



Sustainable Waste Management through Material Flow Analysis and Waste Diversion Rate: A Case Study of Sekolah Alam Bogor, Indonesia

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Abstract

Sekolah Alam Bogor (Bogor Nature School) provides a relevant case for examining school-based circular waste management in Indonesia. Although the school applies reduce, reuse, and recycle (3R) principles, their implementation remains suboptimal due to the absence of systematic flow mapping and quantitative evaluation. This study aims to quantify waste generation and composition, map material flows, and evaluate the Waste Diversion Rate (WDR) of the school's circular waste management system. A mixed-method case study was applied, combining field observation, in-depth interviews, and direct weighing of waste over 14 effective school days across five source units: Pre-School, Elementary School, School Kitchen, Middle School, and School of Makers. The results show an average waste generation of 165.15 kg/day, dominated by organic waste (71.23%), with inorganic waste accounting for 28.77%. Salam Permaculture composts organic waste, recyclables are channeled to Bank Sampah Salam Aid, and residues are incinerated. The system achieved an internal Waste Diversion Rate (WDR) of 76% (77.79% when community-contributed recyclables from the Dropzone program are included), indicating substantial waste diversion. However, approximately 24% of the waste (39.70 kg/day) remains as residue treated through incineration, whose emissions and ash quality were not assessed and require further evaluation. These findings indicate that systematic flow mapping and data-driven evaluation are essential for strengthening source-based waste management in educational institutions.

Keywords: composting, circular economy, material flow analysis, school-based waste management, waste bank

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INTRODUCTION

The problem of waste remains a major challenge for environmental sustainability in Indonesia. Population growth and human activities have led to an increase in the volume of waste generation (Bappenas, 2024). Data from the National Waste Management Information System (SIPSN) in 2024 recorded a total national waste generation of 37.3 million tons, with 67.8 percent of waste unmanaged and only 32.3 percent successfully managed. According to Presidential Regulation No. 97 of 2017 (Peraturan Presiden Republik Indonesia, 2017), the National Policy and Strategy (Jakstranas) targets a 30 percent reduction in waste and 70 percent waste handling by 2025. However, SIPSN 2024 data shows that the actual reduction in waste in Indonesia has only reached 1.33 percent, while waste handling stands at 30.87 percent. This gap indicates ongoing challenges in both reducing and managing waste in every region.

West Java is the province with the largest waste generation in Indonesia in 2023, amounting to 6,153,346 tons per year (SIPSN, 2024). As part of West Java, the Bogor area generates approximately 3,541 tons of waste per day (BPS, 2024; Open Data Jabar, 2024). The Bogor Regional Government has made efforts to manage waste through Integrated Waste Management Sites for Reduce, Reuse, Recycle (TPST 3R), but their handling capacity is only about 20 percent of the total daily waste (Lestari, 2024; Mahmoud et al., 2025; Pambudi et al., 2025). Meanwhile, the Galuga Final Disposal Site (TPA) is now at a critical point, nearly exceeding its storage capacity. This condition raises environmental concerns, as accumulated and unmanaged waste generates leachate that can contaminate soil and water bodies, while the decomposition of organic waste releases greenhouse gases and open burning degrades local air quality (Abubakar et al., 2022; Kristanto & Koven, 2019). Addressing the waste problem cannot rely solely on the government but must involve broad community participation through self-managed approaches at the community level, as close as possible to the source of the waste (Asmarawati & Wibowo, 2024).

Waste generation comes from various sources, including households, industry, agriculture, healthcare, tourism, public facilities, and educational institutions (Ramdhan & Hermawan, 2022). Educational institutions are significant waste-generating units because they concentrate large populations of students and staff who produce food, paper, and packaging waste daily. At the same time, schools are strategic sites for source-based waste reduction where they can institutionalize sorting and recycling routines, shape long-term pro-environmental behavior, and embed sustainability values into the curriculum, so that waste reduction efforts extend beyond the school into students' households and the wider community (Mpuangnan et al., 2023; Haniva et al., 2024; Kristanto et al., 2015). *Sekolah Alam* Bogor (Bogor Nature School), as one of the pioneers of nature-based education, holds a strategic position to serve as a model in implementing sustainable waste management principles. A nature school is an alternative educational concept that integrates environmentally friendly practices in learning (Purnami, 2021; Rahayu et al., 2024; Rapii et al., 2021). The Nature School concept can be a solution for reducing waste by applying principles that emphasize nature conservation and the implementation of sustainable waste management systems.

Waste management at *Sekolah Alam* Bogor has adopted a circular economy approach by applying the principles of Reduce, Reuse, and Recycle (3R). However, this implementation has not yet run optimally. Currently, a lot of waste is still not sorted by type and remains mixed. This condition can decrease the economic value of recycled materials and hinder biological processing, which in turn increases the volume of residue that must be disposed of in the landfill. In addition, the process flow of waste from its source to final processing has not been mapped systematically and measurably. Moreover, previous studies on school-based waste management have largely emphasized environmental awareness, student participation, and program description (Handayani & Widodo, 2024; Napitupulu et al., 2025; Haniva et al., 2024). While relatively few have quantitatively evaluated material flows and Waste Diversion Rate (WDR) within an educational institution (Kristanto et al., 2015; Ratnasabapathy et al., 2020; Widyarsana et al., 2021).

