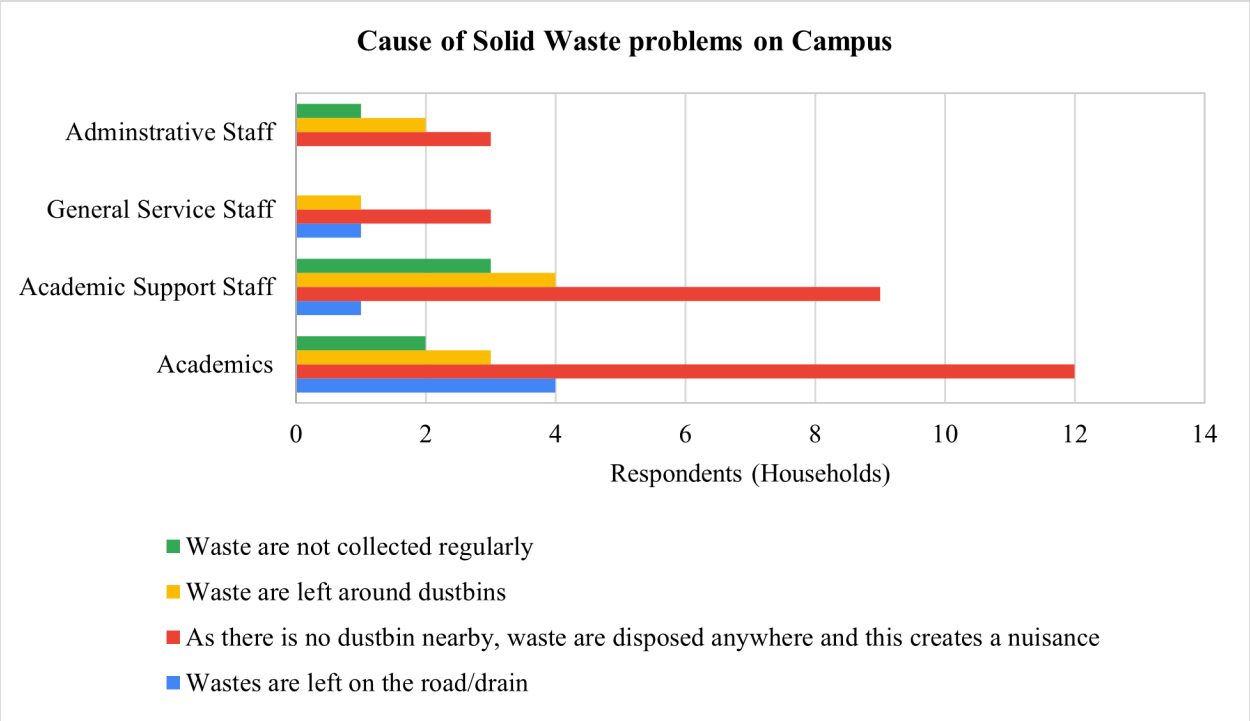


Figure 8: Solid Waste problems on Campus

- **Dominant Fraction of waste from Daily Household Waste**

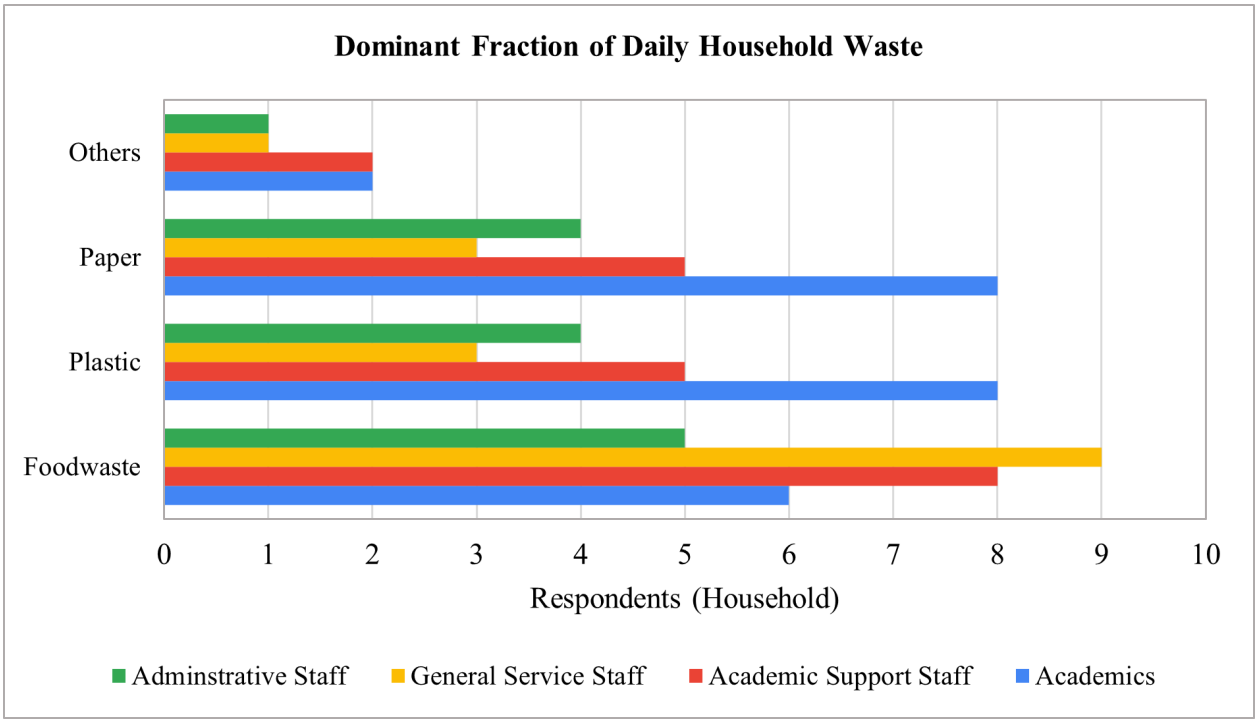


Figure 9: Dominant Fraction of Daily Household Waste

As shown in Fig. 9, the survey results show that food waste constitutes the largest portion of

daily household waste generated on campus. This trend is consistent across all staff categories, with academics and general service staff reporting the highest levels of food waste. However, the data also indicates a variation in waste composition linked to income levels. Higher-income groups, such as academics, reported greater amounts of paper and plastic waste compared to lower-income groups, which primarily generated food waste. This pattern suggests that income influences the type of waste produced, with higher-income households contributing more recyclable materials like paper and plastic, while lower-income households generate more organic waste.

- **Need for waste management initiatives on campus**

  The survey findings indicate a strong demand for waste segregation bins at designated locations across the campus as shown in Fig. 10. Academics expressed the highest need for these bins, followed by academic support staff and general service staff. The use of color-coded bins would help promote proper source segregation and improve awareness among students and staff. This system would also allow the municipality to collect waste more efficiently from these points. In addition, respondents highlighted the importance of organizing regular cleaning campaigns to maintain cleanliness on campus. The need for more frequent waste collection services was also noted, particularly by academic and academic support staff. A small proportion of respondents indicated that no additional measures were necessary, suggesting that most participants recognize the importance of improved waste management practices.

