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Campus Waste Characterization and Preliminary Incinerator Capacity Planning at a Maritime Vocational Polytechnic in Indonesia

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ABSTRACT: Waste management in maritime vocational institutions presents challenges related to heterogeneous waste streams, appropriate treatment technology selection, and the integration of practical environmental training. However, limited site-specific waste characterisation and uncertainty in waste-generation estimates complicate evidence-based technology planning. This study aimed to assess campus waste generation, examine preliminary treatment capacity requirements, and evaluate cadets' willingness to participate in technical training. Data were obtained from 70 waste collection records covering five campus zones over 14 nonconsecutive observation dates (1–20 May 2026), supplemented by document reviews, site observations, and questionnaires completed by 50 cadets. Waste quantities were estimated using the original study tabulations and fixed conversion factors for 120-L bins. The provisional total waste generation was 3,697.8 kg, comprising 2,877.0 kg of organic waste and 820.8 kg of inorganic waste. Inorganic waste averaged 58.63 kg per observed date, with a reported maximum of 100.8 kg. The administration zone contributed the largest proportion (29.1%). Preliminary capacity screening considered 80-, 100-, 125-, and 180-kg/batch options, identifying 125 kg/batch as an illustrative capacity based on peak loading and a 20% reserve, rather than a validated equipment specification. Although 82% of cadets expressed interest in technical training, learning effectiveness was not assessed. Unvalidated conversion factors and unreproducible date-level dispersion statistics limited data reliability. The study concludes that direct gravimetric measurements, waste segregation, technology-specific feasibility assessments, emission controls, and objective competency evaluations are necessary before equipment procurement.

KEYWORDS: Campus solid waste; maritime vocational education; waste characterization; incineration planning; source segregation; MARPOL

1. Introduction

Campus waste management presents significant challenges for environmental governance, resource efficiency, and sustainable infrastructure planning. Effective waste management

requires a systematic hierarchy that prioritises waste prevention, source segregation, material recovery, appropriate treatment, and environmentally safe disposal rather than treating these approaches as interchangeable alternatives [1-3]. Higher education institutions generate heterogeneous waste streams from administrative offices, residential facilities, dining areas, teaching activities, and technical workshops. Consequently, aggregated waste quantities may conceal important differences in waste composition, generation patterns, and treatment requirements across campus locations. These challenges become particularly important when institutions consider thermal waste treatment, as the combustion of recyclable or unsuitable materials may undermine resource recovery and introduce additional risks associated with atmospheric emissions, ash generation, and residue disposal [4-6].

Previous studies have demonstrated the importance of waste characterisation as a prerequisite for selecting appropriate management technologies. Gallardo et al. [7] quantified university waste composition to support institutional waste management planning, while Budihardjo et al. [8] identified variations in waste generation associated with different locations and activities at Diponegoro University, Indonesia. Similarly, Ojuri et al. [9] differentiated waste streams across academic, administrative, and residential facilities, highlighting the importance of location-specific assessments. Fagnani and Guimarães [10] further emphasised continuous improvement in institutional waste management through systematic evaluation and operational adjustments. Although these studies provide valuable insights into campus waste management, their findings do not directly address the combined engineering and educational requirements of residential maritime vocational institutions considering waste treatment infrastructure.

Politeknik Pelayaran Banten (P2B), located in Tangerang Regency, Indonesia, is a residential maritime vocational institution comprising academic buildings, dormitories, administrative offices, dining facilities, and technical workshops. Project documentation indicates that an existing stationary incinerator was no longer operational and showed visible signs of deterioration. The campus also maintains a composting pathway for garden trimmings. These conditions create a practical waste management challenge involving the assessment of existing infrastructure, identification of treatment-eligible waste, and selection of environmentally appropriate management options. The central problem is that treatment equipment cannot be selected reliably without verified waste quantities, location-specific generation patterns, and a clear distinction between recoverable materials and residual waste requiring treatment. Accordingly, waste characterisation and source segregation must precede equipment procurement and should remain consistent with Indonesian waste management principles [3, 11].

Waste management planning at maritime vocational institutions also involves educational considerations. Marine engineering cadets may benefit from supervised practical activities involving equipment operation, occupational safety, environmental monitoring, and technical record keeping. However, research on maritime simulation and vocational education emphasises the importance of realistic training scenarios, structured learning objectives, and competency-based assessment rather than equipment availability alone [12]. Maritime environmental requirements provide additional educational context. MARPOL Annex V regulates ship-generated garbage and associated Garbage Record Book requirements [13], whereas MARPOL Annex VI Regulation 16 addresses restrictions and operating requirements for shipboard incineration [14]. Nevertheless, these maritime regulations do not replace the

national environmental permits and technical requirements applicable to land-based waste treatment facilities [15]. Therefore, the integration of waste treatment infrastructure into maritime vocational education requires separate consideration of environmental compliance, operational safety, and measurable learning outcomes.

