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Waste Analysis and Characterization Study in a Philippine Science and Technology Research and Development Institution

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ABSTRACT

This paper presents the conduct of Waste Analysis and Characterization Study (WACS) in the Industrial Technology Development Institute of the Department of Science and Technology (DOST-ITDI) in Taguig City, Philippines. The study was produced following the introduction of 2020 guidelines developed by the Japan International Cooperation Agency for the Philippines to determine waste generation and generation rate per source, as well as waste composition, per capita generation, and bulk densities of the generated wastes. This then provided fundamental data in the formulation of initial plans and programs for the proper management of solid wastes in the institution. From the gathered results, DOST-ITDI generates 91.56 kg/day of solid waste during the dry season, and 77.54 kg/day during the wet season. The generated waste is composed of residuals for disposal (35.93% and 37.75%, dry and wet season), biodegradables (27.80% and 21.46%), and recyclables (22.54% and 28.95%). Per capita generation rates of 0.21 kg/capita/day (dry season) and 0.18 kg/capita/day (wet season) were also recorded. The research and development cluster of divisions was determined as a major contributor of waste at 42.37 to 57.62 kg/day. Bulk density values varied between waste fractions, with the main residuals for disposal components being the bulkiest at 29.27 to 32.90 kg/m^3. The data collected from the study provided significant information useful in efforts to initiate programs for diversion of biodegradables, recyclables, and residuals-with further potential for recycling wastes, reducing residuals for disposal through proper segregation and recovery, and determining gaps and opportunities in plans, policies, and programs to improve solid waste management of the institution.

1. INTRODUCTION

According to the status report published by the National Solid Waste Management Commission (NSWMC) for 2008-2018, institutional sources such as government offices, medical, and educational institutions contribute about 12.10% of waste generated in a year (EMB, 2018), or about 2.75 million out of the total estimated 23 million tons of municipal waste generated for 2023 (NSWMCa, 2023). Although this is dwarfed by other waste sources like households and commercial establishments, the amount of waste contributed by institutions still requires attention for management and diversion from sanitary landfills. This need for proper waste management is also highlighted by the considerable expectations placed on government offices to adhere to the environmental laws of the land, specifically Republic Act 9003 or the Ecological Solid Waste Management Act of 2000 (DENR, 2001). The Industrial Technology Development Institute or DOST-ITDI is an attached agency of the Department of Science and Technology (DOST) located in Bicutan, Taguig City, Philippines, and is one of DOST's research and development (R&D) institutes that undertakes multidisciplinary

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industry R&D, technical services, and knowledge translation or technology transfer and commercialization. DOST-ITDI's R&D activities are focused on five major areas, namely: food processing, materials science, chemicals and energy, environment and biotechnology, and packaging technology (DOST-ITDI, 2023).

Determining the actual amount of waste generated in institutions as well as its components and source generation to verify the effectiveness of the current practices of the sector in waste diversion and management requires the conduct of waste analysis and characterization study or WACS. The conduct of WACS is an important activity for local government units and other waste generators for managing their solid waste. Data gathered from the study can be used as basis for preparation of solid waste management program, for designing waste storage system, collection system, processing facilities, for developing diversion strategies, and for identifying markets for recovered materials (ADB, 2003). Last September 2020, the National Solid Waste Management Commission approved and released new guidelines for the conduct of WACS (NSWMCb, 2020). The said guidelines provided updated procedures from the preparatory stages, the actual conduct of WACS using international standard procedures described in American Society for Testing and Materials or ASTM for waste characterization, and the needed data processing and report preparation (JICA, 2020). WACS is done through two methods, at-source or generator-based, and end-of-pipe. Generator-based WACS gathers information from the generation stage or from the waste sources, while end-of-pipe WACS collects information before final treatment or disposal such as in transfer stations, waste processing and conversion facilities, and in landfill sites. Generator-based WACS is particularly recommended since these better captures the total waste generation prior to waste diversion, as well as the generation rate of each waste sources (JICA, 2020).

Published articles regarding the conduct of WACS in institutional sources in the Philippines mostly focus on educational institutions. The end-of-pipe WACS of the University of the Philippines Los Baños determined an average daily waste generation of 593.670 kg/day and focused only on the overall generation of non-biodegradable wastes in the university, with plastic and paper wastes determined as the main waste components (Palomar et al., 2019). On the other hand, the pre-COVID-19 conduct of generator-based WACS in the Caraga State University estimates 85.527 kg/day of waste generation. The study was also able to determine the College of Arts and Sciences as its major waste source, and recyclable wastes as the major waste component at 46% (Ciudad et al., 2022). Finally, an average waste generation of 126.010 kg/day was recorded in the 12-day WACS of the University of Southern Philippines-Cagayan de Oro campus, with paper wastes as the major component at 28.42% (Elayan et al., 2019). These studies on academes yielded comparable per capita generation rates, particularly, 0.0132 kg/capita/day for the University of the Philippines Los Baños, 0.018 kg/capita/day for the Caraga State University, and 0.0126 kg/capita/day for the University of Southern Philippines-Cagayan de Oro campus. However, for other institutional sources such as national government agencies, published and accessible WACS data is often sparse. Although previous WACS data in the Department of Science and Technology (DOST) is available and determined that the agency generates 65.630 kg/day of waste and was largely composed of biodegradable wastes at 73%, the end-of-pipe study was not able to determine the waste generation rate of each of DOST's attached agencies, which includes DOST-ITDI, as well as to estimate the per capita generation for the whole of the agency (Tansengco et al., 2016).

The conduct of WACS in DOST-ITDI would determine and update the characteristics and waste generation rate of the institution. The data collected from the study is crucial for developing initial strategies to properly manage and divert waste in compliance with the mandates of RA 9003 and in setting an example for other government institutions to analyze their waste, contributing to a more comprehensive database of waste generation from institutional sources, which can aid in estimating and projecting both local and national waste generation.

2. METHODOLOGY

2.1 Waste characterization study period

The conduct of WACS covered selected dates to represent dry and wet season, specifically, March 13-17, and July 10-14, 2023, respectively. These selected dates were in close concurrence with the dates prescribed by Philippine Atmospheric, Geophysical, and Astronomical Services Administration or DOST-PAGASA regarding the beginning of dry (DOST-PAGASA, 2023a) and wet seasons (DOST-PAGASA, 2023b) for 2023. The study only considered the 4-day waste generation of DOST-ITDI (Monday to Thursday), to cover the actual operations of the Institution as provided in the adopted flexible work arrangements. The selected WACS period is within the 3-7 days sampling prescribed in the new guidelines (JICA, 2020).

2.2 Identification of waste sources

The waste sources selected for DOST-ITDI includes all the divisions of the institute and are clustered per strategic function, namely, research and development, technical services, and support services. In total, DOST-ITDI is composed of a total of 13 divisions, a testing laboratory under the Materials Science Division, and one cooperative office considered under "other sources". Table 1 shows the selected waste sources as well as their total staff population (regular and contract of service (COS)/job order (JO)/casual staff) during dry and wet season. Staff population was gathered through data collected from the human resources office of DOST-ITDI, as well as field interviews with the divisional focal persons.

Table 1. Waste sources and corresponding staff population

	Waste sampling source	Number of staff	
		Dry season	Wet season
Research and development (R&D)	Chemicals and Energy Division (CED)	50	50
	Environment and Biotechnology Division (EBD)	54	54
	Food Processing Division (FPD)	39	39
	Materials Science Division (MSD)	27	27
	Advanced Device and Materials Testing Laboratory (ADMATEL)	22	22
	Packaging Technology Division (PTD)	34	34
Technical services	National Metrology Division (NMD)	33	33
	Standards and Testing Division (STD)	53	53
	Technological Services Division (TSD)	38	43
Support services	Administrative Division (ADM)	28	28
	Financial Management Division (FMD)	23	23
	Planning and Management Information Systems Division (PMISD)	12	12
	Office of the Director (OD)	4	4
	Office of the Deputy Director (ODD)	6	6
Other sources	Science Savings and Loan Association, Inc. (SSLAI)	6	6
Total		437	442

2.3 Collection of wastes

Full day waste generation from each waste source were collected by their designated utility personnel. A set of labeled garbage bags were distributed to the utility personnel prior to daily waste collection between 3:00-4:00 pm. Collectors were reminded to avoid mixing waste with previously collected waste or wastes coming from other divisions or sources, to consider only the waste generated during the work day, and to not include chemical, infectious, and other hazardous wastes generated from the laboratories. Collected wastes were then brought to the designated WACS working area for sorting, weighing, and recording the following day. Figure 1 shows the vicinity map of the DOST-ITDI, laying out the location of the divisions and other waste sources, as well as the solid waste management facilities in the institution.