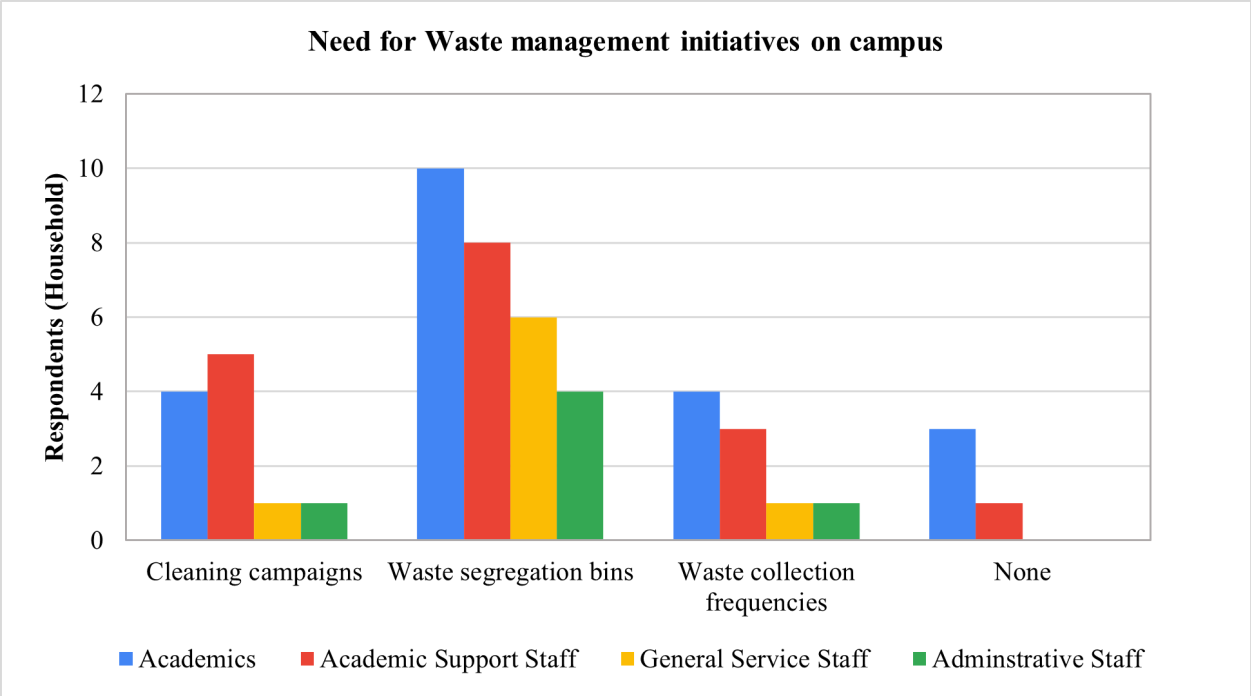


Figure 10: Need for Waste management initiatives on campus

3.4.2 Questionnaire Survey for Students

- **Understanding on Solid Waste among students**

  The survey results indicate that a significant proportion of students lack accurate knowledge about solid waste as shown in Fig. 11. Approximately 70% of respondents provided incorrect responses when asked about their understanding of solid waste. Most students associated solid waste primarily with plastic and paper waste, which accounted for more than half of the responses. A smaller percentage identified other categories such as kitchen waste, CD

waste, and electronic waste, while about 30% mentioned other forms of waste excluding e-waste and CD waste. This pattern suggests that students have a limited and often incomplete understanding of different types of solid waste. The findings highlight the need for targeted awareness programs and educational initiatives to improve knowledge on waste classification and management practices. Such efforts could help students adopt better waste disposal habits and contribute to sustainable campus practices.