Despite growing research on university waste management, an important knowledge gap remains in the development of an integrated preliminary screening framework that combines location-specific waste observations, uncertainty in waste mass estimation, treatment capacity assessment, environmental constraints, and educational considerations within a residential maritime vocational campus. Existing studies have primarily examined waste composition, generation patterns, or institutional management practices independently [7−10]. Limited attention has been given to the implications of using fixed volume-to-mass conversion factors for preliminary equipment sizing, particularly when waste quantities are estimated from 120-L collection bins rather than direct gravimetric measurements. Furthermore, the distinction between average and peak waste generation, the suitability of different waste fractions for treatment, and cadets' perceptions of technical training need to be considered together before infrastructure investment decisions are made.

The novelty of this study lies in integrating these engineering, environmental, and educational considerations into a transparent, traceable preliminary decision framework for maritime vocational institutions. Specifically, the study combines zone-resolved waste collection records, explicit recognition of conversion-related uncertainty, mean-versus-peak loading comparisons, provisional batch-capacity scenarios, and cadet training perceptions. Unlike studies focused exclusively on waste quantities or treatment technology, this approach establishes a segregation-first screening pathway that distinguishes preliminary planning estimates from validated engineering specifications. Importantly, the framework does not assume that incinerator performance, emission compliance, or educational effectiveness has been demonstrated.

Accordingly, this study aims to develop an integrated preliminary waste management planning framework for a maritime vocational institution by characterising campus waste generation, assessing provisional treatment capacity requirements, evaluating environmental and operational considerations, and examining cadets’ perceptions of technical training to support evidence-based infrastructure planning and sustainable waste management.

2. Materials and Methods

2.1. Study Design, Setting, and Observation Period.

This descriptive, mixed-evidence case study combined structured waste collection records, questionnaire data, visual equipment inspections, selected stakeholder interviews, and document reviews. The study was conducted at Politeknik Pelayaran Banten, Sukadiri, Tangerang Regency, Indonesia. Five functional zones, comprising administration, the canteen, dormitories, classrooms, and the workshop, were observed on 14 nonconsecutive dates between 1 and 20 May 2026. The resulting 70 zone-date entries represented repeated observations of campus waste collection locations rather than independent probability samples of annual waste generation. The selection of functional zones was informed by campus-specific waste characterisation approaches described by Gallardo et al. [7], Budihardjo et al. [8], and Ojuri et al. [9].

2.2. Waste Recording and Conversion Procedure.

Field records documented organic and inorganic waste fractions as fractions or multiples of a nominal 120-l Sulo bin. The original study tabulation comprised 70 location-date entries, with fixed conversion factors of 42.0 kg per organic bin-equivalent and 9.6 kg per inorganic bin-equivalent. For observation date t and waste stream j, the estimated mass was calculated as follows:

$$M(j,t) = B(j,t) \times c(j)$$

where $M(j,t)$ represents the estimated waste mass (kg), $B(j,t)$ denotes the recorded number of bin-equivalents, and $c(j)$ is the stream-specific conversion factor (kg per bin-equivalent). Assuming that one bin-equivalent corresponds to 0.120 m³, these conversion factors represent bulk densities of 350 kg/m³ for organic waste and 80 kg/m³ for inorganic waste. However, established waste sampling protocols recommend direct measurements of waste mass, sample volume, and material composition to determine site-specific bulk densities [7, 16, 17].

Because paired weighing records, calibration information, and replicate density measurements could not be verified for individual observations, all waste quantities expressed in kilograms were treated as conversion-based estimates rather than directly measured masses. Furthermore, the classification into organic and inorganic fractions did not permit the determination of individual proportions of plastics, paper, glass, metals, textiles, hazardous materials, or nonrecoverable combustible residues. A subsequent waste characterisation campaign should therefore incorporate direct weighing, container-fill measurements, and material-specific sorting procedures consistent with SNI 3964:2025 and established campus waste sampling practices [7, 9, 16].