2.4 Waste sorting, weighing, and recording

Collected waste from different waste sources was pre-weighed and manually sorted the day after collection following the waste component categories shown in Table 2 as prescribed in the new WACS guidelines (JICA, 2020). The recyclable wastes were then sorted further into subcategories, plastics, paper, metals, and glass. During the conduct of wet season WACS, the recyclables and residuals with potential for recycling were further sorted into second level subcategories after the personnel were familiarized with the primary categories during the dry season WACS (Table 2).

Sorted waste was then stored in separate garbage bags and was weighed using a 40-kg capacity digital weighing scale (Dahongying) with 5 g increments. Measurements were then recorded in prepared raw data forms per waste source.

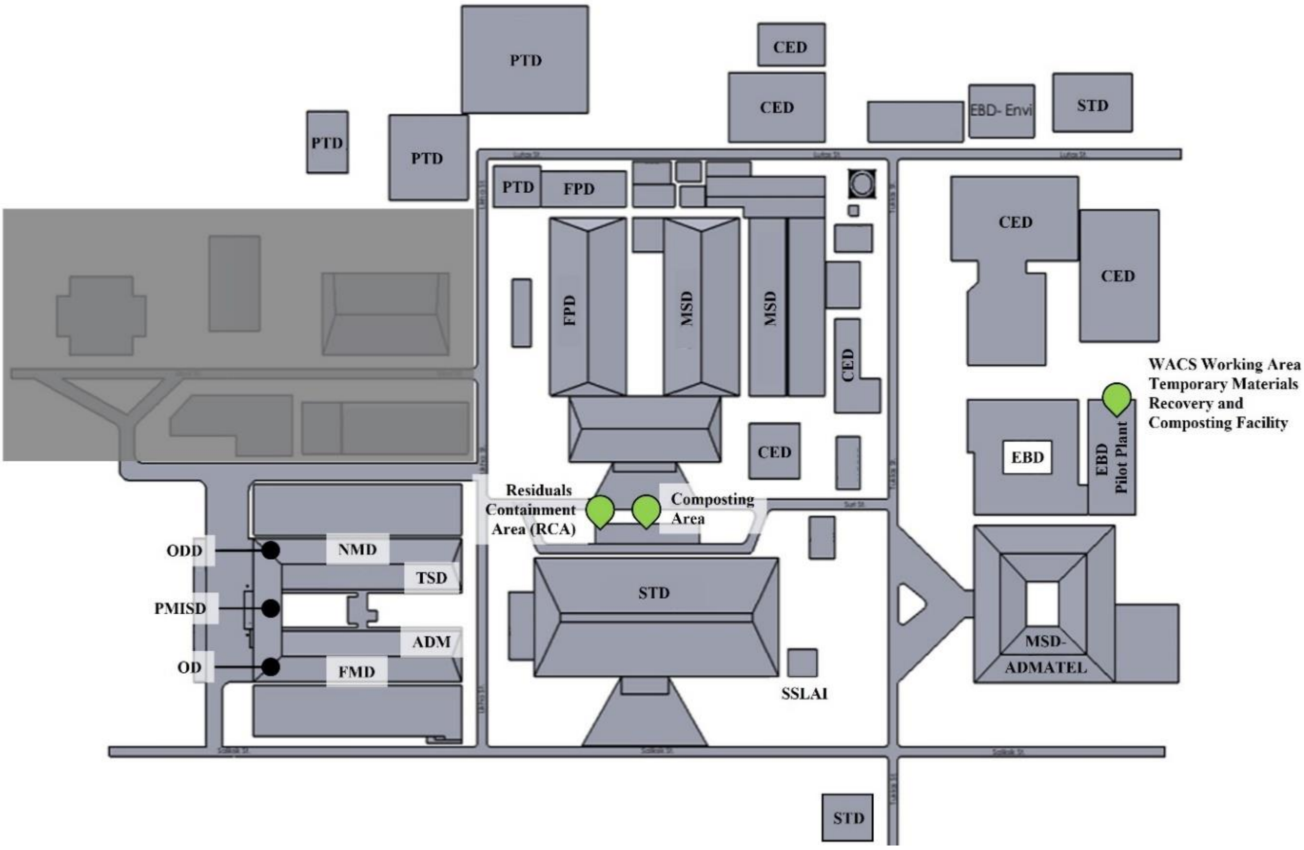

Figure 1. Vicinity map of DOST-ITDI showing the identified waste sampling sources in Table 1 and existing solid waste management facilities indicated by the green markers.

Table 2. Waste component categories, subcategories, and sample waste items (JICA, 2020)

Waste category	Subcategory and sample items
Biodegradables	Food/kitchen waste
	Garden/park waste
	Agricultural/farm waste
	Livestock wastes
Recyclables	Paper (white paper, cardboards, cartons, newspaper, textbooks, magazine, pamphlets, mixed paper, etc.)
	Plastics (PET bottles, beverage jugs, PVC pipes, squeezable bottles/tubes, microwavable containers, pails/chairs, Styrofoam, plastic trays and cutlery, others)
	Glass (bottles, flat glass, cullet)
	Metals (tin cans, aluminum cans and trays, copper tubes and wires, steel)
Residuals with potential for recycling	Flexible plastics(pouches, sachets, wrappers, tarpaulins, drinking straw, grocery/food bags)
	Leather
	Rubber (slippers, mats)
	Textile (rags)
Residuals for disposal	Soiled paper (coated paper, food contaminated paper)
	Soiled plastics (labo, etc.)
	Others (cigarette butts, etc.)
Special wastes	Hazardous wastes (WEEE, pesticide and cleaning containers, paint and chemical containers, etc.)
	Household Healthcare Wastes (Sanitary composites)
	Healthcare waste from hospitals (gloves, masks, syringes, expired medicines, etc.)
	Bulky wastes (bulky yard waste, rubber tires, construction/demolition/disaster debris

2.5 Bulk density determination

Bulk density of waste was determined following ASTM E1109-19 or the "Standard Test Method for Determining the Bulk Density of Solid Waste Fractions". A 0.6×0.6×0.6 m internal dimension bulk density box was used for the procedure in which sorted waste fractions were loaded, tamped three times, and weighed (ASTM, 2019). Weights were also determined using a 40-kg capacity digital weighing scale (Dahongying) with 5 g increments and a 60 kg capacity mechanical weighing scale (General Master) with 200 g increments for weight measurements exceeding the capacity of the digital scale, while a standard steel tape meter was used to measure the internal dimensions of the bulk density box. For waste fractions with smaller volumes, cardboard boxes and other smaller rectangular containers were used as makeshift bulk density boxes, taking note of their respective tare weights and dimensions. Bulk density (kg/m^3) was calculated using Equation (1) (JICA, 2020):

$$\text{Bulk density} = \frac{(W_G - W_T)}{V} \quad (1)$$

Where; W_G is the gross weight of the box and the waste (kg), W_T is the tare weight of the box (kg), and V is the volume of the box (m^3) based on the internal dimensions measured.

Figure 2 shows the waste handling flow for the waste samples, as well as the destination of the segregated wastes after the conduct of WACS.