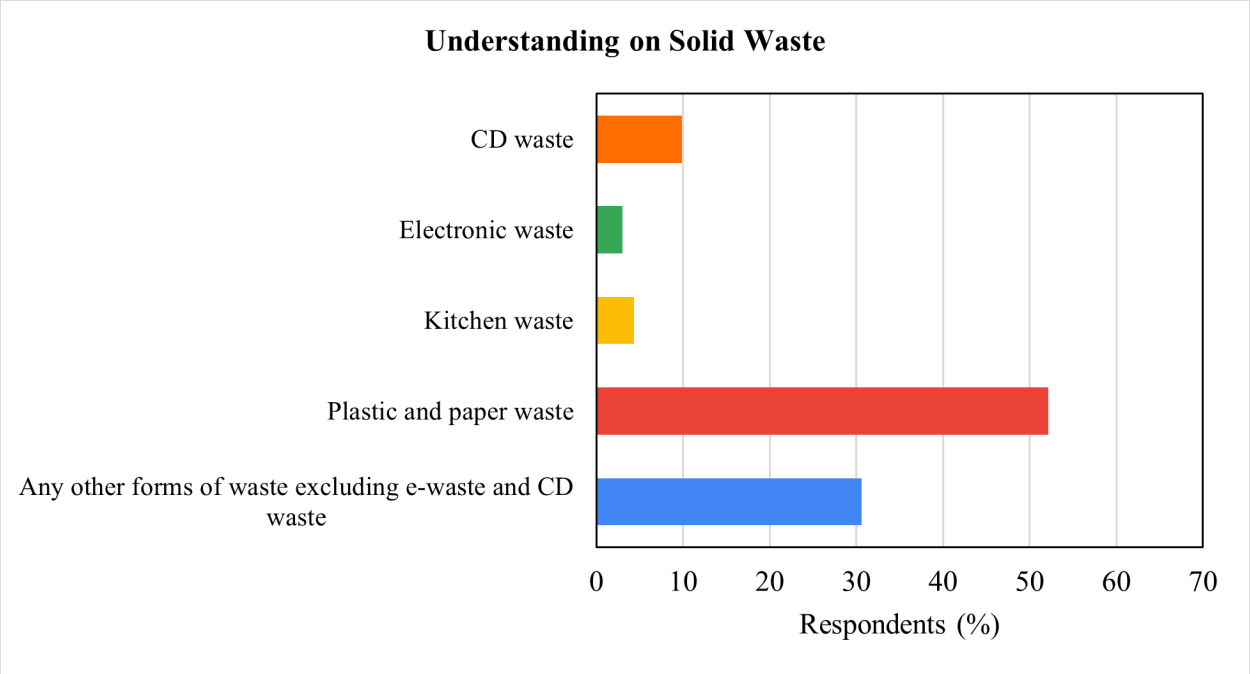


Figure 11: Understanding on Solid Waste

- **Rating for current waste management facilities on campus**

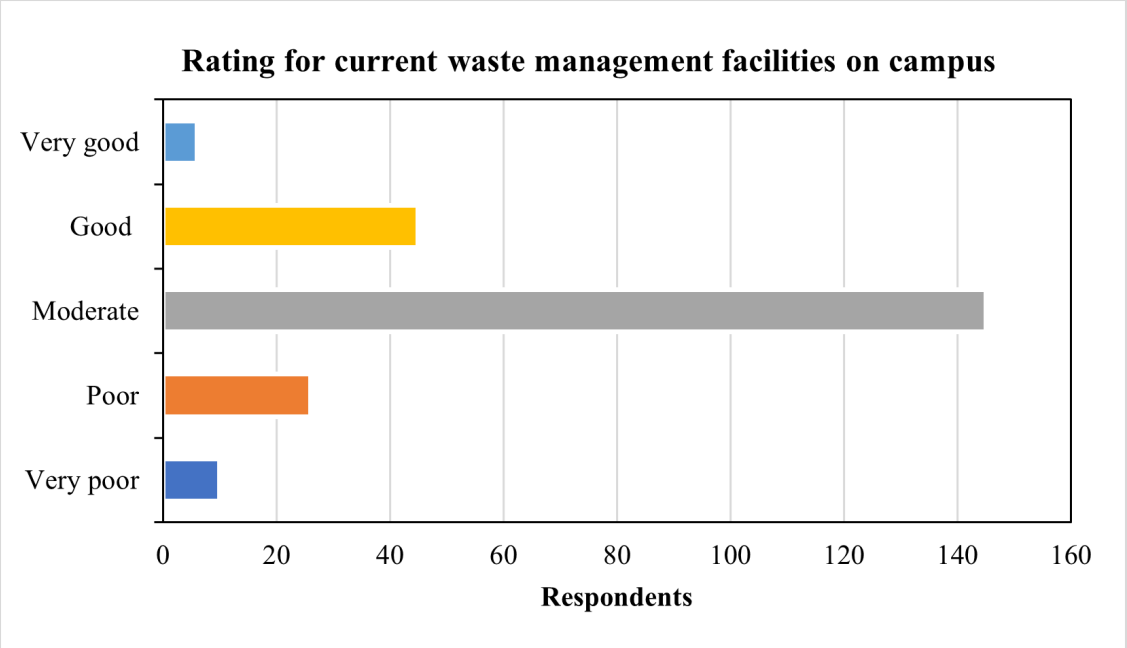


Figure 12: Student's rating on Solid Waste

Fig. 12 shows the ratings for current waste management facilities on campus. Although waste management facilities are available on campus, most students expressed dissatisfaction with their effectiveness. According to the survey, most respondents rated the current system as "moderate," while smaller groups rated it as "poor" or "very poor." Only a few considered the system "good" or "very good." Students reported that the existing infrastructure is overburdened and does not meet its intended purpose. One common issue is that waste is often left along the roadside during collection times, which creates an untidy environment. Furthermore, the absence of designated collection bins results in mixed waste, making segregation difficult and reducing the efficiency of disposal. These shortcomings indicate that the current system requires significant improvement, including better infrastructure, more organized collection points, and stricter adherence to waste segregation practices. Addressing these concerns would help enhance cleanliness and sustainability on campus.

- **Waste Composition on Campus**

  The analysis of waste composition on campus as depicted in Fig. 13 shows that plastic waste is the most dominant category, accounting for 46.55% of the total waste generated by students. Food waste represents the second largest fraction at 37.50%, followed by paper waste at 12.07%. A small proportion, about 3.88%, falls under other types of waste. These figures indicate that both recyclable dry wastes, such as plastic and paper, and organic wet waste, such as food scraps, make up most of the campus waste. This composition highlights the potential for implementing effective recycling and composting programs. By focusing on plastic and paper recovery and introducing systems for food waste composting, the campus can significantly reduce the volume of waste sent to landfills. Such measures would not only improve sustainability but also promote responsible waste management practices among students.