2.3. Original Data Selection and Traceability.

The original compiled research report and its initial waste recapitulation were used as the sole numerical sources for this manuscript. The report documented an estimated total waste mass of 3,697.8 kg across 154.0 equivalent 120-l bins during the 14 observation dates. Bin-equivalent quantities were recalculated using the original fixed conversion factors of 42.0 kg for organic waste and 9.6 kg for inorganic waste to maintain consistency between estimated mass and recorded volume. Subsequent worksheet revisions were excluded from the analyses and figures to maintain consistency with the original dataset. Nevertheless, access to the original date-level records remains necessary to independently verify the reported maximum daily waste generation and calculate dispersion statistics, including standard deviations. This procedure reflects the importance of data traceability and transparent reporting in integrated waste management and environmental measurement [4, 7, 16].

2.4. Equipment Inspection and Stakeholder Evidence.

The condition of the nonoperational stationary incinerator was assessed through a visual review of available field documentation, with particular attention to reported corrosion and deterioration of refractory materials. Interviews with representatives of campus administration, cleaning personnel, dormitory management, and canteen management provided contextual information on waste collection practices, operational requirements, and potential technical

training needs. Supplier documentation and observations from a comparative site visit were used exclusively to describe potential treatment technology characteristics. These sources were not considered evidence of verified treatment capacity, emission performance, or operational suitability under local conditions. This distinction between contextual observations and controlled engineering performance assessments is consistent with established principles of technical evaluation [5, 18, 19].

2.5. Cadet Survey and Descriptive Statistical Analysis.

Descriptive questionnaire results were obtained from 50 cadets enrolled in Nautical Studies (n = 27), Marine Engineering (n = 15), and Marine Transportation Management (n = 8). Responses were summarised using frequencies and percentages to describe perceptions of equipment procurement needs, perceived importance, familiarity with incineration technology, regulatory awareness, and willingness to participate in technical training. The sample was not established as representative of the entire cadet population. Accordingly, the findings were interpreted as self-reported perceptions rather than objective measures of technical knowledge, practical competence, or learning effectiveness. The educational interpretation was informed by previous evaluations of simulator-based learning and competency-oriented maritime instruction [12].

2.6. Preliminary Capacity Screening and Decision Criteria.

Preliminary treatment capacity screening used the estimated inorganic waste stream as a deliberately conservative upper-bound category rather than as a verified quantity of combustible waste suitable for thermal treatment. The original inorganic waste data were summarised using the total estimated mass across 14 observation dates, the calculated mean mass per observed date, and the previously reported maximum daily value. Standard deviations and minimum daily values were not recalculated because the original date-level records were unavailable for independent verification. Four nominal batch capacities of 80, 100, 125, and 180 kg/batch were compared against the reported maximum daily inorganic waste load. An additional 20% capacity reserve was considered solely as an illustrative planning assumption. These comparisons were intended to demonstrate the implications of average and peak waste generation for preliminary capacity screening rather than to establish an optimal equipment specification. The screening did not evaluate hourly throughput, operating cycle duration, annual equipment availability, design temperature, emission-control performance, or economic feasibility. These parameters require further assessment using verified waste characteristics, original equipment manufacturer (OEM) specifications, applicable emission requirements, and comparisons with alternative integrated waste management strategies before procurement decisions can be justified [5, 15, 16, 18, 19].

3. Results and Discussion

3.1. Waste Generation Across the Five Campus Zones.

The original study tabulation recorded 68.5 organic and 85.5 inorganic 120-L bin-equivalents across 14 nonconsecutive observation dates. Based on the fixed conversion factors, these quantities corresponded to estimated masses of 2,877.0 kg of organic waste and 820.8 kg of inorganic waste, giving a combined total of 3,697.8 kg. The corresponding mean waste quantities were 205.50 kg of organic waste, 58.63 kg of inorganic waste, and 264.13 kg of total

waste per observed date. Organic waste accounted for 77.8% of the estimated total mass. However, because different conversion densities were applied to the two waste categories, this proportion should not be interpreted as a directly measured waste composition. Similar location-specific waste inventories have been recognised as important for institutional waste management planning [7−9]. Table 1 presents the estimated organic and inorganic waste quantities across the five campus zones, including their respective bin-equivalents, converted masses, and contributions to total waste generation.

Table 1. Provisional Waste Mass Estimates by Campus Zone During 14 Observation Dates.