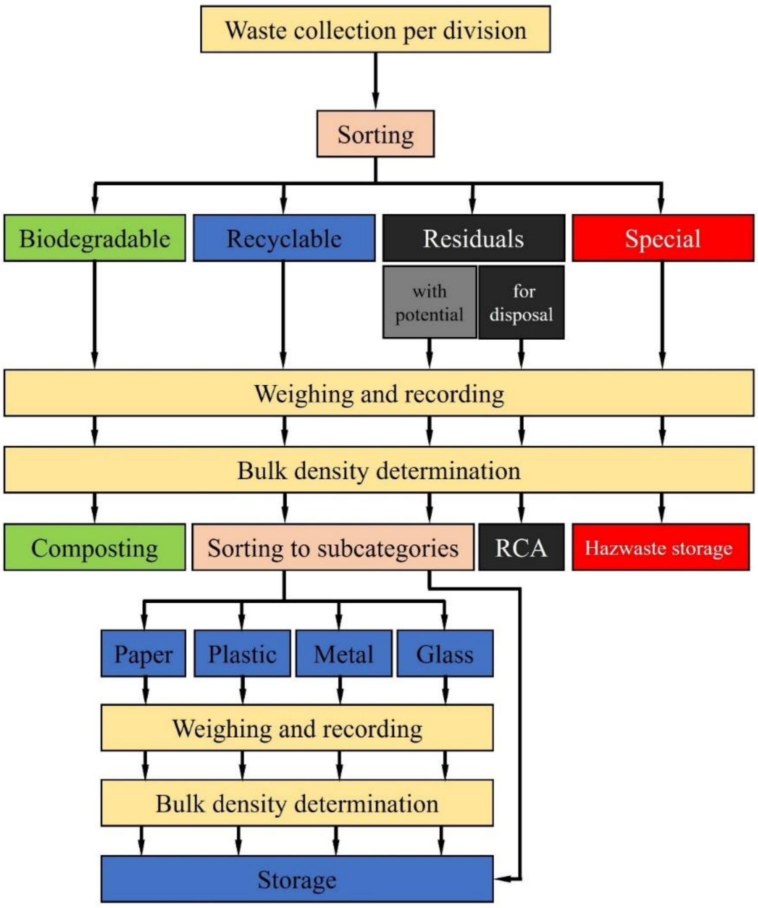

Figure 2. Waste handling flow for WACS

2.6 Data processing

Equation (2) was used in calculating average daily waste generation (kg/day) for each waste source and for the whole DOST-ITDI:

$$WG_{ave} = \frac{D_1 + D_2 + \cdots + D_n}{N} \quad (2)$$

Where; WG_{ave} is the average daily waste generation (kg/day), D_n is the weight of waste generated for the day (kg), and N is the number of WACS days.

On the other hand, per capita waste generation (PCG) or the amount of waste generated by an individual per day is calculated using Equation (3):

$$PCG = \frac{WG_{ave}}{P} \quad (3)$$

Where; PCG is the per capita generation (kg/capita/day), WG_{ave} is the average daily waste generation (kg/day), and P is the staff population.

Further, Equation (4) is used to determine the percent waste composition:

$$\%_{composition} = \frac{WG_{component}}{WG_{total}} \times 100\% \quad (4)$$

Where; $WG_{component}$ is the waste generation of a specific waste component and WG_{total} is the total waste generation.

Finally, potential waste diversion percentage is computed using Equation (5)

$$\%_{potential\ waste\ diversion} = \frac{WG_{biodegradables} + WG_{recyclables} + WG_{residuals\ with\ potential}}{WG_{total}} \times 100\% \quad (5)$$

Where; $WG_{biodegradables}$, $WG_{recyclables}$, and $WG_{residuals\ with\ potential}$ are the waste generation of biodegradables, recyclables, and residuals with potential for recycling, respectively, and WG_{total} is the total waste generation.

2.7 Statistical analysis

Statistical analysis, specifically one-way analysis of variance (ANOVA) and comparison of means, were applied to the processed data. Specifically, t-tests were applied to compare waste generation data between seasons, while Fisher Pairwise comparisons were applied to compare waste generation between waste sources and determine significant changes in waste generation for each working day. Minitab® statistical software was used for the one-way ANOVA analysis, while Microsoft Excel was used for the t-tests, as well as in preparing the bar and pie graphs presented.

2.8 Implementation of initial waste management programs

Initial solid waste management programs such as seminar-orientations on proper segregation to the DOST-ITDI staff and the utility personnel, implementation of a waste monitoring scheme, the establishment of a temporary materials recovery and composting facility, and partnerships with local recyclers were implemented after the conduct of the wet season WACS. These programs were primarily identified through information gathered from the WACS data, as well as in assessments and meetings with DOST-ITDI staff. The effects of these programs to the solid waste management practice, as well as the resulting waste diversion rate in the established temporary facility were determined through the data collected from the waste monitoring scheme implemented and is then processed and compared with the WACS results.

2.9 Waste generation projection

Considering the influence of population growth to waste generation (US EPA, 2023), the 5-year waste generation of DOST-ITDI was projected using the baseline PCG multiplied to the projected population which was calculated using Equation (6):

$$P_{current\ year} = P_{previous\ year} \times (1 + GR) \quad (6)$$

Where; $P_{current\ year}$ and $P_{previous\ year}$ are the projected population for the current year and the base year populations, respectively, and GR is the growth rate calculated using the population data from previous years. A linear population growth was assumed for DOST-ITDI as a more realistic projection considering the limitation set for the number of regular staff that can be employed by the institution in the Staffing Summary for 2024 of the Department of Budget and Management (DBM, 2024).

3. RESULTS AND DISCUSSION

3.1 Waste composition

3.1.1 Waste composition by major categories

Residuals for disposal constitutes the largest portion of waste generated at DOST-ITDI in both seasons, accounting for 35.93% during the dry season and 37.75% during the wet season. Figure 3(a) and 3(b) graphically compare the waste composition for the dry and wet season.

From a total of 91.56 and 77.54 kg/day dry and wet season waste generation, 32.9 and 29.27 kg/day are residuals for disposal (Figure 3(c)).

The residuals for disposal are mostly composed not only of used paper towels, bathroom tissue, and soiled plastic bags, but of soiled paper food and beverage packaging as well. Although paper food packaging is currently being touted as a sustainable alternative to plastic packaging (Junior et al., 2022), contamination complicates and reduces its potential to be recovered and recycled, ending up as residuals for disposal as observed during the study.

Although there were changes in the waste generation per component, the overall percentage of waste generated during the dry and wet season are closely identical. The variation in biodegradable waste between seasons is attributed to changes in the research and development activities of the Food Processing Division, which is a major source of organic waste. Meanwhile, the increase in recyclables during the wet season may be due to the higher use of rigid plastic packaging to protect products from rain.

