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Original Research Article

Analysis of Carbon Emission Mitigation Potential from Solid Waste Management at Campus Environment

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Abstract

Greenhouse gas emissions from waste management contribute to climate change, including in higher education institutions. This study aimed to evaluate the potential for carbon emission mitigation from waste management at the Politeknik Perkapalan Negeri Surabaya campus through organic waste composting and inorganic waste recycling using a waste bank system. The application of solid waste generation measurement was combined with the Intergovernmental Panel Climate Change guidelines and SNI 3964:2025. A descriptive quantitative approach was employed, utilizing primary data on solid waste characteristics from selected campus buildings. Baseline emission estimates and mitigation scenarios were used, assuming partial implementation of the 3R program: organic waste composting and recycling. The results indicate that the waste management sector produces approximately 5.44 tons of CO_2 per year, and the proposed emission reductions could reduce emissions by approximately 63%. The findings of this study indicate that integrated waste management has significant potential for reducing carbon emissions and supporting the development of low-carbon campuses aligned with Sustainable Development Goals 12 and 13, despite the methodological limitations related to the assumptions of emission factors and the level of implementation.

Keywords: Carbon Emissions; mitigation; reduce-reuse-recycle; sustainable campus; solid waste management

1. Introduction

Climate change is a global issue triggered by high concentrations of greenhouse gases (GHGs), such as CO_2, CH_4, and N_2O, due to human activities (IPCC, 2021). One crucial contributor to emissions is the waste management sector, particularly in systems that still rely on open dumping and lack waste sorting (UNEP, 2020; UNEP, 2021). The anaerobic decomposition of organic matter in landfills releases methane, which has a stronger impact on the atmosphere than carbon dioxide, thus exacerbating the climate crisis (IPCC 2021).

Implementing the 3R principle (Reduce, Reuse, Recycle) is a strategic step in reducing emissions in the waste sector by minimizing waste at its source and recovering material value through recycling (Rahmah et al., 2024). Although the effectiveness of the 3R in reducing landfill load and methane emissions has been recognized as a vital component of mitigation policies (Rifai et al., 2025), empirical evidence measuring its direct impact on emission reduction at the higher-education institution level remains significantly limited.

Universities contribute to greenhouse gas emissions through intensive energy operations, such as the use of air conditioning and electrical appliances (Ismail, 2020; Afiuddin and Priastuti, 2016). In addition to energy, campus solid waste increases the carbon footprint; organic decomposition in landfills produces biogas dominated by methane 60% (CH_4) and 40% CO_2, which accelerates global warming (Chuenwong et al., 2022). This underscores the importance of an integrated waste management strategy that can quantify the potential for specific emission reductions in an academic environment.

Effective mitigation efforts are crucial for the success of educational institutions in controlling greenhouse gas emissions. The use of aerobic biological composting methods for organic waste offers a low-emission solution that is far more environmentally friendly than landfill disposal and produces beneficial outputs for soil fertility (Manea, 2024). Studies have shown that composting can produce 38–84% lower emissions than degradation processes in landfills (Perez et al., 2023). To complement this strategy, waste banks on campus play a crucial role in managing valuable inorganic materials. This system not only reduces reliance on landfills but also lowers upstream emissions by reducing the demand for raw materials (Atmanti and Rejekiningsih 2024). Furthermore, waste banks provide added value by building awareness of the circular economy and pro-environmental behavior in the academic community (Rangkuty et al., 2024).

The implementation of sustainable waste management aligns with the vision of a green campus, which balances ecological, social, and economic dimensions, as evaluated by the UI GreenMetric instrument (Suwartha and Sari, 2017). However, the urgency of carbon mitigation now transcends administrative rankings and is an absolute prerequisite for achieving a net-zero commitment. Valls-Val and Bovea (2021) liken universities to "small cities" with complex metabolisms, where the lack of precise carbon footprint measurements can lead to "carbon blindness." Without local and empirical emissions data support, sustainability policies are often merely symbolic and have no real impact (Robinson et al., 2022). In this context, Politeknik Perkapalan Negeri Surabaya (PPNS) is a highly relevant research subject because of the diversity of its waste characteristics, representing the composition of waste originating from office to industrial sources, allowing for the empirical evaluation of the potential for real emission reductions (Oliveira and Proença, 2025).