Zone	Organic (bins)	Inorganic (bins)	Organic (kg*)	Inorganic (kg*)	Total (kg*)	Share (%)
Administration	20.5	22.5	861.0	216.0	1,077.0	29.1
Canteen	15.5	20.5	651.0	196.8	847.8	22.9
Dormitories	12.0	18.5	504.0	177.6	681.6	18.4
Classrooms	11.5	15.0	483.0	144.0	627.0	17.0
Workshop	9.0	9.0	378.0	86.4	464.4	12.6
Total	**68.5**	**85.5**	**2,877.0**	**820.8**	**3,697.8**	**100.0**

Note: Mass values were estimated using fixed conversion factors of 42.0 kg per organic bin-equivalent and 9.6 kg per inorganic bin-equivalent. Each bin-equivalent represents a nominal 120-L container. The values were recalculated from the original zone-level mass estimates and do not represent direct weighing measurements.

The spatial distribution of estimated waste generation is illustrated in Figure 1. Administration contributed the largest estimated mass (1,077.0 kg; 29.1%), followed by the canteen (847.8 kg; 22.9%), dormitories (681.6 kg; 18.4%), classrooms (627.0 kg; 17.0%), and workshop (464.4 kg; 12.6%). The administration zone recorded 20.5 organic and 22.5 inorganic bin-equivalents. Its relatively high estimated waste generation may reflect collection-route aggregation, grounds maintenance, or activity intensity, although these potential explanations were not independently verified. The canteen recorded 15.5 organic and 20.5 inorganic bin-equivalents, indicating the importance of distinguishing food residues from recyclable packaging. Dormitory records reflected residential waste generation, whereas classroom and workshop waste streams require additional material-specific assessments to identify recyclable paper, packaging, and potentially regulated residues. Previous campus studies have similarly reported differences in waste composition across functional areas, although establishing the underlying causes requires additional occupancy, floor-area, and collection-route information [7−9].

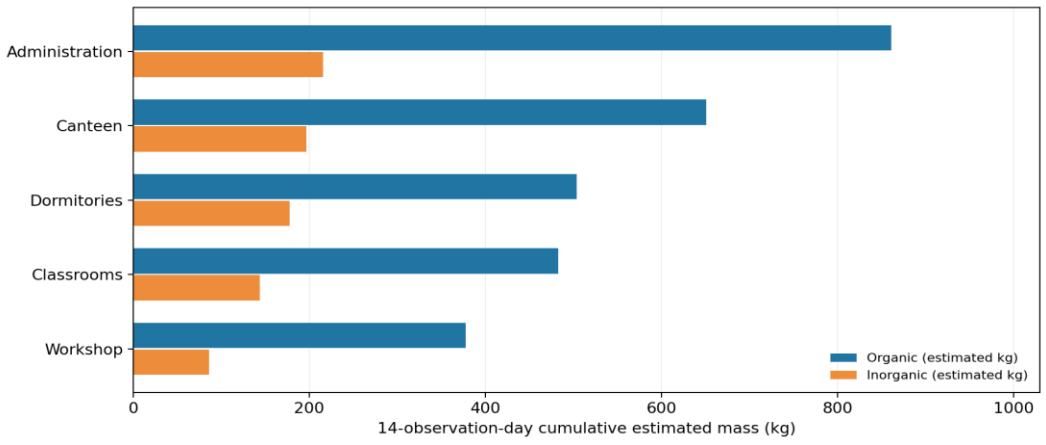

Figure 1. Original-tabulation distribution of conversion-based organic and inorganic waste mass by campus zone over 14 observation dates.

3.1.1. Organic–Inorganic Patterns Compared with Other Campuses.

The estimated organic waste proportion at P2B (77.8%) exceeded the approximately 50% organic composition reported for several academic and support areas at Diponegoro University [8]. However, these findings should not be directly compared because the studies employed different waste characterisation methods. The P2B estimates were derived from fixed density conversion factors applied to broad waste categories, whereas the Diponegoro study employed a more detailed material inventory. Therefore, the apparent predominance of organic waste should be considered a preliminary observation requiring verification rather than evidence that the P2B waste stream is inherently more biodegradable. Gallardo et al. [7] and Ojuri et al. [9] similarly demonstrated that functional activities and sampling procedures influence reported waste composition. Subsequent investigations should directly weigh and separate food residues, garden waste, plastics, paper, glass, metals, and mixed residual materials before selecting treatment technologies.

Across the five zones, organic waste represented approximately 74–81% of the estimated total mass. This apparent consistency was partly attributable to the application of identical conversion factors across all locations. Although the inorganic fraction is relevant to waste collection and transportation planning, it should not be considered equivalent to combustible incinerator feed. Recyclable plastics, metals, glass, polyvinyl chloride (PVC), foil, and potentially contaminated materials require separate identification and screening. Previous studies have emphasised the importance of prioritising waste prevention, resource recovery, composting, and residual treatment before determining the capacity of final treatment technologies [8−10].