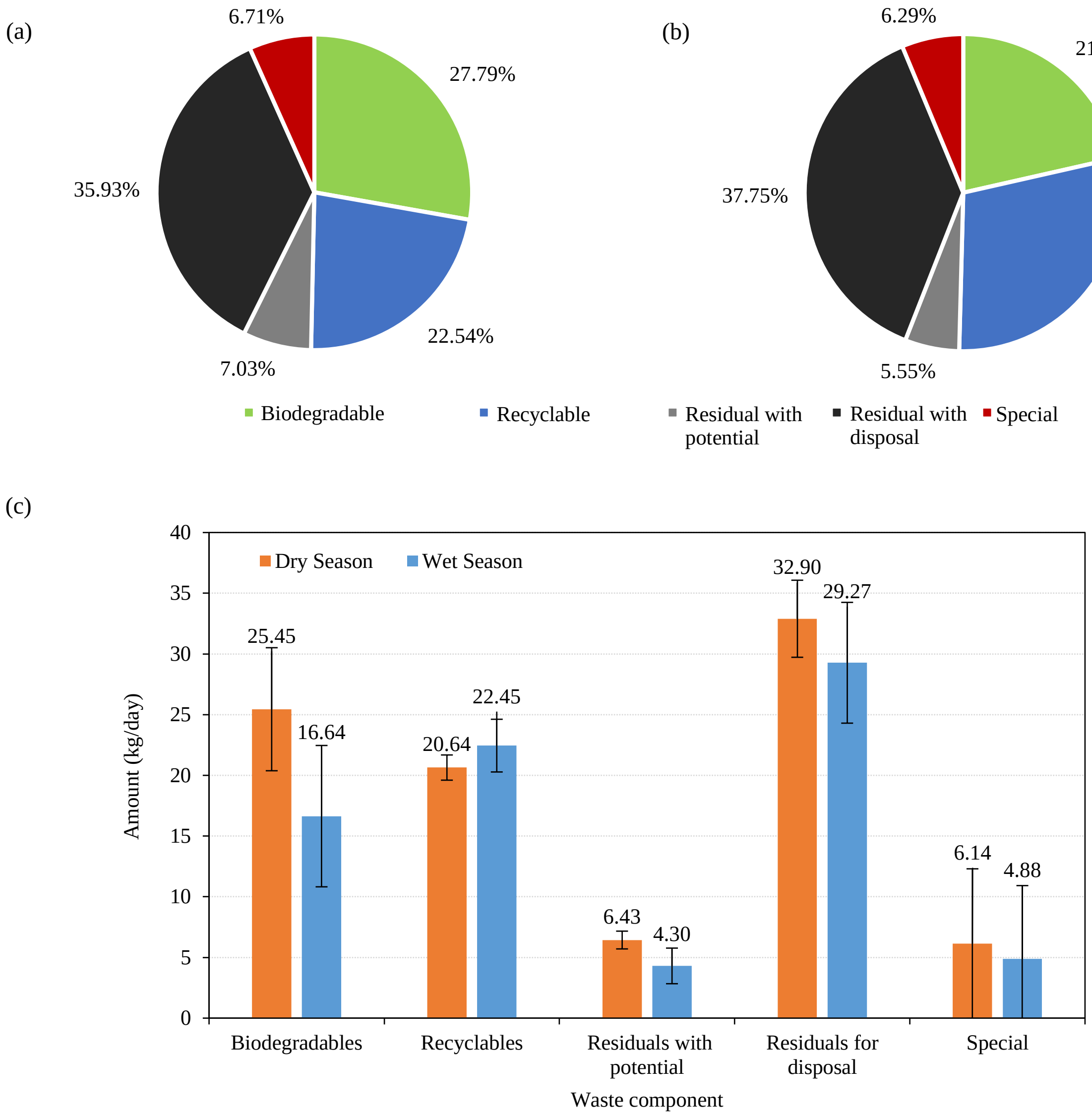

Figure 3. (a) Dry, (b) wet season waste composition, and (c) waste generation per composition

3.1.2 Waste composition by subcategories

Recyclable wastes were further sorted into subcategories namely, paper, plastics, metals, and glass. Figure 4 compares the percentage composition of the recyclable wastes per season and shows paper wastes as a steady major component of recyclable wastes which can be attributed to the heavy use of paper in DOST-ITDI for documentary requirements and reports which was also observed in other institutional sources (Palomar et al., 2019; Ciudad et al., 2022). An increase in the recyclable plastics being used and therefore disposed of was also further shown and supports the previous assumption of the increase in the use of rigid plastic packaging due to the wet weather.

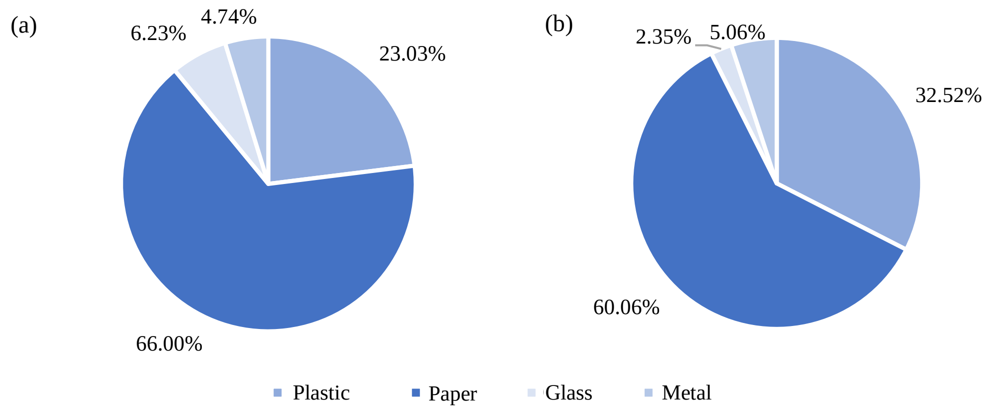

Figure 4. (a) Dry and (b) wet season percentage recyclable waste composition

Sorting into second-level recyclable subcategories shown the effect of the frequent equipment and supplies delivery (cartons and cardboard), documentation requirements (used white paper), and food and beverage consumption (PP and PET packaging) to the characteristics of recyclable wastes generated in DOST-ITDI (Figure 5(a)). On the other hand, the determined composition of residuals with potential for recycling (Figure 5(b)) exhibited the consumption habit of the DOST-ITDI staff, specifically in ordering food and beverages typically contained in paper clam shells or in paper cups (laminated paper), the continuous use of plastic bags in buying food and/or supplies (LDPE plastic bags), and the consumption of products in sachets (foil packs, sachets, wrappers). These findings reveal that the typical Filipino consumer habits, influenced by the prevalent sachet economy (Gozum, 2024) and reliance on single-use plastics (Schachter and Karasik, 2022), are also reflected in government offices.

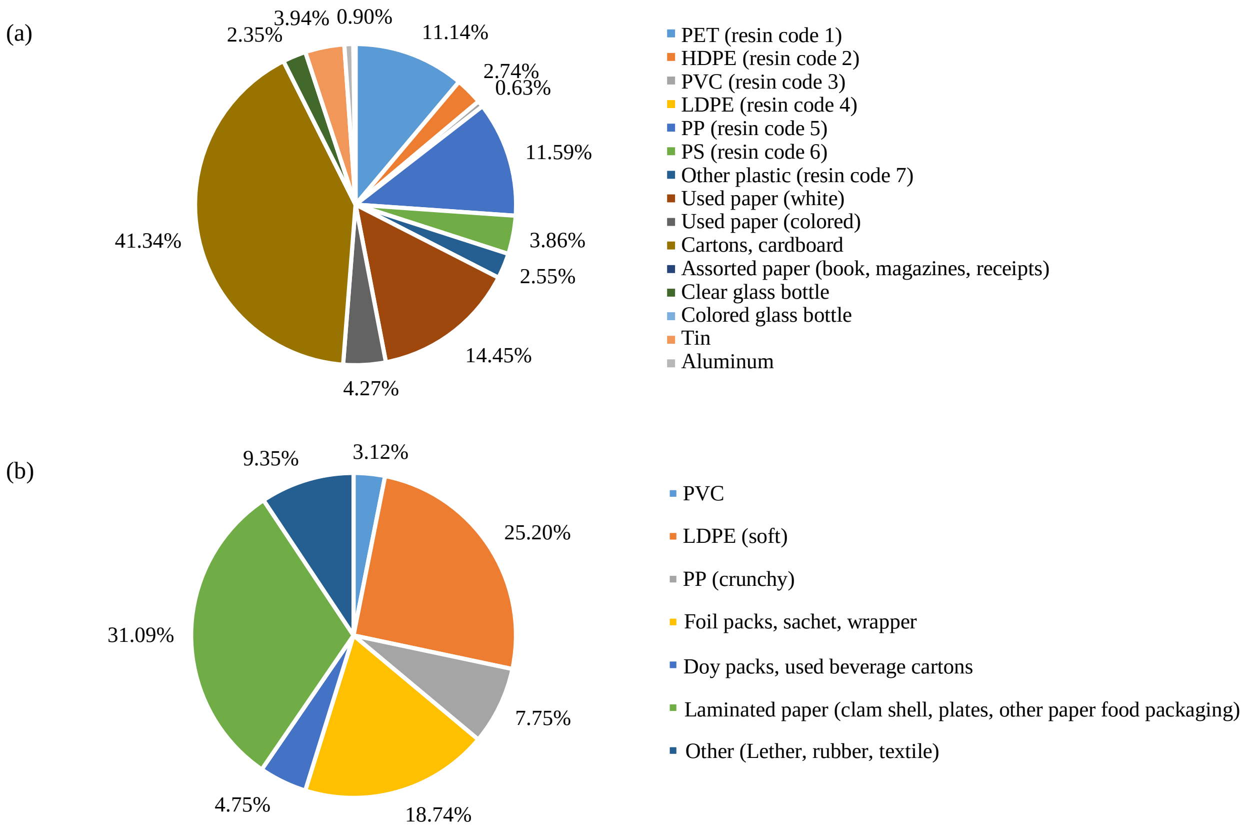

Figure 5. Percentage composition of (a) recyclables at second-level category and (b) residuals with potential for recycling determined during the wet season WACS

3.2 Waste generation

3.2.1 Per capita waste generation by major waste categories

Per capita generation for the total and per component waste generation were calculated and statistically compared using t-tests to determine significant changes between seasons (Table 3).

The comparisons show that although the per capita generation of residuals with potential for recycling has significantly changed between seasons (p-value=0.036, p-value<0.05 is significant), there is no significant change in the total per capita generation in DOST-ITDI between seasons (p-value=0.0502) implying consistent individual waste generation.

3.2.2 Waste generation per source

The waste contribution of each major waste source (research and development, technical services, support services, other sources), were also determined from the dry and wet season WACS data. Figure 6 shows the waste generation per major waste source for both seasons.