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2. Methods

The calculation of potential carbon emissions from waste management at Politeknik Perkapalan Negeri Surabaya (PPNS) used a descriptive quantitative method. The sampling locations for measuring waste characteristics were determined using a random sampling method. Primary data collection for waste samples from buildings, including schools, laboratories, offices, workshops, gardens, mosques, and canteens, referred to SNI 19-3964-1994. The average waste generation per person per day from each building was used as a basis for estimating waste production in other buildings with similar characteristics. Subsequently, the weight and composition of the waste were calculated to determine the carbon emissions, referencing the IPCC 2006 methodology, which includes estimating methane (CH_4) and carbon dioxide (CO_2) production from each type of waste. Based on Youchai (2018), the analysis continues with the calculation of emission mitigation potential through the Recovery Factor (RF) approach based on the types of recyclable materials, including organic matter, plastics, paper, metals, and glass. The results of the analysis are presented in the form of tables and graphs comparing the total emissions before and after mitigation efforts, thus illustrating the contributions of the 3R (Reduce, Reuse, Recycle) activities in reducing carbon emissions.

2.1 Determination of Sampling Quantity

The determination of sampling locations follows the methodology outlined in SNI 19-3964-1994. A total of 10 sampling locations were selected, including Building E, Building T, Building C, the Cafeteria and Inbis, the Repair Workshop, Building J, Building K, Building P and M, the Mosque, and the Garden. The formula used for sample selection according to SNI 19-3964-1994 is as follows:

$$T = C_d \sqrt{TS} \quad (1)$$

In Eq. (1), where T is the number of sampled buildings, Cd = 1, and TS was Total number of buildings.

The PPNS has a total of 23 communal waste bins. The sampling method employed in this study was cluster sampling. The sources of waste to be sampled were categorized into six locations based on their building functions: offices, laboratories/workshops, classrooms, mosques, cafeterias, and gardens. Descriptions of the six location groups. The offices group take in 8 locations which were library, directorate building, student practice building, theory building, P3M building, teleconference building, music hall, and training center building. The laboratories/workshops group had eight locations: the central workshop, north workshop, building J laboratory, new workshop, south workshop, tool workshop, wood Workshop, Building K Laboratory. The classroom group comprised three locations: buildings N, P, and M. The facilities and infrastructure include a mosque, cafeteria, and front and back gardens.

2.2 Calculation of Waste Generation Rate

Carbon emissions were calculated using the IPCC (2006) methodology with default parameter values (MCF, DOC, and OX) because site-specific landfill gas data were unavailable. The default value is widely accepted in institutional-scale assessments, ensuring methodological consistency with acknowledged uncertainties, although it is less representative of the local conditions. Waste generation measurements were conducted for eight consecutive days in accordance with SNI 19-3964-1994, and waste generation was calculated using the following equation:

$$Waste\ Generation\ \left(\frac{L}{day.capita}\right) = \frac{Vs\ \left(\frac{L}{day}\right)}{u(capita)} \quad (2)$$

In Eq. (2) Vs is the measured waste volume, and U is the number of waste-generating units.

2.3 The Carbon Emission Calculation from Waste Management at PPNS

According to the IPCC (2006), carbon emissions are calculated using the following formulas:

$$DDOCm = W \times MCF \times DOC \times DOCf \quad (3)$$

$$(Lo) = DDOCm \times 16/12 \times F \quad (4)$$

$$ECH_4 = (\text{Amount of Methane} - R) \times (1 - OX) \quad (5)$$

$$CO_2 = \text{Total } CH_4 \text{ Emissions} \times ((1 - F) / F + OX) \times (MR\ CO_2 / MR\ CH_4 \quad (6)$$

$$Etotal = (\text{Total } CH_4 \text{ Emissions} + CO_2 \text{ Emissions}) \times 365 \text{ days} \quad (7)$$

In Eq. (3) DDOC is the mass of decomposable DOC, and Wiss is the weight of the waste composition, which is defined daily. In addition, MCF was the methane correction factor (0.8), and DOC was the degradable organic carbon based on IPCC default values. DDOC_f was the fraction of DOC that can decompose (0.5 for the Indonesian context), and L_o is the amount of CH_4 generated. In Eq. (4), 16/12 represents the molecular weight ratio of CH_4/C, and F is the methane fraction in landfill gas (0.5). In Eq. (5), where ECH_4 and ECO2 are the total emissions of methane and carbon dioxide, respectively. In addition, R is the amount of recovered methane (assumed to be 0 for this study area), and OX is the oxidation factor (0.1). In Eq. (6), the ratio of molecular weights MR CO2/MR CH4 was utilized for gaseous conversion. In Eq. (7), E Total was the total annual emissions converted to tons CO2-eq per year which was defined annual.