This leaves a gap in the objective, data-driven assessment of circular performance in school-based waste systems. The absence of a flow diagram makes it difficult to identify points of potential material reuse, so the economic value of waste is overlooked, and the volume of residue disposed of into the environment remains high (Darmawan et al., 2020). The lack of comprehensive data also hampers school management in objectively evaluating environmental performance and formulating targeted waste reduction strategies. Therefore, this study aims to quantify waste generation and composition, map material flows, and evaluate the Waste Diversion Rate (WDR) of the circular waste management system at *Sekolah Alam* Bogor. The novelty of this study lies in (i) applying material flow analysis and the Waste Diversion Rate (WDR) in a school-based setting, (ii) characterizing an integrated circular system that links composting (Salam Permaculture), source separation (Dropzone), and a waste bank (Salam Aid), and (iii) documenting how the value of recovered materials is returned to the school community through agricultural and social/health-benefit pathways. Together, these provide a comprehensive and replicable model for sustainable waste management in educational institutions.

METHOD

Research Design

This research uses a descriptive mixed-methods approach, combining quantitative and qualitative analysis through a case study design, in which the qualitative and quantitative components were integrated to construct the material flow: observation and interviews characterized the management system and operational practices, while direct weighing quantified waste generation and composition, and the two strands were combined to map and interpret the material flow. The research location is *Sekolah Alam Bogor*, West Java, Indonesia, which was deliberately selected (purposive sampling) because this institution already has a circular waste management system, is a pioneer of nature-based education, and holds excellent accreditation, making it an information-rich case for examining school-based circular waste management. The quantitative approach is used to objectively measure the physical parameters of waste material flow, while the qualitative approach is used to explore in depth the management processes in the field, the participation of school members, and the alignment of the system with the SA Way educational quality standards.

Data Requirements and Sources

Primary data collection in this research was conducted through three main approaches: field observation, in-depth interviews, and physical measurement. Field observation was conducted by observing and descriptively recording the behavior of school members in sorting waste in classroom areas, daily waste collection routes, and the physical condition of internal processing facilities. In-depth interviews were conducted with relevant stakeholders at the school to obtain data regarding school policies, operational constraints, and the awareness levels of school members. Interviews were conducted with the principal of each program (5 people), the cleaning coordinator (1 person), the cleaning staff (4 people), the manager of Salam Permaculture (1 person), and the manager of Salam Aid Waste Bank (1 person).

Physical measurement involved directly weighing waste at five main source points: the Pre-School area (PS), Elementary School (SD), School Kitchen, Middle School (SM), and School of Makers (SMX). Physical measurements were conducted over 14 consecutive effective school days to obtain more comprehensive daily statistics. Measurements were conducted from 27 January to 13 February 2026, excluding weekends and non-school days, and the period reflected normal school operation with no special events that could distort waste generation. All five units were weighed every effective day, and the number of students and staff present remained relatively stable throughout the period.

The sampling coincided with the rainy season; rainfall is likely to have increased the moisture content and therefore the weight of waste, particularly garden waste, which should be considered when interpreting the generation and density figures. Weighing was done in the morning or afternoon before the waste was transported to the temporary collection point. In general, the weighing procedure refers to the Indonesian National Standard (SNI) 3964:2025, with a modification of extending the duration beyond the SNI minimum standard of only eight consecutive days. Secondary data collection was carried out by gathering data such as the school profile, total number of school members (students, teachers, staff), as well as documents of the SA Way environmental curriculum quality guidelines. All data from field physical measurements were processed using Microsoft Excel.

Waste Categories

Waste was classified into organic and inorganic fractions. Organic waste comprised garden waste (leaves and plant trimmings) and food waste (kitchen scraps and food leftovers). Inorganic waste comprised recyclable materials – cardboard and rigid plastic – and residue. Residue is defined as non-recyclable, non-compostable material with no economic value, including multilayer and contaminated packaging, tissue, sanitary waste, and mixed waste, which is directed to incineration. This distinction is important because only recyclable inorganic waste (channelled to the waste bank) contributes to diversion, whereas residue does not.

Waste Measurement and Data Analysis

Waste measurement at the research site aims to obtain quantitative data for the analysis of waste flow and mass balance calculation. The mass balance calculation determines the total waste load entering and exiting the management system based on the principle of mass conservation. Because compost output was estimated from interviews, and incinerator ash and composting moisture loss were not measured, this study presents an input-based material-flow and diversion analysis. According to methods referring to the Indonesian National Standard (SNI) 3964:2025, the sources at the school location fall into the category of Household-Like Waste (SSSRT) from educational facilities. The sampling- unit definitions, volume measurement, waste sorting, and weighing procedures followed SNI 3964: (Badan Standardisasi Nasional [BSN], 2025); the only modification was extending the sampling duration from the standard minimum of 8 days to 14 effective days to better capture daily variation in school activity. The calculation procedure refers to the formulas set in SNI 3964: (Badan Standardisasi Nasional [BSN], 2025).

Waste Generation and Density Calculation (ρ)

In this study, several waste-quantity parameters were measured. The unit's average daily waste generation refers to the total weight of waste produced by a unit per day (B_s , kg/day), while its average daily volume refers to the corresponding total volume (V_s , L/day). These unit-level values were then expressed on a per-capita basis: per-capita daily waste weight (B , kg/person/day) and per-capita daily waste volume (V , L/person/day) were obtained by dividing the unit's daily generation by the number of people in the unit. The daily waste generation weight (B) and volume (V) were calculated as equations (1) and (2):

$$B = \frac{B_s}{U} \quad (1)$$

$$V = \frac{V_s}{U} \quad (2)$$

where:

- B = per-capita daily waste weight (kg/person/day);
- B_s = average daily waste generation of the unit (kg/day);
- V = per-capita daily waste volume (L/person/day);
- V_s = average daily volume of the unit (L/day);
- U = number of people in the unit (persons).