Table 3. Comparison overall per capita waste generation and per component PCG for dry and wet seasons

Component	Mean PCG (kg/capita/day)		p-value
	Dry season	Wet season	
Biodegradable	0.06±0.010	0.04±0.010	0.0570
Recyclable	0.05±0.002	0.05±0.005	0.2400
Residual with potential for recycling	0.01±0.002	0.01±0.003	0.0360
Residual for disposal	0.08±0.010	0.07±0.010	0.2250
Special waste	0.01±0.010	0.01±0.010	0.7690
Overall PCG	0.21±0.010	0.18±0.030	0.0502

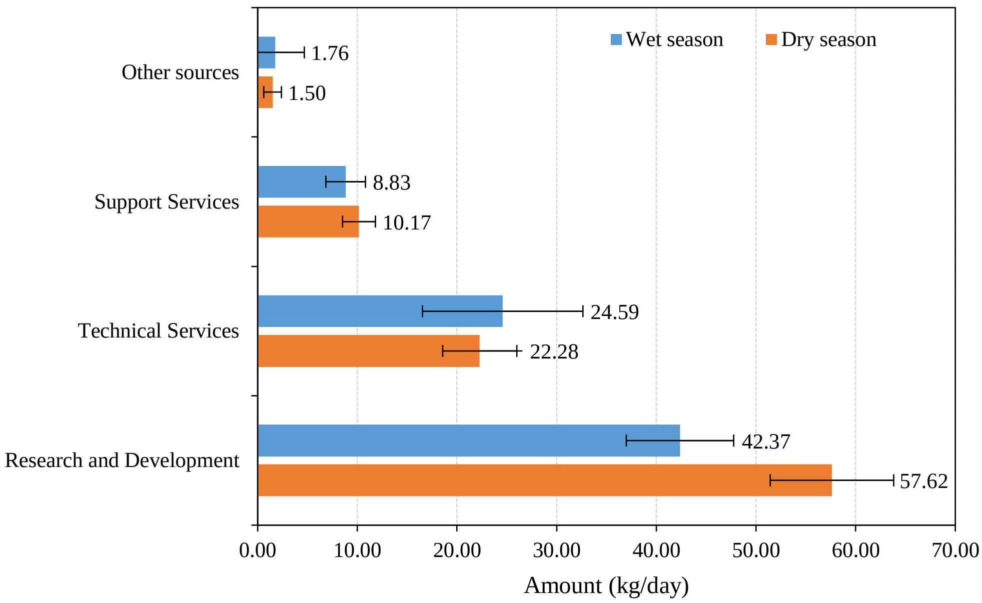

Figure 6. Waste generation per major waste source

The research and development divisions, with the largest population in DOST-ITDI, contribute the most to waste generation, accounting for 63% during the dry season and 55% during the wet season.

Subjecting the calculated PCG of each waste sources to t-test (Table 4) determined that R&D divisions experienced significantly different PCGs between dry and wet seasons (p-value=0.010) which may be due to changes in activities within the cluster between these periods affecting waste generation. However, as with the findings on waste components, the difference in PCG for R&D divisions between seasons did not affect the overall consistency of waste generation in DOST-ITDI.

Table 4. Comparison of dry and wet season PCG per major waste sources

Source	Mean PCG (kg/capita/day)		p-value
	Dry season	Wet season	
Research and development	0.25±0.03	0.19±0.02	0.0100
Technical services	0.17±0.03	0.18±0.06	0.7590
Support services	0.13±0.02	0.11±0.02	0.3390
Other sources	0.25±0.15	0.29±0.49	0.8680
Overall PCG	0.21±0.01	0.18±0.03	0.0502

Finally, Fisher Pairwise comparisons were applied to evaluate whether PCG values differ between major waste sources each season, identifying if staff from specific sources generate significantly more waste compared to others.

The confidence interval plot (Figure 8(a)) indicates that there is no significant overall difference in PCGs across waste sources at DOST-ITDI for both the dry (p=0.119) and wet seasons (p=0.784). However, a significant difference is observed between the PCGs of the R&D and support services divisions during the dry season. This indicates that individual waste generation rates across major sources are not significantly different, allowing a PCG of 0.18 to 0.21 kg/capita/day to be reliably used for estimating and projecting waste generation for the entire institution.

3.2.3 Weekly waste generation trend

Referring to both the plotted per capita waste generation data collected per day for each season (Figure 7), for the dry season, there seems to be consistency in the PCG values collected per day. On the other hand, the wet season PCG trend shows increased generation rates as the work week ends.

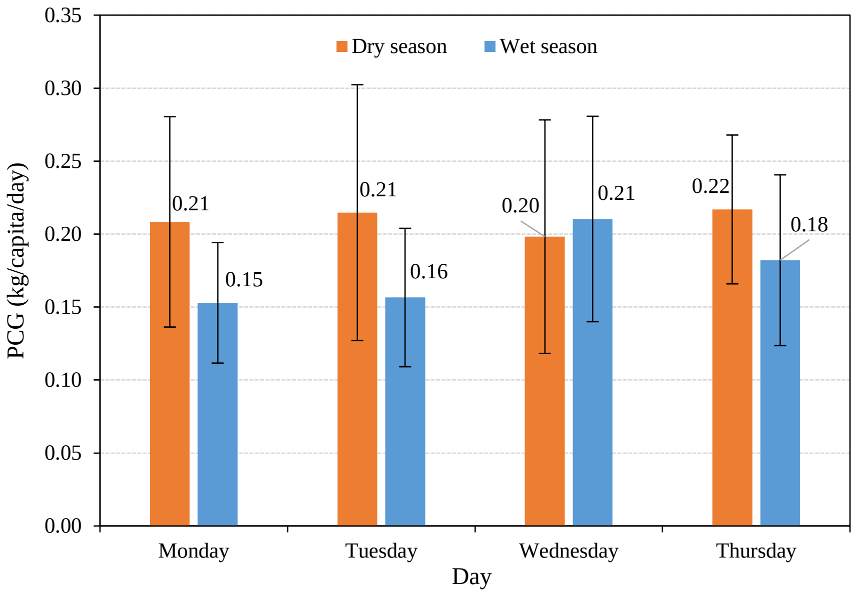

Figure 7. PCG trend for a whole week for both dry and wet seasons

Fisher Pairwise comparisons were then applied to compare PCGs per workday and determine if each day has significant differences in the per capita waste generation rate. Based on the group comparisons between PCGs collected from Monday to Thursday, there was no significant difference among the PCGs during the work week both for dry (p-value=0.613) and the wet season (p-value=0.528). These values then support the notion of a consistent weekly waste generation in the entire institution and further confirmation of the reliability of using the overall PCG values determined in the WACS. Figure 8(b) shows the generated interval plots for the group comparisons made between workdays.