2.4 The Calculation of Recovery Factor

The recovery factor (RF) is the potential for recycling, which represents the percentage of waste mass that is technically and economically recoverable through recycling, composting, or reuse (Tchobanoglous, 2002). The RF value for each waste composition in the PPNS was determined from direct field observations using the standard range reported by Kreith and Tchobanoglous (2002). Operationally recoverable waste is defined as the fraction of waste that is operationally recoverable and separable at the source of the PPNS facility, including aerobically compostable organic waste, recyclable plastics (PET and HDPE), paper and cardboard, metal, and glass. The RF calculation was obtained from the ratio between the mass of recoverable waste and the total mass of waste collected before sorting, and the mass of recoverable waste had economic value or potential for reuse. A high RF value indicates a large potential for waste diversion that supports the implementation of sustainable waste management principles (Dwi et al., 2024), which was calculated using the following equation:

The recovery factor can be calculated using the following equation:

$$\%RF = \frac{Final\ Waste\ Mass}{Initial\ Waste\ Mass} \text{ x } 100\% \quad (8)$$

In Eq. (8), RF is the percentage of recovery factor (%) for solid waste. The final waste location was solid waste that had been potentially processed, whereas the initial waste was solid waste that had not been processed. The recovery factor is determined by identifying the percentage of waste mass that can potentially be recovered (such as through recycling, composting, or reuse) from the total waste mass generated (Dwi et al., 2024). The total waste mass was obtained from the total weight of the waste collected from its source (e.g., within the PPNS environment) before any sorting was conducted. The recoverable waste mass was obtained from the weight of the waste components that are technically and economically feasible to recover. This category typically consists of materials with economic value or reuse potential, such as plastics (bottles, packaging), paper and cardboard, metals (iron, aluminum), glass, and organic waste (for composting).

2.5 The Emission Mapping

The mapping of emissions data calculated using the formulas in accordance with the IPCC Guidelines will be represented using the AutoCAD software. The results of these calculations were mapped based on frequency distribution calculations. The following describes the process for determining the range and number of colors used for mapping the carbon footprints:

$$R = X\ max - X\ min \quad (8)$$

$$K = 1 + 3.3 \log n \quad (9)$$

$$I = \frac{Range}{K} \quad (10)$$

In Eq.(9), R is the range of the data, which is calculated as the difference between the maximum value Xmax and the minimum value Xmin. K is the number of classes, where n is the total number of observations (data points). Finally, i represents the class interval length derived from the ratio of the range to the number of classes. These parameters ensured that the waste generation profiles were systematically categorized for further emission analysis. Emission mapping was conducted using AutoCAD at the building level to visualize the spatial distribution of carbon emissions across the campus zones. Class intervals were defined using frequency distribution methods to distinguish emission intensities, and the results were validated by cross-checking emission patterns with measured waste generation data across functional clusters.

3 Result and Discussion

3.1 Solid Waste Management at PPNS

This study estimates greenhouse gas (GHG) emissions from non-hazardous solid waste management at Politeknik Perkapalan Negeri Surabaya (PPNS), classified into functional building categories—classrooms, laboratories, offices, workshops, gardens, mosques, and cafeterias—following SNI 19-3964-1994. All waste management stages, from generation to final disposal, cumulatively contribute to emissions, consistent with the waste management emission framework proposed by Kristanto and Koven (2019).