Waste density (ρ) is calculated as in equation (3):

$$\rho = \frac{B_s}{V_s} \quad (3)$$

where:

- ρ = waste density (kg/L);
- B_s = weight of waste (kg);
- V_s = volume of waste (L).

Waste Composition Calculation

The waste composition calculated includes general categories such as organic, inorganic, and residue. More detailed waste composition includes food waste, garden waste, paper, cardboard, carton, and rigid plastics. Waste composition was calculated as in equation (5):

$$\% \text{ Weight} = \frac{B_i}{B_s} \times 100\% \quad (5)$$

where:

- $\% \text{ Weight}$ = Percentage of the i -th type of waste by weight;
- B_i = Weight of the i -th type of waste (kg);
- B_s = Total weight of all waste samples (kg).

Waste Diversion Rate

Waste Diversion Rate (WDR) is a performance metric that measures how much waste is successfully kept away from final disposal (landfill, incineration, or dumping) through pathways such as reuse, composting, recycling, and energy recovery. It captures the overall effectiveness of a waste management system in recovering materials rather than discarding them. Waste Diversion Rate (WDR) was calculated as in equation (6) (Ratnasabapathy et al., 2020).

$$WDR = \frac{\text{Total Waste Diverted}}{\text{Total Waste Generated}} \times 100\% \quad (6)$$

Because the Dropzone program collects recyclables brought from students' homes, these materials are external to the waste generated internally by school activities. Including it directly in the Waste Diversion Rate calculation without adjustment would overestimate the system's internal performance, since material would be added to the numerator without a corresponding addition to the denominator. To address this, the Waste Diversion Rate is reported in two forms: an internal WDR, calculated using only waste generated within the school's operational units, and an expanded WDR, which incorporates community-contributed Dropzone materials in both the numerator and denominator to maintain a consistent basis for comparison. The Waste Diversion Rate (WDR) was calculated as in equation (7) (Widyarsana et al., 2021).

$$WDR \text{ (including external input)} = \frac{(\text{Total Waste Diverted} + \text{External Recyclables Diverted})}{(\text{Total Waste Generated} + \text{External Recyclables Collected})} \times 100\% \quad (7)$$

Residue Treatment (Incineration)

Residue that cannot be recovered through composting or recycling is treated by on-site incineration. The incinerator is a simple, locally constructed unit consisting of a box-shaped cement chamber equipped with a chimney and an electric blower that supplies forced air to the combustion chamber. Despite the forced-air supply, the unit operates without any emission-control filter, so combustion still occurs under uncontrolled conditions. Incineration is carried out daily for approximately one hour, around midday, immediately after the residue has been sorted. The ash produced is collected and stored but currently receives no further treatment, characterization, or utilization. In this study, flue-gas emissions and ash quality were not measured. Accordingly, incineration is treated only as the existing final-treatment practice and is acknowledged as a limitation of the system; it is not presented as an environmentally validated waste-treatment method.

RESULTS AND DISCUSSION

Material Flow Analysis (MFA)

Based on field observations and measurements during the sampling period, the waste management flow at *Sekolah Alam* Bogor has developed an integrated circular system involving various internal and external units, as shown in **Figure 1**. The quantitative internal and external material flows are further detailed in **Figures 2** and **3**, respectively. Waste management at *Sekolah Alam* Bogor includes sorting, collecting, transporting, processing into compost, and collecting at the waste bank. The sources of waste at *Sekolah Alam* Bogor come from both internal and external environments. Internal waste comes from teaching and learning activities as well as daily operations in the Preschool (PS), Elementary School (SD), Middle School (SM), School of Makers (SMX), and the school kitchen units. External waste comes from students' homes and is brought to school for donation to the Dropzone unit, also known as the "Waste Charity" program. Dropzone locations are at several points: preschool (PS), elementary school (SD), and middle school (SM). Dropzone is a designated area for collecting certain types of recyclable waste, such as cardboard/paper, plastic bottles, packaging plastic, glass bottles, and electronic waste. The waste collected at the Dropzone is weighed and transported by the Salam Aid Waste Bank.

The material flow of waste at *Sekolah Alam* Bogor, as shown in **Figure 1**, begins with the independent sorting of organic and inorganic waste by school members. Then, staff from each area transport the waste in trash bags, categorizing it as organic (food scraps) or inorganic. Organic waste from the garden, such as leaves, is transported using barrels. Waste from the PS and SD areas,

including the school kitchen (in the SD area), is collected and transported on a three-wheeled motorcycle. This vehicle then collects waste from the SM and SMX areas and transports it to Salam Permaculture for further sorting. The SMX location is close to Salam Permaculture, so staff can independently bring organic waste from SMX to Salam Permaculture.