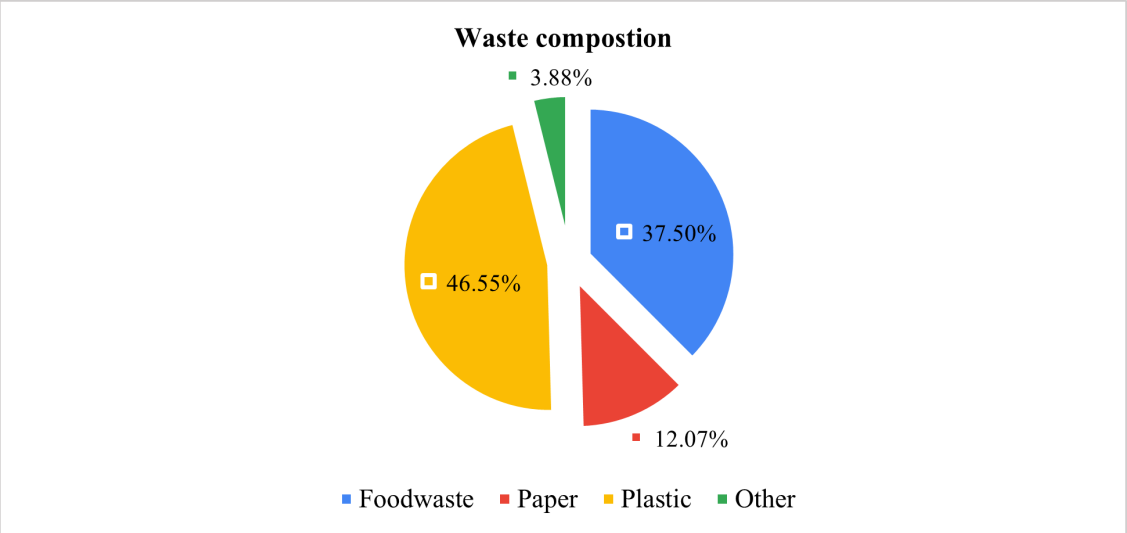


Figure 13: Waste Composition on Campus

- **Waste Segregation challenges on Campus**

  As shown in Fig. 14, the campus faces significant challenges in waste segregation, primarily due to inadequate infrastructure. A large majority of respondents, 90.54%, stressed the need for improved waste collection facilities, while 68.10% recommended the installation of dedicated recycling bins at strategic locations. These findings suggest that the current system does not support effective segregation practices. When students were asked about specific difficulties encountered during segregation, 43.53% reported problems with commingled waste,

which is likely a result of insufficient segregation bins. Additionally, 42.67% cited the lack of bins as a major obstacle, and 7.33% mentioned that segregation is time-consuming. A small proportion, 6.47%, indicated that they faced no challenges. These responses highlight the urgent need for better infrastructure, including color-coded bins and clearly marked collection points, to facilitate proper segregation. Addressing these issues would not only improve waste management efficiency but also encourage responsible disposal practices among students.

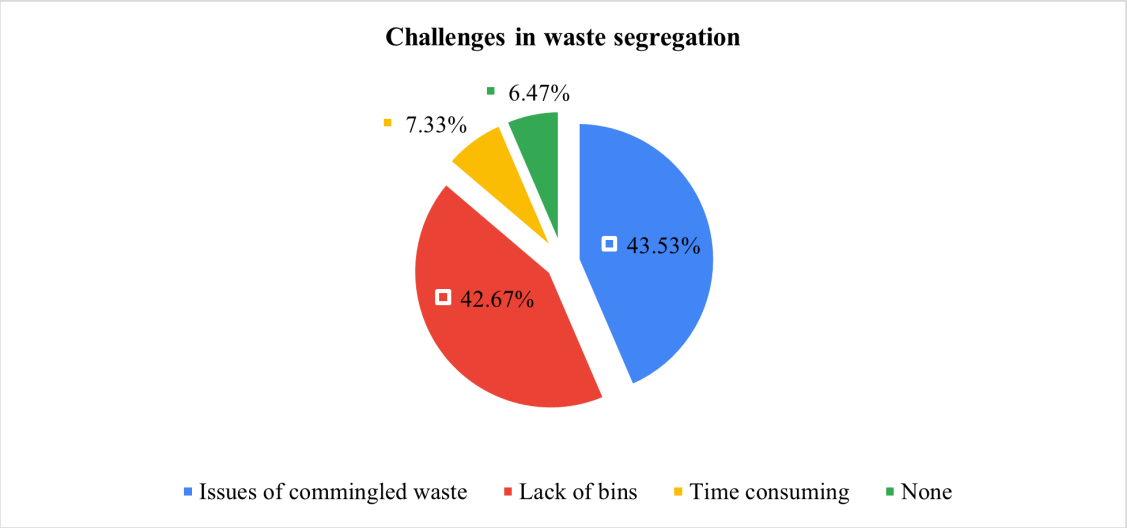


Figure 14: Challenges in Waste Segregation

- **Need for waste management education on campus**

  The institute currently undertakes several waste management initiatives, including weekend cleaning activities that involve both students and staff.