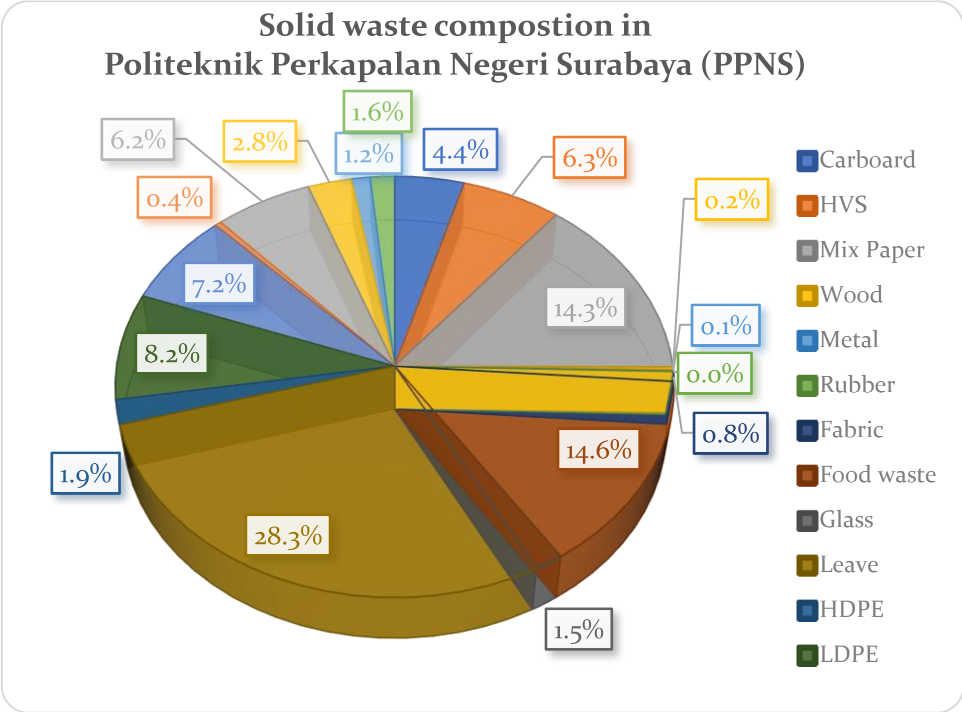

Figure 1 Solid waste composition at Politeknik Perkapalan Negeri Surabaya (PPNS)

Solid waste originating from various buildings is collected by cleaning personnel and temporarily stored at the PPNS Temporary Storage Facility (TPS). Subsequently, the accumulated waste is transported by a third party for processing. The accumulation of waste at PPNS has the potential to generate GHG emissions, as noted by Kristanto and Koven (2019). The calculation of carbon emissions from waste management at PPNS is based on the weight of each waste composition. Figure 1 presents a visualization of the waste composition generated by all buildings selected as sampling points at the PPNS. SNI 19-3964-1994 outlines that waste composition includes physical components such as food waste, paper and cardboard, wood, textiles, rubber and leather, plastics, ferrous and non-ferrous metals, glass, and other materials such as soil, sand, stones, and ceramics. The solid waste composition can affect the carbon emission potential because each type of waste has different emission factors(Liu et al., 2017; Ou et al., 2026).

Figure 1 shows that the largest solid waste composition in PPNS is garden waste (28.3%), while the smallest is diaper waste (1.2%). The majority of the waste consists of non-compostable waste, such as plastics and glass, which have a high recycling potential. A study at Diponegoro University reported that emissions from solid waste management contributed 0.76% of the total carbon emissions (Willentiana et al., 2019). When aggregated, non-compostable but recyclable materials, such as plastics, glass, paper, and metals, account for more than 45% of the total waste composition. This proportion is comparable to the findings at Diponegoro University, where recyclable fractions ranged between 42% and 48% of the total campus waste (Willentiana et al., 2019), indicating that PPNS exhibits a similar structural waste profile to that of other Indonesian higher education institutions. The research results align with those of Fauzi et al. (2022), who found that sorting and recycling solid waste can reduce landfill accumulation while generating economic value through effective composting, recycling, and waste sorting strategies to reduce emissions (Saputra et al., 2024; Sunarto, 2013). Waste bank programs and environmental education on recyclable waste can reduce waste by up to 94% (Meilani et al., 2021).

The average waste generation per person per day at the sampled waste sources was used as a reference to calculate the average weight of the waste composition. Therefore, this approach represents waste generation across all waste sources, reflecting the actual conditions.

Carbon emission values obtained from sampled waste sources can be compared with and used as a reference for unsampled waste sources, provided that both have similar characteristics (Pihawiano et al., 2024). Representative waste sources include Building E representing Teleconference (S), Building T representing Buildings A and B, the Canteen and Inbis representing the Library and Shipmart, the Repair Shop representing Tool, Construction, Welding, CNC, and Wood Workshops, and Buildings P and M representing Building N. The estimated weight composition of the waste supports subsequent analysis, which correlates with recycling potential and emission calculations using this classification. According to Sofriadi et al. (2017), there is a strong correlation between the weight of the waste, which is influenced by the type of waste composition, and the amount of carbon emissions produced. The results of this study also demonstrated that the amount of emissions from each building is influenced by the weight of the waste components produced by that building. Furthermore, moisture content, carbon-to-nitrogen (C/N) ratio, and aeration level significantly influence the amount of greenhouse gas emissions produced, as high moisture content can accelerate the rate of gas emissions (Tang et al., 2023).

Contribution-based analysis indicated that organic waste from garden waste and food scraps contributed approximately 51% of the total carbon emissions in PPNS. Organic carbon content is easily decomposed and has the potential for high methane generation. The recyclable inorganic waste fraction (plastic, paper, metal, and glass) contributes approximately 45% of the total waste composition but contributes a relatively smaller share of emissions owing to its limited biodegradability. This difference suggests that material characteristics and decomposition behavior influence emission intensity more than waste quantity does.