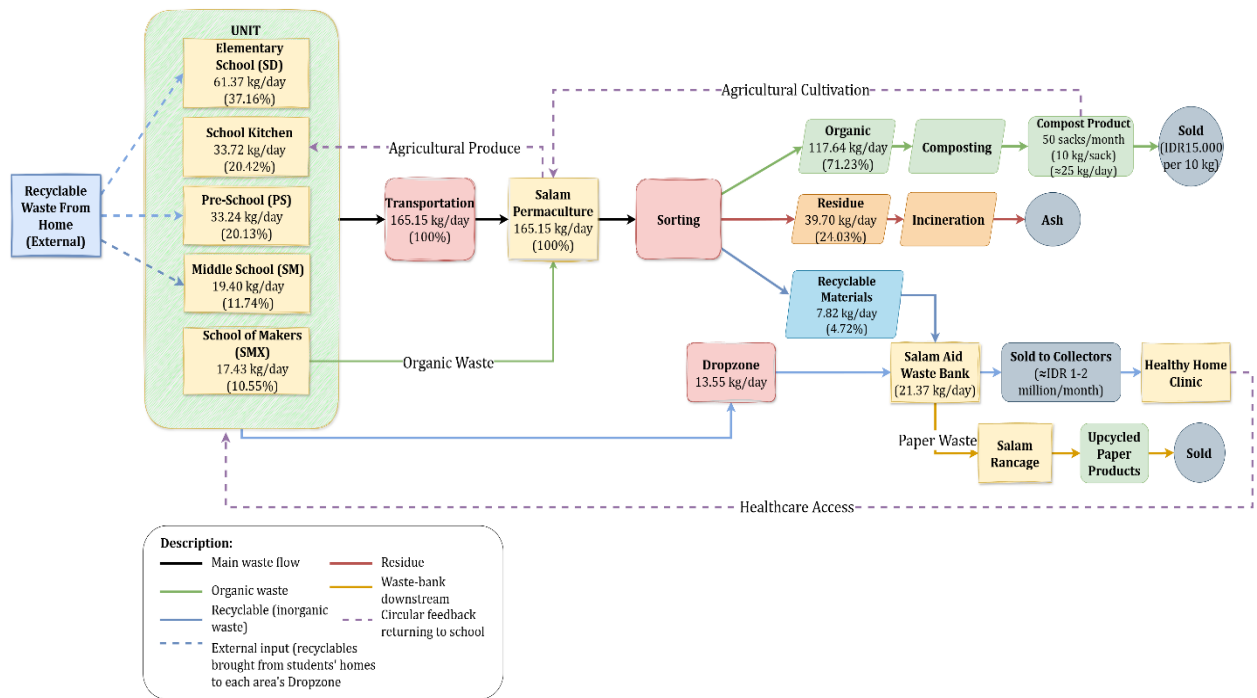


Figure 1. Integrated Circular Waste Management System at Sekolah Alam Bogor; [Source: Primary Data Processing (2026)]

Salam Permaculture is an entity within Salam Bogor that focuses on agricultural cultivation using the permaculture concept and manages organic waste. Salam Permaculture separates organic waste (leaves and food scraps), residual waste that cannot be reused, and valuable recyclable materials such as plastic bottles, cardboard, and glass. Organic waste is processed into compost using a layered composting method that combines food scraps and leaves. Based on interviews, the resulting compost output is estimated at approximately 500 kg per month, or about 25 kg per day when averaged over 20 effective working days. This estimate was obtained from staff interviews rather than direct weighing and represents a substantial mass reduction from the organic waste input, consistent with the moisture evaporation and decomposition losses typical of composting. Because composting moisture loss and the precise compost output were not directly measured, this figure should be interpreted as an approximate value rather than a measurement (Sari et al., 2023; Wielgosiński et al., 2021).

The resulting compost is reused for the school's internal agricultural activities, and some is sold for IDR 15,000 per 10 kg. The harvested vegetables are distributed to the school kitchen and school community members, such as parents and teachers, creating a closed-loop cycle. Residual waste is incinerated, leaving ash. Valuable recyclable waste is sorted and sent to the Salam Aid Waste Bank. This composting practice is consistent with broader findings on Adiwiyata-aligned schools in Indonesia, where converting organic waste into compost or ecoenzyme is reported as one of the most common and effective waste-management initiatives undertaken under the policy (Saputra et al., 2024). These internal flows are quantified in Figure 2, 117.64 kg per day to composting, 7.82 kg per day to recyclables, and 39.70 kg per day to incineration.

The Salam Aid Waste Bank is an innovative inorganic waste management program initiated by Salam Aid, a humanitarian and philanthropic organization focused on education, empowerment, health services, and disaster response. The Waste Bank collects valuable waste from the PS, SD, SM, and Salam Permaculture areas and then sells it to waste-collection partners. In addition to these internally recovered materials, the Waste Bank receives recyclable waste contributed by students'

households through the Dropzone program (13.55 kg/day), which is external to the school’s own waste generation. This external flow, combined with internally sorted recyclables before being sold to collectors, is quantified in **Figure 3**.