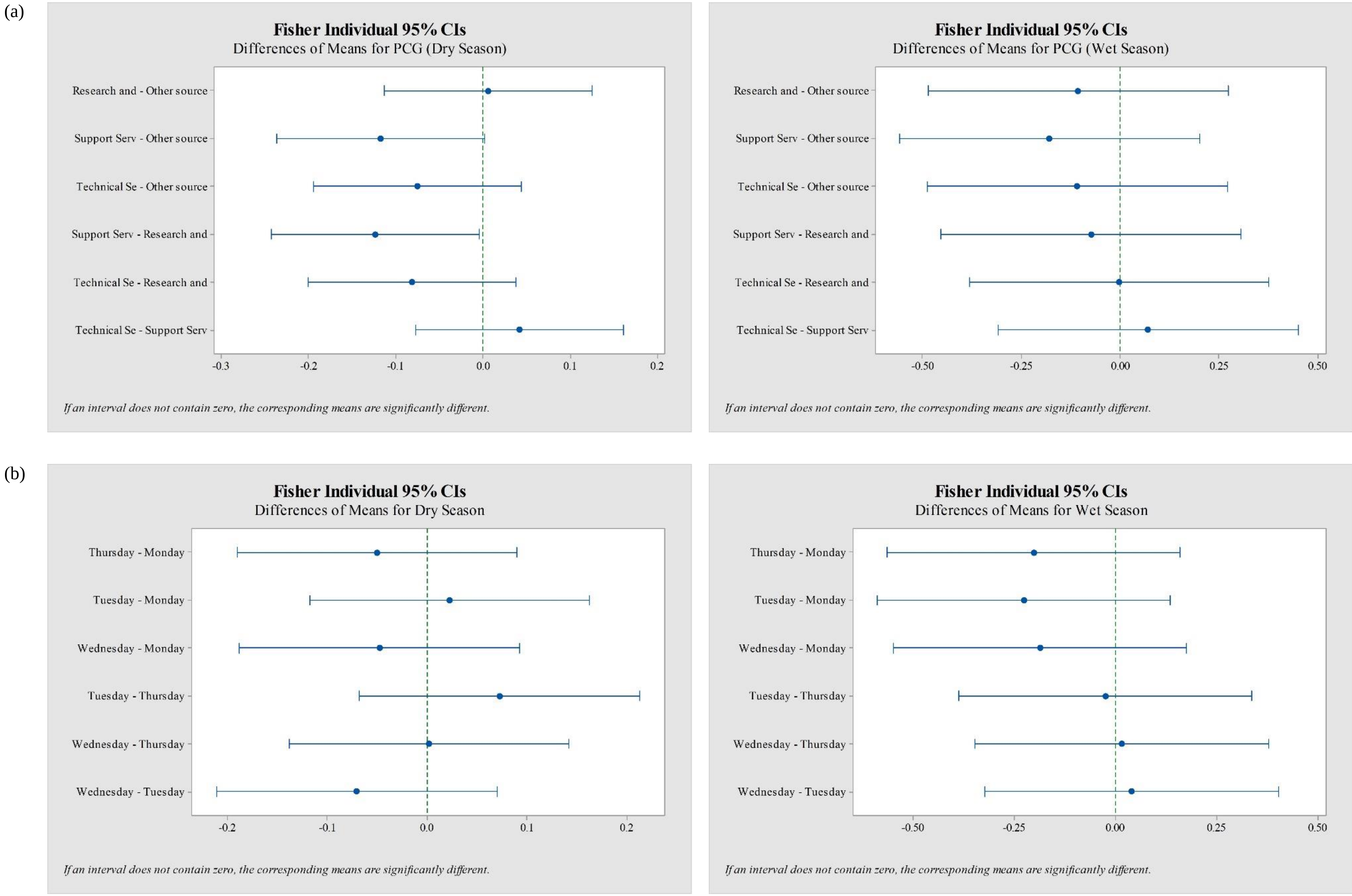

Figure 8. Fisher Individual 95% confidence interval plots comparing PCGs (a) per major waste source and (b) per workday for dry and wet seasons.

3.3 Bulk density

Table 5 shows the recorded loose bulk density values for major waste components and subcomponents for the dry and wet season, as well as bulk density values from other references. Note that no bulk density data for glass were determined due to low volume and generation during the conduct of WACS.

Table 5. Bulk density values for major waste components and subcomponents

Waste component	Bulk density (kg/m^3)			Reference
	Dry season	Wet season	Reference value	
Biodegradable	368.01±122.20	435.24±162.12	130-490	Worrell and Vesilind (2011)
Recyclable				
Plastic	33.43±2.59	28.08±5.18	42-130	Worrell and Vesilind (2011)
Paper	168.42±172.04	26.66±7.62	12-240	Worrell and Vesilind (2011)
Metal	94.48±37.12	58.92±8.59	30-44	Worrell and Vesilind (2011)
Residual with potential for recycling	20.80±7.78	16.95±3.96	-	-
Residual for disposal	39.17±5.89	36.69±2.87	-	-
Special	84.54±23.09	55.05±26.96	-	-

Individual bulk density values were also determined per second-level subcomponent of all recyclables and residuals with potential for recycling after enough amount was accumulated in the established temporary materials recovery facility (Table 6).

The measured bulk density values from waste samples collected in DOST-ITDI are comparable to the values presented in references (Worrell and Vesilind, 2011). Moreover, the bulk density measurements of plastic packaging wastes (including PVC, PP sheets, films, labels, bags, and multilayered packaging) serve as valuable reference values, addressing the current lack of data on their specific bulk densities. The measured bulk densities can be used as a reference to the preparation of storage spaces for the waste components in the planned permanent materials recovery facility or MRF.

Table 6. Bulk density values for recyclables and residuals with potential for recycling subcomponents

Component			Bulk density (kg/m^3)		Reference
			Measured	Reference values	
Recyclables	Plastics	PET (resin code 1)	22.88±1.09	18-24	Worrell and Vesilind (2011)
		HDPE (resin code 2) Containers	24.45±2.21	14	Worrell and Vesilind (2011)
		HDPE (resin code 2) Caps	136.79±2.46	-	Worrell and Vesilind (2011)
		PVC (resin code 3) rigid	-	-	-
		LDPE (resin code 4) rigid	-	-	-
		PP (resin code 5) rigid	19.59±1.32	-	-
		PS (resin code 6) expanded	5.40±0.17	5.4-5.7	Worrell and Vesilind (2011)
		Other Plastics (resin code 7)	-	-	-
	Paper	Used Paper (White)	168.42±2.09	240	Worrell and Vesilind (2011)
		Used Paper (Colored)	13.69±0.56	12-33	Worrell and Vesilind (2011)
		Cartons, Cardboard	34.61±2.43	9.9-237.3 (old corrugated carton, OCC)	Worrell and Vesilind (2011)
	Glass	Clear	259.96±12.22	300-420	Worrell and Vesilind (2011)
		Colored	-	-	-
	Metals	Tin	76.63±1.88	504	Worrell and Vesilind (2011)
		Aluminum	22.40±0.60	30-44	Worrell and Vesilind (2011)
		Others (Copper, Steel)	-	-	-

Table 6. Bulk density values for recyclables and residuals with potential for recycling subcomponents (cont.)

Component			Bulk density (kg/m^3)		Reference
			Measured	Reference values	
Residuals with potential for recycling	Plastic sheets, labels, and films	PVC	6.38±0.13	-	-
		LDPE (Soft)	8.16±1.00	10.9 (loose plastic) 13.4 (bubble wrap)	Worrell and Vesilind (2011)
		PP (Crunchy)	5.75±0.63	-	-
	Multilayered packaging	Foil packs, sachet, wrapper	18.85±0.74	-	-
		Doy packs, used beverage cartons	21.34±1.49	-	
		Laminated paper (clam shell, cups, plates, other paper food packaging)	14.87±1.61	-	

3.4 Implementation of initial waste management programs

3.4.1 Conduct of seminar-orientation on proper workplace waste management

A series of seminars on proper workplace waste management were conducted after WACS. These seminar-orientations discussed topics on national solid waste management policies, waste classifications, workplace waste management, as well as the summary of results of the conduct of WACS. Initial orientations were attended by the divisional representatives and committee members on safety, health, and environment, the clean and green committee, and the utility personnel. Further seminars were then conducted to individual divisions. In total, 11 seminars were conducted and attended by a total of 233 participants.

3.4.2 Establishment of temporary materials recovery and composting facility

A temporary materials recovery and composting facility was established at the EBD pilot plant to support the growing practice of waste segregation in DOST-ITDI. The temporary materials recovery facility (Figure 9(a)) consisted of segregated containers such as one-tonner bins and boxes which would contain the segregated recyclables and residuals with potential for recycling. The accumulated recyclables were then collected monthly by DOST-ITDI's partner recycler and local waste management service company that collects, sorts and processes various waste categories. In exchange for the collected recyclable waste items, DOST-ITDI receives reams of recycled A4 paper.

(a) (b)

Figure 9. (a) Temporary materials recovery facility for collected segregated recyclables; (b) Plastic drum used for pile composting of biodegradables

On the other hand, the composting facility established is composed of composting bins made of large plastic drums and containers (Figure 9(b)).

3.4.3 Waste generation monitoring

Waste generation monitoring involved the recording of weights of collected biodegradables prior to composting, and residuals for disposal prior to transfer to the residuals containment area. In addition, the weights of accumulated recyclables and residuals with potential for recycling were recorded weekly before transferring to the temporary materials recovery facility.

Figure 10 shows the average daily waste generation and PCG from the monitoring data from August 2023 to March 2024 as compared to the July 2023 wet season WACS data. Note that special wastes are not included in the monitoring as it is currently being monitored as a component of hazardous wastes.