These contribution patterns indicate different mitigation priorities for each region. The highest emission reduction potential for organic waste can be achieved through composting and processing at waste sources, such as gardens and food service areas, where the emission intensity per unit mass is the highest of all waste sources. Conversely, recyclable inorganic waste offers indirect mitigation benefits through material recovery, landfill diversion, and circular resource flow, although its direct emission contribution is lower. Therefore, waste-type-specific mitigation strategies that prioritize organic waste stabilization by maximizing the recovery of the recyclable fraction are more effective than uniform waste reduction approaches.

Accordingly, waste-type–specific mitigation strategies—prioritizing organic waste stabilization while maximizing the recovery of recyclable fractions—are more effective than uniform waste reduction approaches. Carbon emission reduction can be achieved by reducing waste at the source (Mühle et al., 2010; Tian et al., 2025). Processing various types of solid waste can be achieved with the support of strong campus programs and policies for environmental sustainability (Jawjit et al., 2025; McGushin et al., 2026).

3.2 Carbon Emission Mitigation

The Recovery Factor (RF) is an indicator that represents the percentage of waste that can be managed (Sofriadi et al., 2017). The calculated RF values were then used to estimate the emissions from waste components that have the potential to be reduced. The RF calculation for recyclable waste is based on the compositional potential that holds economic value and can be distributed through collaboration with the PPNS Waste Bank. This calculation process refers to the guidelines developed by Kreith and Tchobanoglous (2002) and is presented in Table 2.

Tabel 2 Ideal composition recovery factor percentages

Material	**Recovery percentage (recovery factor)**	
	Range (%)	**Typical (%)**
Easily biodegradable organic waste		80
Paper	40 - 60	50
Plastic	70 - 90	80
Glass	50 - 80	65
Metal	70 - 95	85

Source: (Kreith and Tchobanoglous, 2002)

The recovery factor values for each waste composition at PPNS were determined through direct field observation, while still referring to the benchmark values established by Kreith and Tchobanoglous (2002). The following is an example of the calculation of the metal waste generated at PPNS:

Weight of metal waste composition= 0.285 Kg
Weight of recovered metal waste= 0.255 Kg

$$\%RF = \frac{Final\ waste\ mass}{Initial\ waste\ mass} \times 100\%$$
$$= \frac{0.255}{0.285} \times 100\% = 89.47\ \%$$

The potential for metal waste recovery reached 0.255 kg, with a recovery factor of 89.47%. Table 2 shows that the values resulting from the direct sampling calculations are in the range of 70% to 95%. Once the recycling potential of waste at PPNS was identified, the next step was to calculate the resulting emissions. Utilizing this recycling potential can yield significant positive impacts if it is implemented optimally and effectively. The carbon emissions listed in Table 1 can be reduced by optimizing waste recovery, as previously described. Quantitatively, the optimization of recycling activities through the PPNS Waste Bank could reduce emissions from the solid waste sector by up to 3.4372 tCO_2/year, equivalent to approximately 63% of the baseline solid waste emissions, as shown in Figure 2 and calculated using the following equations:

CO_2 emissions from all waste components in Building C: 0.2672 tCO_2/year
CO_2 emissions from recyclable waste in Building C: 0.1773 tCO_2/year

$$Total\ CO_2\ emissions\ after\ recycling$$
$$= CO_2\ emissions\ from\ all\ components - CO_2\ emissions\ from\ recyclable\ waste = 0.2672 - 0.1773$$
$$= 0.0899\ tCO_2/year$$

Figure 2 shows that the mitigation of carbon emissions from solid waste management in PPNS was reduced by the 3R program (Recycle, Reuse, and Recovery). This reduction rate is higher than the 0.76% contribution reported for total campus emissions at Diponegoro University (Willentiana et al., 2019), reflecting the differences in system boundaries and the relatively high recyclable fraction at PPNS. The implementation of recycling programs in Indonesia has successfully reduced waste volume while simultaneously lowering greenhouse gas emissions (Rahmah et al., 2024). Therefore, collaboration among all stakeholders, including the government, community, and private sector, is essential for developing a more efficient waste management system. Figure 2 shows that campus cafeterias generate the highest carbon emissions among all buildings because emissions are also influenced by the spatial activities of the building. The spatial activities of these cafeterias also result in high waste generation (Panda et al., 2026; Steven et al., 2025). Carbon emissions can be reduced if campuses implement sustainable and technologically intelligent waste management (Abulibdeh, 2024).