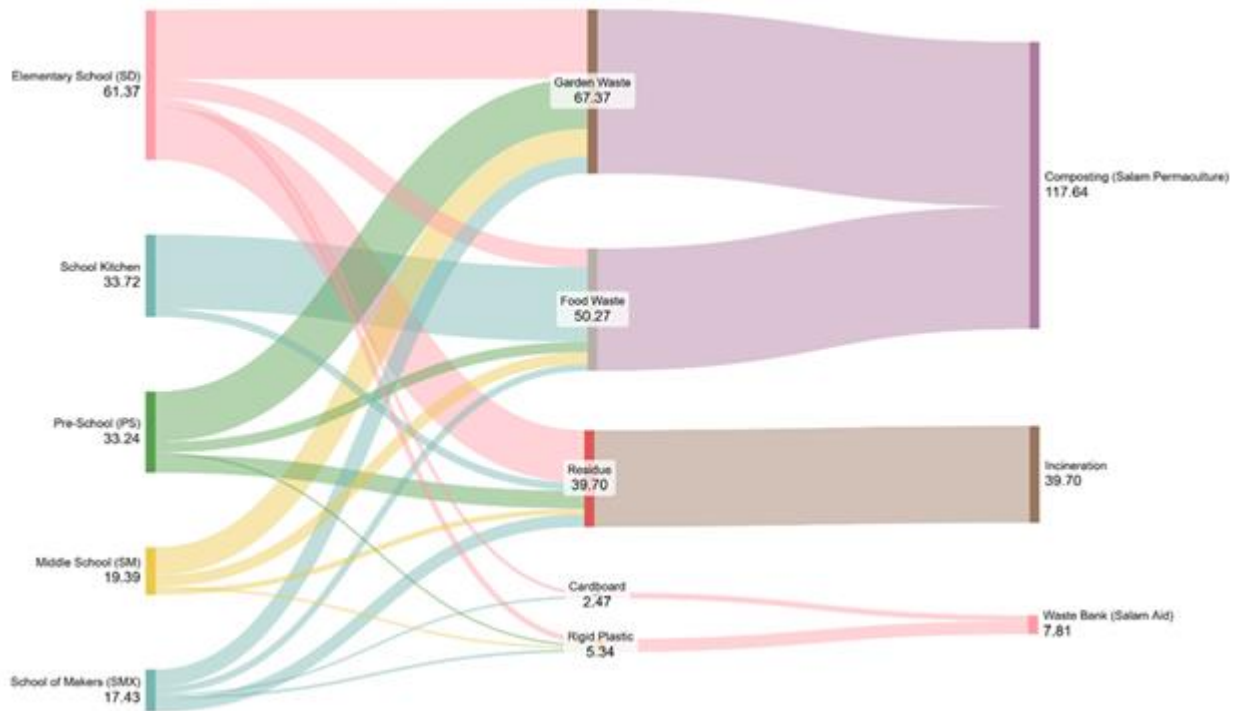


Figure 2. Internal Material Flow of Waste Management at *Sekolah Alam Bogor* (kg/day); [Source: Primary Data Processing (2026)]

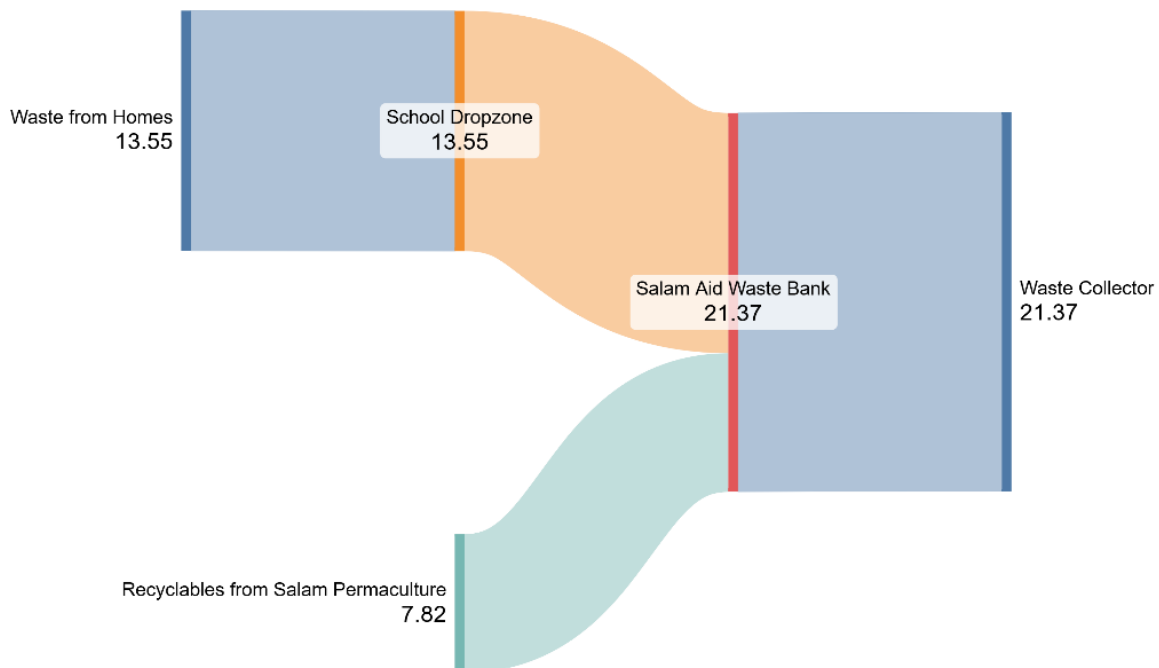


Figure 3. External (Community-Contributed) Recyclable Flow through the Dropzone Program (kg/day); [Source: Primary Data Processing (2026)]

The proceeds from the Waste Bank, around IDR 1–2 million, are used to operate the Healthy Home Clinic, creating a feedback loop. The Healthy Home Clinic provides free healthcare services to school and surrounding community members, with payment accepted in the form of valuable waste, such as plastic bottles. Paper waste collected at the Salam Aid Waste Bank is sorted and sent to Salam

Rancage, a women's empowerment-based social enterprise that transforms paper waste into woven handicraft products. The paper waste is upcycled into creative products, thereby increasing its economic value and expanding its market reach. This model echoes the broader pattern observed in Adiwiyata schools across Indonesia, where waste management effectiveness and channeling recovered materials toward community benefit (Saputra et al., 2024).