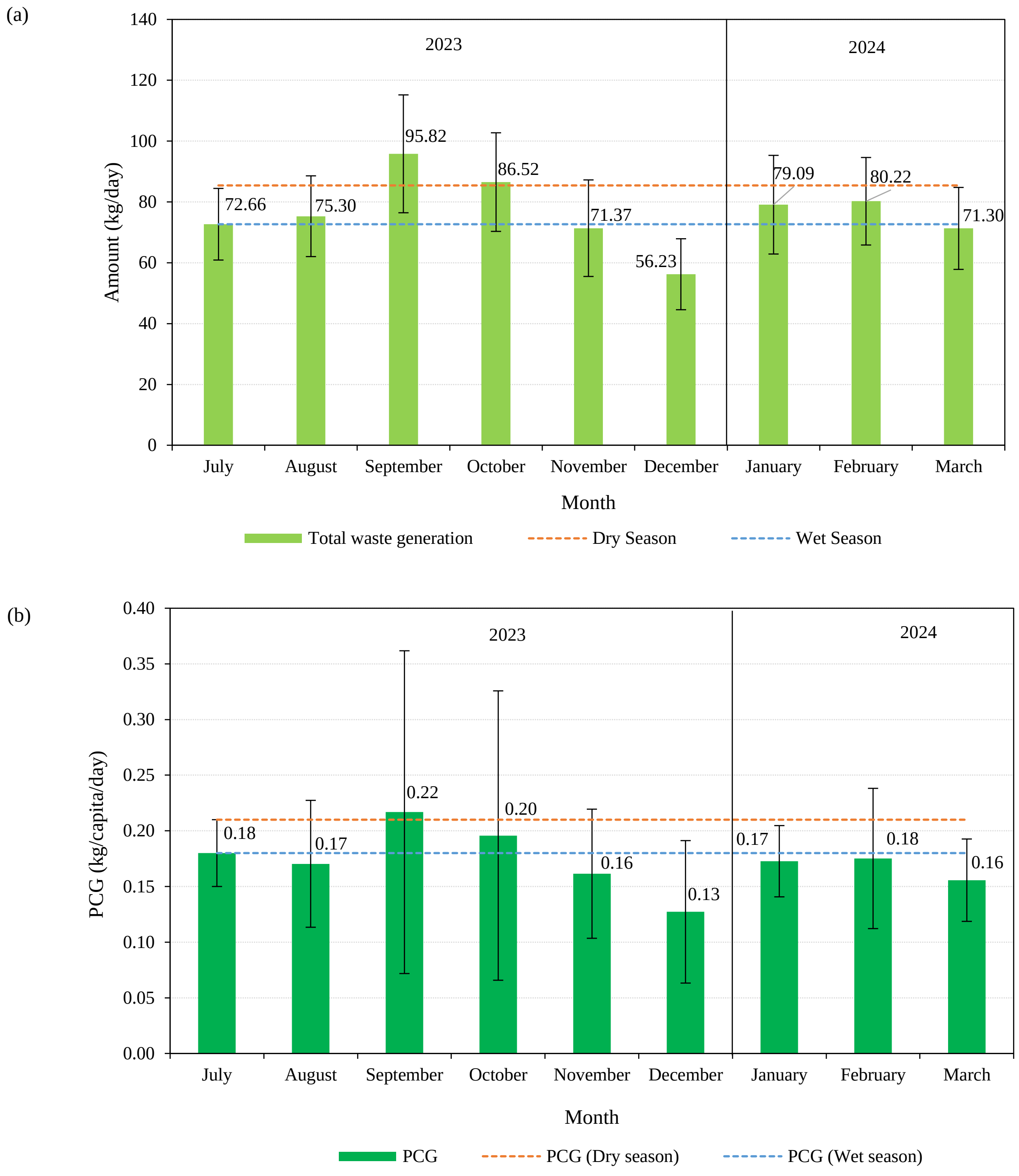

Figure 10. (a) Daily waste and (b) per capita generation from July 2023 to March 2024

The data trend in Figure 10(a) exhibited a decrease in waste generation in September 2023 and a decrease in December 2023, which is due to the decline of the number of staff reporting in office due to the holidays. However, with the continuation of regular operations at the beginning of 2024, the waste generation increased to normal levels. In addition, the recorded PCG values recorded (Figure 10(b)) are still near or within the per capita range calculated during the dry (0.21 kg/capita/day) and wet (0.18 kg/capita/day) season WACS which indicates consistency in waste generation even at the individual level. This further supports the findings of waste generation consistency in DOST-ITDI while also suggesting that waste reduction practice is still lacking individually as the PCG rates are still comparable pre- and post-implementation of the initial solid waste management programs.

Finally, the monthly waste composition trend was also captured during the monitoring (Figure 11).

A decrease in the percentage of residuals for disposal can be noted starting September 2023 which coincides with the implementation of the initial programs, indicating improving segregation in DOST-ITDI as other waste components are being properly sorted and recovered instead of being disposed. However, further waste recovery and implementation of other methods such as waste reduction or use of more reusable and recyclable products instead of disposables are necessary to further reduce residuals for disposal generation.

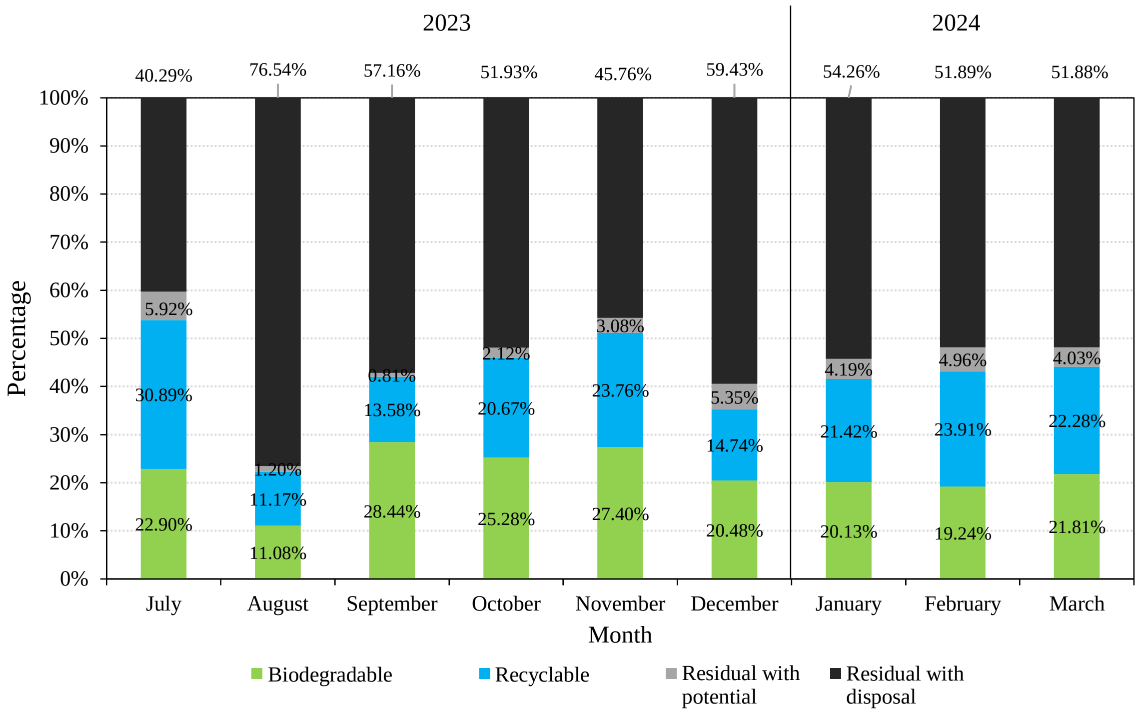

Figure 11. Percent waste composition trend from July 2023 to March 2024

3.4.4 Waste diversion

Although no waste diversion targets are imposed on specific waste sources such as institutions, the ultimate basis and baseline shall be on the results of waste characterization (DENR, 2001). As such, the potential waste diversion rate for DOST-ITDI is at 57.36% (dry season) as determined during WACS, or at 59.71% considering the exclusion of special wastes.

Figure 12 shows the percent waste diversion trend calculated from the monitoring data from the implementation of initial programs in August 2023 to March 2024.

The current waste diversion trend shows potential in achieving the adjusted potential waste diversion rate with the sustained operation of the temporary facilities established and segregation practice. However, as implied by the monitored waste composition and PCG rates, increased waste recovery and reducing residuals for disposal waste generation are necessary to achieve the current potential waste diversion target. Once achieved, the waste diversion target can then be increased to 80% following targets set for solid waste diversion in the Philippine Development Plan for 2017-2022 (NEDA, 2021).