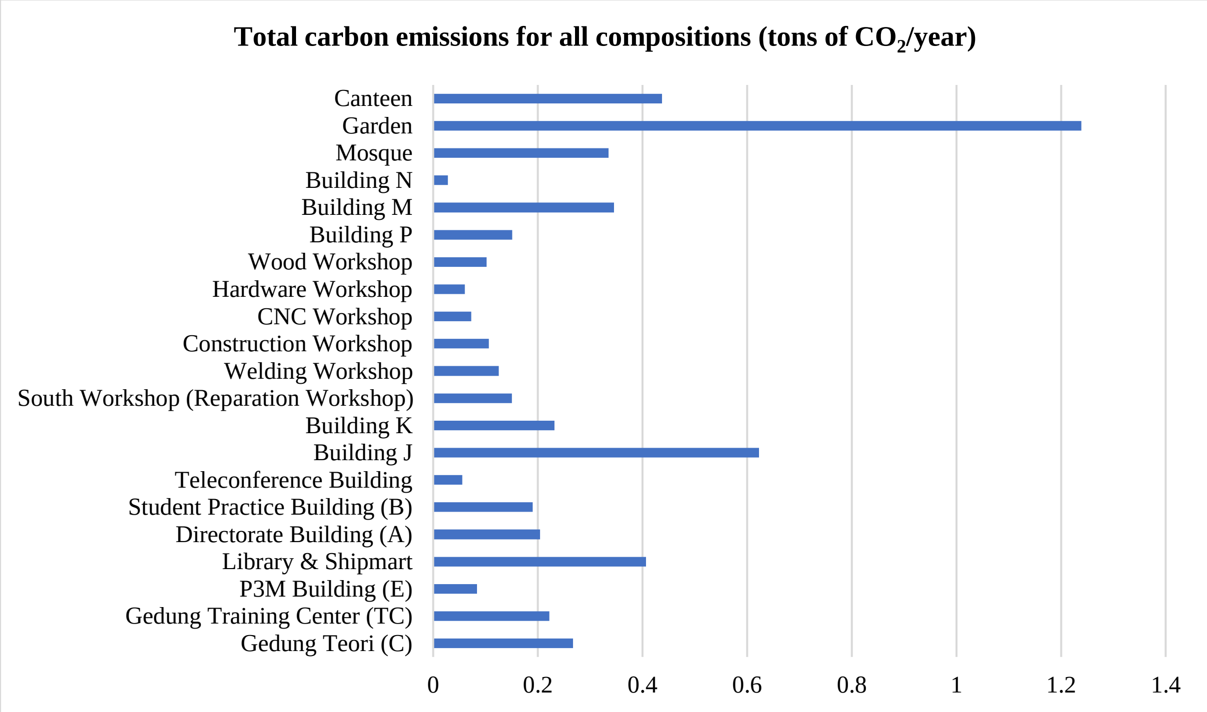

Figure 2. Total solid waste emissions after and before mitigation

According to Try Julita et al. (2021), waste management strategies, such as recycling and composting, are crucial in campus environments for reducing methane (CH_4) emissions. A study by Irawan et al. (2025) demonstrated that the application of the 4R principles (Reduce, Reuse, Recycle, Replace) at the Politeknik Negeri Jember campus has significant potential to reduce greenhouse gas emissions by up to 1.2 tons CO_2-eq per month, with the largest reductions resulting from reduce and recycle activities. Through such measures, higher education institutions can contribute to mitigating methane emissions from waste that ultimately ends up at final disposal sites (TPA). Achieving this, however, requires strong support and commitment from campus management and the entire academic community. Furthermore, campuses must have routine integrated waste management systems. One way to treat organic waste is through composting, which can significantly reduce carbon emissions (Jakimiuk et al., 2023).

3.3 Carbon Footprint of All Buildings with Mapping and Mitigation Measures

The carbon footprint map illustrates the distribution of emissions generated by campus environmental activities, including non-hazardous solid waste management. In this study, carbon footprint mapping focused on environmental activities within the PPNS, as shown in Figure 4. The carbon footprint values calculated for the PPNS were analyzed using map-based visualizations. The map was classified according to the results of frequency distribution calculations, which aimed to determine the color categories representing different emission levels across the mapped areas. The emission classes were determined using frequency distribution methods, with calculations based on Equations 8–10. The mapping resolution is limited to the building level, meaning that emissions are aggregated per functional unit rather than measured at point sources. This assumption should be considered when interpreting the spatial differences.