Input and Mass Flow Analysis by Unit

The results of the measurements in **Table 1** show that *Sekolah Alam* Bogor generates a total average daily waste of 165.15 kg, with an average per capita waste generation of 0.17 kg per person per day. In general, the volume of waste produced is directly proportional to the number of people in each area. The per-capita generation rate observed is notably higher than rates reported for school canteens in Mataram, Indonesia, which is 0.04 kg/person/day (Littaqwa et al., 2025) and Hulu Selangor, Malaysia, which is 0.0196 kg/person/day (Kasavan et al., 2020), but broadly compared to a boarding high school in Long An, Vietnam, where boarding students generated 0.18 kg/person/day while out-boarding students generated only 0.028-0.12 kg/person/day (Nguyen et al., 2024). This pattern suggests that the comparatively low rates reported in canteen-focused studies reflect a narrower measurement scope (food-service waste only), whereas the present study captured waste across all internal source units, more akin to a boarding context where students spend the full day on campus or school. This indicates that per-capita generation in school settings is highly sensitive to the scope of waste streams measured, rather than reflecting inherently higher consumption.

The Elementary School (SD) unit is the largest contributor to waste, generating 61.37 kg per day and accounting for 37.16 percent of the school's total waste. The large volume of waste in this area corresponds to the number of SD members, which is the largest population group at 518 people. The school kitchen generates 33.72 kg of waste per day, accounting for 20.42 percent of the total, mostly from operational activities such as leftover raw materials and food waste. Preschool (PS) generates 33.24 kg per day, or 20.13 percent, with an average per capita waste generation of 0.16 kg per person per day. Middle School (SM) produces 19.39 kg of waste per day, or 11.74 percent, with an average per-capita waste generation of 0.11 kg per person per day. The linear correlation between population size and total waste does not apply to per capita waste intensity when viewed by activity type. The School of Makers (SMX), with the smallest population of 46 people, has the highest per-capita waste generation at 0.38 kg per person per day. The high per capita waste generation in SMX is suspected to be due to project-based learning activities, experiments, and prototype creation. Such activities naturally consume more raw materials and generate significantly more material residue per individual than those in other units.

Table 1. Total and Average Daily Waste Generation by Source Unit

No	Unit	Number of Members (People)	Total Waste (kg)	Average Daily Generation (kg/day)	Average Per Capita Generation (kg/person/day)	Percentage of Waste (%)
1	Pre-school (PS)	210	444.69	33.24	0.16	20.13
2	Elementary School (SD)	518	728.00	61.37	0.12	37.16
3	School Kitchen	-	327.82	33.72	-	20.42
4	Middle School (SM)	180	271.55	19.39	0.11	11.74
5	School of Makers (SMX)	46	244.03	17.43	0.38	10.55
	Total	954	2,016.08	165.15	0.17	100.00

Source: Primary Data Processing (2026)

The school provides a Dropzone facility for collecting economically valuable recyclables and involves students in the "Waste Donation" program. Each unit regularly schedules times for students to bring recyclable waste from home to school. The Dropzone accepts cardboard, duplex, plastic, and other materials (such as cans, glass bottles, iron, and aluminum). **Table 2** shows the results of recyclable waste collected at the Dropzone, totaling 271.00 kg with an average daily generation of

13.55 kg. The total recyclable waste generated was dominated by cardboard at 89.00 kg and plastic at 90.00 kg. Based on the source unit, the Elementary School (SD) contributed the most recyclable waste, totaling 198.00 kg and averaging 9.90 kg per day. The amount of recyclable waste produced by the Elementary School (SD) is significantly higher than that of the Middle School unit, which collected only 18.00 kg, and the Preschool (PS) unit, which collected 55.00 kg. The Elementary School (SD) unit showed the highest collection volume, with the following breakdown: 61 kg of cardboard, 39 kg of duplex, 59 kg of plastic, and 39 kg of other materials. In contrast, the Middle School (SM) unit recorded the lowest accumulation of recyclable waste, with 7 kg of cardboard, 5 kg of duplex, 6 kg of plastic, and no materials in the “others” category. The data in **Table 2** indicate that the volume of recyclable waste collected through the Dropzone is greatly influenced by the population size and the frequency of waste collection in each school area.

Table 2. Amount of Recyclable Waste Generated from Dropzone

No	Unit	Cardboard (kg)	Duplex (kg)	Plastic (kg)	Others (kg)	Total (kg)	Daily Average (kg/day)
1	Pre-school (PS)	21.00	7.00	25.00	2.00	55.00	2.75
2	Elementary School (SD)	61.00	39.00	59.00	39.00	198.00	9.90
3	Middle School (SM)	7.00	5.00	6.00	0.00	18.00	0.90
	Total	89.00	51.00	90.00	41.00	271.00	13.55

Source: Primary Data Processing (2026)

The measurement results in **Table 3** show that the total daily waste volume generated by all units at *Sekolah Alam Bogor* is 1,771.78 liters per day, with an overall average waste density of 0.09 kg per liter. In total, the Elementary School (SD) unit produced the highest waste volume at 694.68 liters per day, which aligns with the greatest total daily waste weight in that area. Conversely, the Middle School (SM) unit produced the lowest waste volume at 184.52 liters per day. Regarding physical characteristics, waste density (ρ) is the ratio of weight to volume, indicating the level of material compactness. The total density value of 0.09 kg per liter suggests that the waste generated at this school tends to be voluminous or low in specific gravity light but occupying a lot of space.

The School Kitchen has no assigned member count because its waste originates from meal preparation for the entire school population rather than from a fixed group of individuals; its generation is therefore reported as unit total. It should be noted that kitchen waste is included in the total daily generation used to compute the school-wide per-capita figure (0.17 kg/person/day), so this value should be read as an institutional average rather than a strict per-person rate. The School Kitchen recorded the highest density, 0.18 kg per liter. This value indicates that waste from the School Kitchen tends to be heavier and denser due to the high water content in food scraps and cooking ingredients (Bappenas, 2022; Islam et al., 2024; Jaringan Sekolah Alam Nusantara [JSAN], 2025; Lendo Novo Foundation [LNF], 2023). Conversely, the School of Makers (SMX) unit had the lowest density, at 0.06 kg per liter. This figure indicates that waste from SMX activities is very light and dominated by hollow or bulky materials, such as paper scraps, cardboard, plastic, and leftover project materials, which occupy more space relative to their weight.