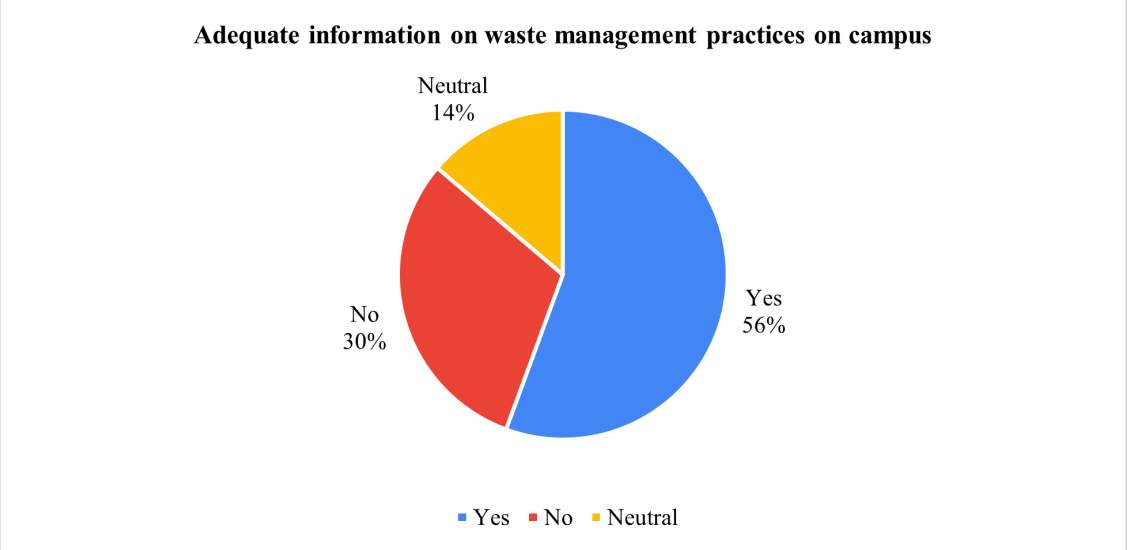


Figure 15: Need for waste management education on campus

Programs such as the Zero Waste Hour, which is part of a national campaign, and regular cleaning drives aim to maintain a clean campus environment while promoting environmental responsibility. Survey results show that 56% of respondents believe the institute provides adequate information about waste management practices and consider these efforts timely and

effective. However, 30% of participants indicated that the existing measures are insufficient and require further advocacy, while 14% remained neutral. These findings, as shown in Fig. 15 suggest that although many respondents appreciate the current system, there is a considerable proportion that feel improvements are necessary. Furthermore, when asked about the need for additional sensitization and awareness programs on source-level waste management, 89% of respondents strongly supported this requirement. This indicates that educational campaigns focusing on proper segregation and disposal practices could significantly enhance the effectiveness of waste management on campus and encourage sustainable behavior among the campus community

4 Conclusion

This study examined the solid waste management practices at Jigme Namgyel Engineering College, focusing on waste generation, composition, and associated greenhouse gas emissions. The findings revealed that the college generates approximately 170 grams of waste per person per day, with organic waste accounting for 35 percent, followed by plastic at 24.24 percent and paper/cardboard at 19.09 percent. Over a six-month period, the institution produced 6 metric tons of wet waste and 4.5 metric tons of dry waste. Using the LANDGEM model, the estimated annual greenhouse gas emissions from the college's waste were 3472 cubic meters, equally divided between methane and carbon dioxide. If current disposal practices continue, the landfill is expected to reach its full capacity by 2040 due to waste from the college alone. The questionnaire survey provided additional insights into the perceptions and behaviors of both staff and students. Most staff expressed dissatisfaction with municipal waste collection services, citing irregular collection and inadequate infrastructure. Among students, a significant portion lacked a clear understanding of solid waste management, and many rated the existing facilities as moderate or poor. Plastic and food waste were identified as the most common types of waste generated by students.

These findings highlight the need for improved waste segregation, enhanced infrastructure, and targeted awareness programs. Introducing color-coded bins, promoting composting and biogas initiatives, and strengthening waste collection systems could contribute to more sustainable waste management practices at the college.

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