1. Determining the Range

$$Range = X_{max} - X_{min} = 1.2387 - 0.0282 = 1.211 \quad (11)$$

2. Determining the Number of Classes (k)

$$k = 1 + 3.3log\ n = 1 + 3.3log\ (21) = 5 \quad (12)$$

3. Determining the Class Interval (i)

$$i = \frac{Range}{k} = \frac{1.211}{5} = 48.35 \quad (13)$$

In Eq. (11), where Xmax is the maximum range and Xmin is the minimum range. In Eq. (13), where i is the class interval length and K is the number of classes or colors to be used in the map (Fig. 5). The results of the carbon emissions mapping for the non-hazardous waste sector at the PPNS campus are shown in Figure 4, which indicates that the garden area has the highest emissions, with a total of 1.2387 tons of CO_2/year. The high emission rate in this area is due to the dominance of garden waste, such as leaves, twigs, and pruning waste, which contain high organic matter that has the potential to produce greenhouse gases during decomposition.

Building J ranked second with emissions of 0.6226 tons of CO_2/year. This high emission rate is due to intensive activities, including laboratory work and practical sessions that generate a significant volume of waste. The canteen ranked third with emissions of 0.4375 tons of CO_2/year owing to the composition of the waste generated, which consists of food waste that produces methane (CH_4) and single-use plastics.

Quantitatively, garden emissions were nearly three times higher than the average building emissions (≈0.41 tCO_2/year), underscoring the dominant role of organic waste in emission formation. This finding aligns with that of Sardi et al. (2021), who stated that garden areas can generate substantial CO_2 emissions from various biological and soil processes. However, when well managed and supported by productive vegetation, gardens can also serve as important elements for carbon sequestration and for reducing net emissions in campus or urban environments. In addition, campus development can impact carbon emissions. Campus development that prioritizes infrastructure will result in fewer carbon emissions, supported by waste management education and programs for the campus community (Abulibdeh, 2024; Winarto et al., 2022).

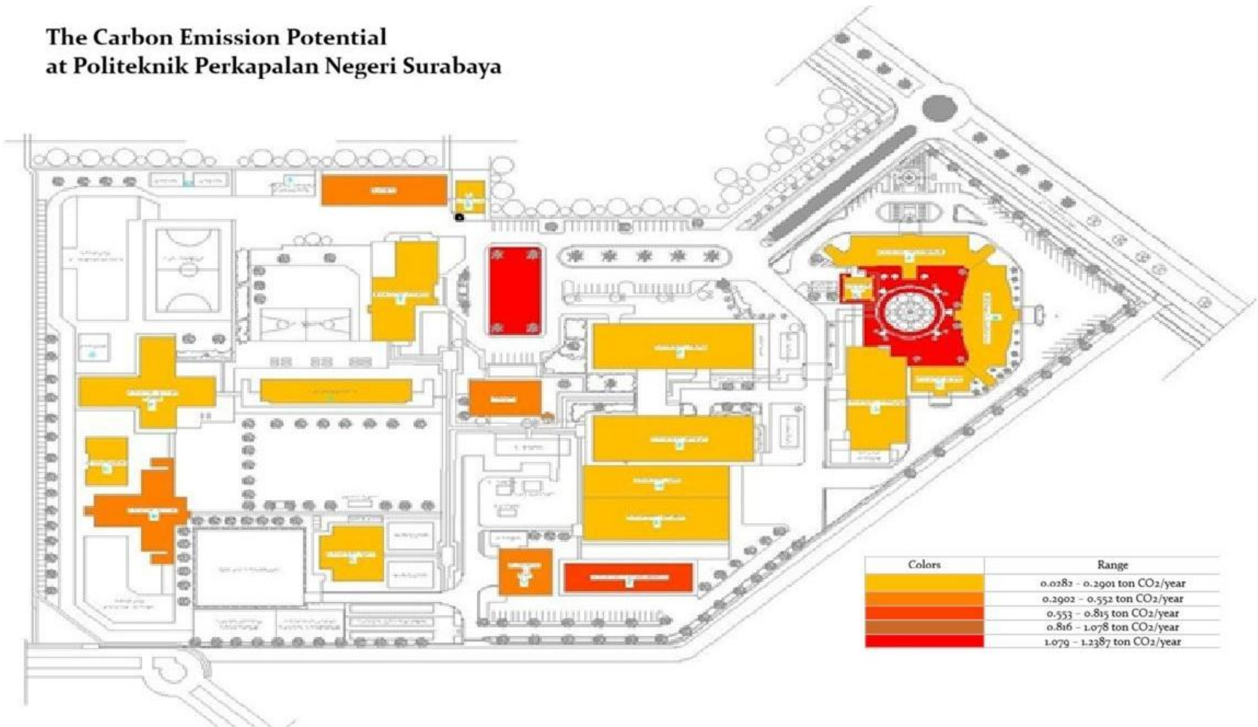

Figure 4. Mapping results of *Non* B3 Solid Waste *management* CO_2 emissions in buildings at Politeknik Perkapalan Negeri Surabaya (PPNS)

Additionally, the Library and Shipmart generated 0.4067 tons CO_2/year, followed by Building M with 0.3457 tons CO2/year and the mosque with 0.3353 tons CO_2/year. This distribution pattern indicates that areas with high activity levels or large amounts of organic waste contribute significantly to total carbon emissions within the PPNS campus. There is a strong correlation between waste generation, waste composition and carbon emissions (Sofriadi et al., 2017).