Table 3. Average Weight, Volume, and Density of Daily Waste at *Sekolah Alam Bogor*

No	Unit	Average Daily Weight (kg/day)	Average Daily Volume (L/day)	Average Waste Density (ρ) (kg/L)
1	Pre-school (PS)	33.24	389.67	0.09
2	Elementary School (SD)	61.37	694.68	0.09
3	School Kitchen	33.72	188.65	0.18
4	Middle School (SM)	19.39	184.52	0.11
5	School of Makers (SMX)	17.43	314.26	0.06
	Total	165.15	1771.78	0.09

Source: Primary Data Processing (2026)

The waste composition analysis results presented in **Table 4** show that garden waste has the highest percentage at 41 percent, followed by food waste at 30.44 percent, rigid plastic at 3.24 percent, cardboard at 1.50 percent, and residue at 24.03 percent. Organic waste categories are the largest contributors, accounting for 71.23 percent of the total waste, with garden waste amounting to 67.37 kg per day and the largest average contribution coming from the SD unit at 28.26 kg. Food waste totals 50.27 kg per day, with the School Kitchen contributing the most at 30.47 kg per day, consistent with its role in meal preparation. The SD unit produces the highest amounts of both garden and food waste because it has the largest land area and the most intensive school activity among the areas. The dominance of organic waste in this study (71.23%), with garden waste (40.79%) as the largest single category, is in line with [Riany et al. \(2025\)](#), who reported organic waste at 64.83 percent, and [Aulani et al. \(2025\)](#), in which leaf (garden) waste was the largest category at 35 percent. A similar pattern was observed in Depok, Indonesia, where the waste stream is dominated by organic material (food waste 72.96% and green waste 3.65%). The high proportion of organic waste has direct consequences for greenhouse gas emissions, given that landfilling of organic waste is a major source of methane in the waste sector ([Kristanto & Koven, 2019](#)). Inorganic waste consists of cardboard, rigid plastic, and residue, accounting for 28.77 percent of the total waste. Among inorganic waste, residue or non-recyclable waste is the largest by mass, at 39.70 kg per day. Meanwhile, rigid plastic waste accounts for 5.35 kg per day, and cardboard accounts for 2.47 kg per day, both of which are relatively small figures. The low levels of plastic and cardboard waste indicate the effectiveness of the school's Dropzone program. Students at *Sekolah Alam Bogor* are instructed to sort and place recyclable waste into the Dropzone according to category before it reaches the sorting stage at Salam Permaculture. The relatively low volume of rigid plastic waste in the internal waste stream is also supported by the school's canteen policy, which restricts the use of single-use plastics. Vendors are not permitted to use disposable plastic packaging, and buyers are required to bring their own containers when purchasing food or beverages. This policy reduces single-use plastic waste at its source, complementing the Dropzone program's role in capturing plastic waste originating from outside the school environment. As a result, the remaining inorganic material arriving at the final sorting stage is dominated by residue with no economic value.

Table 4. Average Daily Waste Composition at *Sekolah Alam Bogor*

Category	Waste Composition	Average (kg/day)					Total Average (kg/day)	Composition Percentage (%)
		PS	SD	School Kitchen	SM	SMX		
Organic	Garden Waste	20.68	28.26	0.00	11.37	7.06	67.37	40.79
	Food Waste	4.38	7.75	30.47	4.75	2.92	50.27	30.44
	Sub-Total Organic	25.06	36.00	30.47	16.12	9.98	117.64	71.23
Inorganic	Cardboard	0.00	1.47	0.00	0.00	1.00	2.47	1.50
	Rigid Plastic	0.89	2.31	0.00	0.97	1.17	5.35	3.24
	Residue	7.29	21.58	3.25	2.30	5.28	39.70	24.03
	Sub-Total Inorganic	8.18	25.36	3.25	3.28	7.45	47.51	28.77
	Total Waste Mass	33.24	61.37	33.72	19.39	17.43	165.15	

Source: Primary Data Processing (2026)

Analysis of Reduction Potential and Waste Management Performance

The waste management performance at *Sekolah Alam Bogor* is evaluated using the Waste Diversion Rate (WDR). Based on **Figure 1**, the waste sorting conducted at Salam Permaculture categorizes the materials into three main groups. First, the organic waste designated for processing into compost amounts to 117.64 kg per day. Second, the recyclable waste collected from this unit is 7.82 kg per day. Together, these two streams form an internally diverted waste mass of 125.46 kg per day (117.64 + 7.82), which corresponds to an internal WDR of 76.0 percent (125.46/ 165.15). The remaining 39.70 kg per day constitutes residual waste, which is subsequently managed through incineration and is excluded from the diverted waste mass, as it receives no further material diversion.

Furthermore, there is additional diverted waste from Dropzone collection, estimated at 13.55 kg per day. Because Dropzone materials originate from students' homes and are external to the

school's internally generated waste, they are reported separately. Including this community-contributed recyclable waste consistently yields an expanded WDR. The expanded WDR is the sum of the internal diverted mass (125.46 kg/day) and the Dropzone contribution (13.55 kg/day), totaling 139.01 kg per day, against a combined waste base of 178.70 kg per day (165.15 + 13.55). This results in the expanded WDR of 77.79 percent (139.01/178.70).