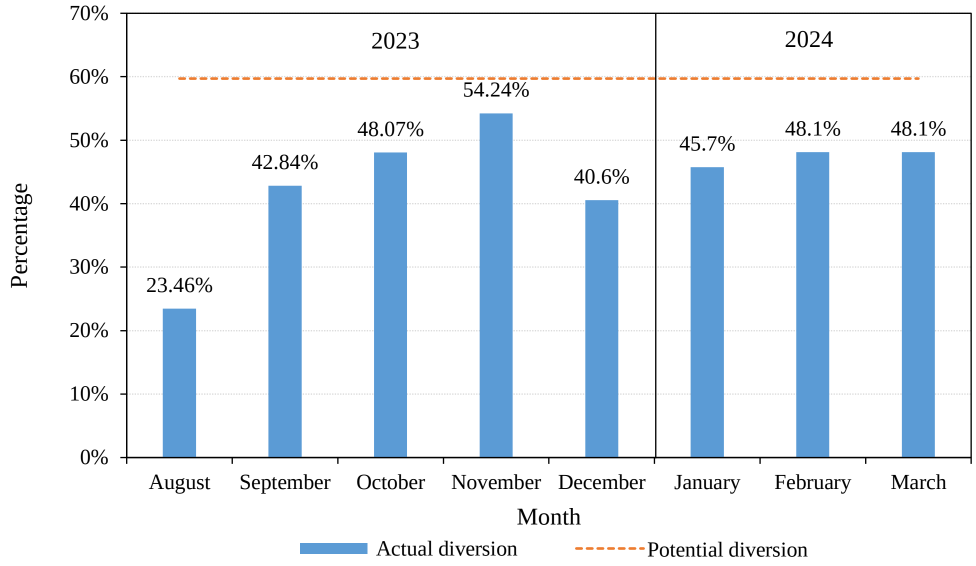

Figure 12. Waste diversion trend from August 2023 to March 2024

3.5 Waste generation projection

Using Equation (6) and using a growth rate, GR, of 4.57% based on the 2023 and 2024 staff population of 438 and 458, respectively, Figure 13a shows the 5-year population projection for DOST-ITDI, with 2024 as the base year.

The estimated ratio of non-regular staff (COS/JO/Casual) to the total population was set at an average of 30.65% and was also based on the 2023 (29.00%) and 2024 (32.31%) data. Note that the regular staff population was capped at 370 for the 2027 population projection and beyond due to the staffing limit stated earlier, and as such, latter population growth only relies on the increase in population of non-regular staff.

From the population projection, a 5-year waste generation for DOST-ITDI from 2025 to 2029 with 2024 as the base year was projected (Figure 13(b)). Note that for the waste generation projection, the dry season per capita generation (PCG) of 0.21 kg/capita/day was used, then multiplied to the projected population and the total number of working days per year. In the case of DOST-ITDI as a national government agency, one year is equivalent only to 264 days, or 22 working days multiplied to 12 months.

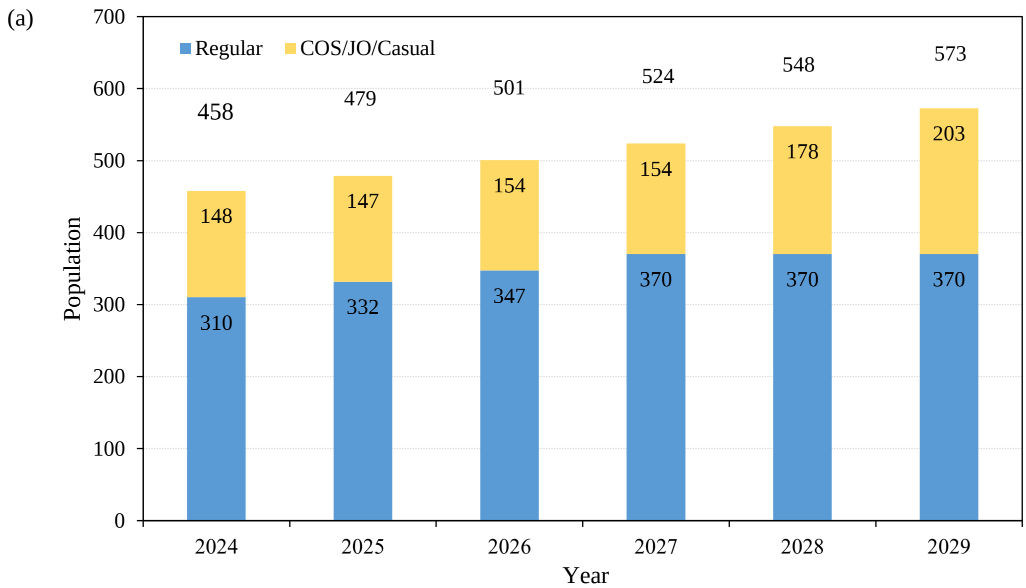

Figure 13. Five-year (a) population and (b) waste generation projection for DOST-ITDI

(b)

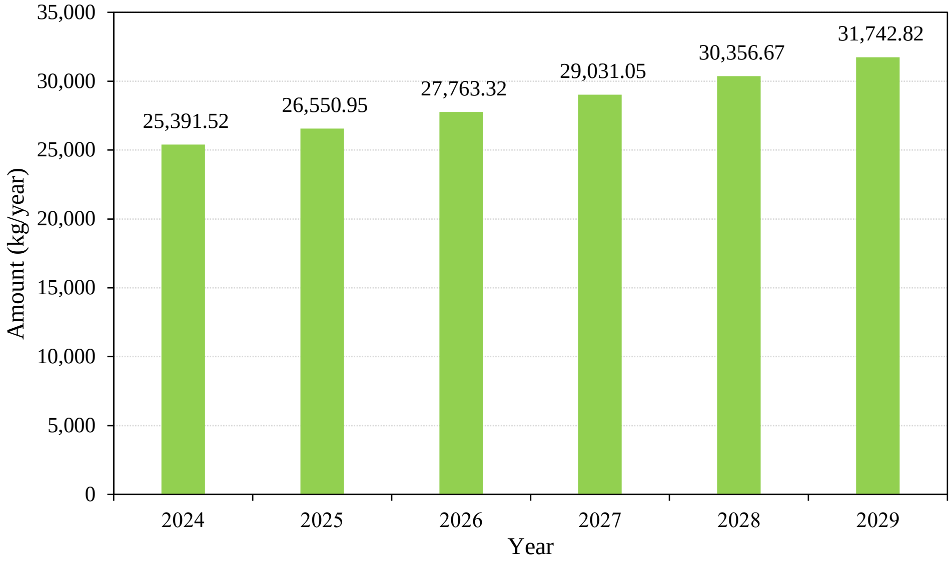

Figure 13. Five-year (a) population and (b) waste generation projection for DOST-ITDI (cont.)

With the projected increase from 25,391.52 kg/year (96.18 kg/day) in 2024 to 31,839.20 kg/year (120.60 kg/day), the need for an increased waste recovery and reduction strategies is emphasized to mitigate or at least slow the growth in waste generation. Finally, the establishment of a permanent materials recovery and composting facility is also paramount in ensuring the sustainability of the current waste diversion programs considering the projected increase in waste generation with the increase of staff population in DOST-ITDI.

4. CONCLUSION

The conduct of WACS highlighted the characteristics, generation rate of the identified waste sources, as well as the consistency of waste generation in DOST-ITDI between dry and wet seasons. The generated waste is composed of residuals for disposal (35.93% and 37.75%, dry and wet season), with the research and development divisions as the major source of waste due to its large population, contributing up to 63% of the waste generated by the institution. Further, per capita generation rates between seasons and between major sources were found to be consistent, indicating that the PCG of 0.18 and 0.21 kg/capita/day can be reliably used to estimate and project waste generation in DOST-ITDI. Finally, the implemented initial solid waste management programs based on the data gathered from the conduct of WACS showed potential in promoting waste segregation practice, ensuring waste diversion, and overall improving the waste management in the institution. However, additional strategies for waste recovery and reduction are still necessary to further reduce residuals for disposal and increase waste diversion rates, as well as the establishment of a permanent materials recovery and composting facility to sustainably support the management of the current and projected increase in solid waste generation in DOST-ITDI.

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