This study aligns with global research on campus areas, such as a study conducted at the University of Lagos, Nigeria, which showed that organic waste contributes more than 50% of total institutional waste generation, which is a major source of methane emissions if left unmanaged (Adeniran et al., 2017). Other research conducted at the Universities of Cassino and Southern Lazio in Italy indicates that cafeterias and gardens are high carbon emitters (Iannone et al. 2021). Furthermore, energy consumption contributes significantly to the total carbon footprint. One cause of carbon emissions in universities in Asia is the highwater content of organic waste in tropical regions, which accelerates decomposition (Tangwanichagapong et al., 2017).

Therefore, this study emphasizes that mitigation strategies should prioritize organic waste processing, such as composting and recycling, especially in parks and food service areas, by integrating waste reduction policies, green open space management, and behavioral education that supports waste reduction to improve environmental sustainability by reducing carbon emissions.

The stricter a campus's waste management policy, the better the carbon mitigation that can be implemented (Li et al., 2022). Although this study provides a comprehensive overview of solid waste-related emissions at PPNS, several limitations remain. The absence of statistical testing limits the quantitative assessment of the relationship between waste composition and emission intensity. Additionally, the use of default IPCC parameters and assumed optimal 3R implementation introduces uncertainty in the absolute emission values. Nevertheless, the methodological framework and spatial mapping approach offer a practical decision-support tool for campus-scale emission management and can be replicated by other higher-education institutions in Indonesia. In line with this, the campus has implemented various strategies to reduce carbon emissions. One strategy is the use of smart digital-based management technology (Aghamolaei and Fallahpour, 2023; Geng et al., 2025). In addition, the strategy of mitigation has invited bottom-up and top-down participation in waste management in the area (Zhu and Li, 2025).

4. Conclusions

This study demonstrates that solid waste management constitutes a relevant and actionable source of carbon emissions within higher education institutions, while simultaneously offering substantial mitigation potential when managed using an integrated 3R-based framework. The main scientific contribution lies in linking waste composition–specific emission intensities with recovery-oriented mitigation scenarios, enabling function-based prioritization of emission reduction strategies at the campus scale. The results of this study indicate that organic waste with readily decomposable organic content is the primary contributor to carbon emissions, whereas the recyclable fraction of inorganic waste has the greatest potential for emission reductions through material recovery and diversion. Significant emission reductions are possible if the technical implementation of composting and recycling as recovery factors is incorporated into waste management plans. However, numerous factors influence the realization of potential emission reductions, including institutional and behavioral factors, such as the consistency of source separation, operational stability of composting facilities, waste bank logistics, and long-term managerial commitment. These factors can influence practical performance relative to ideal recovery scenarios and should be explicitly considered in sustainable campus policies. The findings of this study offer a replicable framework that integrates waste characterization, IPCC-based emission estimates, recovery factor analysis, and spatial emission mapping. However, further research is needed, particularly regarding the long-term monitoring of emissions reductions in waste management, crosscampus comparison studies, and the integration of life cycle assessments to capture broader environmental trade-offs and strengthen the robustness of campus-scale carbon mitigation assessments.

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Ethical Statement

This research does not involve human subjects, animal experimentation, or the collection of sensitive personal data. All data collection procedures were conducted in accordance with the institutional environmental safety guidelines of Politeknik Perkapalan Negeri Surabaya. No specific ethical approval was required for the analysis of institutional solid waste streams.

CRediT Authors Statement

Vivin Setiani, Ulvi Priastuti, and Ahmad Erlan Afiuddin: Conceptualization, methodology design, and drafting of the original manuscript. **Mar'atus Sholihah, Denny Dermawan, and Mirna Apriani**: Performed data collection and the calculation of carbon emission mitigation. **Dewi Kurniasih, Agus Khumaidi, Aulia Della Cornellia, and Lina Indawati**: Conducted the formal analysis, visualization, and critical revision of the manuscript for intellectual content.

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