Table 5. Diverted Waste Mass and Waste Diversion Rate (WDR) for Each Category

Category	Diverted Waste Mass (kg)	WDR (%)
Organic	117.64	71.23
Inorganic	7.82	4.74
Internal Subtotal	125.46	Internal WDR = 76.00
Dropzone (Community)	13.55	8.20
Expanded Total	139.01	Expanded WDR = 77.79

Source: Primary Data Processing (2026)

These figures indicate that a substantial share of the total waste generated is diverted from final disposal (incineration) through composting and recycling systems, with the inclusion of Dropzone materials further strengthening the school's overall diversion performance. The internal WDR states around 76 percent of total internal waste is diverted from final disposal, while 39.70 kg per day (24% of total waste) is still managed through incineration, indicating residue reduction remains the primary area for improvement. The expanded WDR of 77.79 percent shows that incorporating community-contributed Dropzone materials further increases the share of waste diverted from disposal, demonstrating that the operational integration between Salam Permaculture and Dropzone meaningfully strengthens the school's overall diversion performance.

As an operational performance indicator, these results show that the school has developed circular economy-oriented waste-management practices that substantially reduce, but do not eliminate, the residue requiring final disposal. This circular flow is further strengthened by the "Agricultural Cultivation" and "Healthcare Access" pathways, which return the benefits of waste processing to the source units (PS, SD, SM, and SMX). Although the WDR has not yet reached 1.00 (100%), this achievement represents the school's success in minimizing the residue that must be handled at the final stage to just 24% of total daily waste generation. Moving closer to a WDR of 1.00 would require further reducing the residual fraction, for example, by limiting multilayer and single-use packaging from outside the school, improving source separation among students and staff, and developing partnerships for hard-to-recycle materials – rather than relying on incineration as the final treatment step (Kristanto et al., 2015). In addition, the adoption of automated organic-inorganic sorting technologies could complement behaviour-based source separation and reduce the proportion of mixed waste reaching the final sorting stage, thereby lowering the residual fraction directed to incineration (Harini et al., 2024).

Compared with other studies, the WDR achieved by *Sekolah Alam Bogor* (0.76-0.78) is considerably higher than the actual WDR reported at the provincial scale by Widarysana et al. (2021) for Bali Province (11.79%), although it is comparable to the potential WDR they estimated for Bali if recycling were fully optimized (77.35%), suggesting that an integrated, institution-scale circular system with dedicated composting, source separation, and a waste bank can approach the diversion performance that remains largely theoretical at the provincial scale.

CONCLUSION

This study shows that *Sekolah Alam Bogor* has implemented an integrated circular-economy-oriented waste management system. The total average daily waste generated is 165.15 kg per day, with a volume of 1,771.78 liters per day and an average waste density of 0.09 kg per liter. The overall average per capita waste generation is 0.17 kg per person per day. This figure includes School Kitchen waste, which is generated collectively rather than by individual occupants, and should therefore be read as an institutional average rather than a strict per-person rate) Overall, *Sekolah Alam Bogor* produces 71.23 percent organic waste and 28.77 percent inorganic waste. The Elementary School (SD) unit is the largest contributor to waste, generating 61.37 kg per day, with the composition dominated by garden waste at 41 percent, food waste at 31 percent, residue at 23 percent, rigid

plastic at 3 percent, and cardboard at 2 percent. The mapping of material flow revealed that organic waste is processed into compost through Salam Permaculture, recyclable materials are channeled to the Salam Aid Waste Bank to help fund the Healthy Home Clinic, while final residues are managed through incineration. Sekolah Alam Bogor diverts a substantial share of its waste from final disposal through the integration of the Dropzone sorting system, Salam Permaculture processing unit, and Salam Aid Waste Bank. Performance indicators show an internal Waste Diversion Rate (WDR) of 0.76 (76.00%), and an expanded WDR of 0.78 (77.79%) when community-contributed Dropzone materials are included, indicating that residue incineration remains the system's main constraint. The results of the study demonstrate that clear material flow mapping and the integration of business units in waste management are crucial to optimizing the application of the 3R (Reduce, Reuse, Recycle) principles. This study has several limitations, including the exclusion of hazardous and toxic waste (B3) from the scope of the analysis and the fact that the quantitative evaluation of residues was limited to calculating the mass of the input to the incinerator. Additionally, this study has not measured the exhaust gas emissions or the quality of the ash resulting from the combustion process of the simple incinerator. Compost output was also based on interview estimates rather than direct weighing, and composting moisture loss was not quantified, so a complete mass balance could not be established. Furthermore, sampling took place during the rainy season, which may have increased the moisture content and weight of waste, particularly garden waste; the reported generation and density figures should therefore be interpreted as representative of wet-season conditions rather than an annual average. Therefore, further research is strongly recommended to conduct laboratory tests on the ash from the school incinerator to determine the safety levels of the exhaust gas emissions and the resulting ash. Furthermore, this combustion ash holds potential for further research as a raw material mixture for the production of eco-friendly bricks or paving blocks, only after such safety testing confirms the ash is free from harmful contaminants.

AUTHOR CONTRIBUTIONS

Conceptualization, NFH, ERC, and MA; methodology, NFH and ERC; software, NFH; validation, ERC and MA; formal analysis, NFH; investigation, NFH; resources, NFH, ERC, and MA; data curation, NFH; writing—original draft preparation, NFH; writing—review and editing, ERC and MA; visualization, NFH; supervision, ERC and MA; project administration, NFH; funding acquisition, NFH, ERC, and MA.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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