3.2. Original Data Summary and Interpretation of Measurement Precision.

The original waste estimates and directly derived descriptive indicators are summarised in Table 2. The estimated organic and inorganic waste masses were 2,877.0 and 820.8 kg, respectively, resulting in a combined total of 3,697.8 kg from 154.0 bin-equivalents. The mean inorganic waste generation was 58.63 kg per observed date, while the original report identified a maximum of 100.8 kg on 5 May 2026.

Table 2. Summary of Original Waste Estimates and Derived Indicators for 14 Observation Dates.

Indicator	Original data	Unit
Organic mass estimate	2,877.0	kg
Inorganic mass estimate	820.8	kg
Total mass estimate	3,697.8	kg
Total container-equivalents	154.0	120-L bins
Mean inorganic waste per observed date	58.63	kg/day
Reported peak inorganic waste	100.8	kg/day

The numerical precision of these estimates reflects the arithmetic calculations rather than the accuracy of direct field measurements. In particular, reporting one or two decimal places does not demonstrate equivalent measurement precision. A subsequent field investigation should retain the original collection records and verify the conversion factors through repeated paired measurements of waste mass and container volume. Such procedures would improve the reliability and traceability of waste generation estimates [4, 7, 16].

3.3. Existing Equipment, Source Management, and Integrated Waste Pathways.

Available visual documentation indicated deterioration of the existing incinerator shell and refractory lining, and the equipment was reported to be nonoperational. These observations suggest that a comprehensive technical inspection is necessary before considering rehabilitation. However, visual inspection alone cannot establish the equipment's remaining service life, structural integrity, operational safety, or replacement costs. Similarly, supplier brochures and comparative site visits cannot substitute for controlled performance testing or site-specific emission assessments. Previous studies have emphasised that incineration systems should be evaluated comprehensively, including combustion performance, pollution control, residual waste management, and operating conditions [18, 19].

The existing campus composting facility offers a potential treatment pathway for leaves and garden trimmings, although the proportion of organic waste currently processed through this facility remains unverified. Accordingly, waste management should prioritise separation into compostable organic materials, recyclable materials, special or hazardous waste requiring authorised handling, and nonrecoverable residual waste. Figure 2 presents the proposed material-specific decision pathway, beginning with source segregation and resource recovery before considering residual treatment. This approach is consistent with established waste management principles and continuous-improvement strategies for institutional waste management [3, 9, 10]. Treating all inorganic waste through incineration would overlook important differences in material recoverability, combustibility, and regulatory requirements [5, 15].

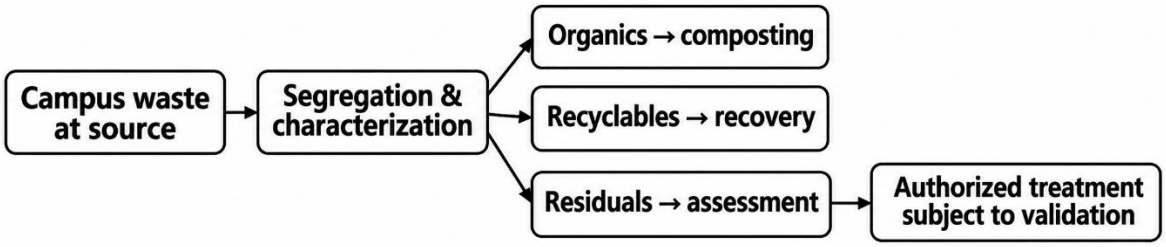

Figure 2. Proposed Material-Specific Decision Pathway. Thermal Treatment, Where Considered, is Restricted to Residuals that Pass Legal and Technical Screening.

The original inorganic waste estimate was 820.8 kg across 14 observation dates, corresponding to a mean of 58.63 kg per observed date. The highest reported daily quantity was 100.8 kg on 5 May 2026, approximately 1.72 times the mean. This difference highlights the limitations of using average waste generation alone for preliminary equipment capacity assessment. Similar temporal variations in campus waste generation have been reported in previous studies [7, 8].

Figure 3 illustrates the difference between the mean and reported peak inorganic waste loads, together with nominal batch-capacity reference levels of 100 and 125 kg. The comparison demonstrates that equipment capacity based solely on average waste generation may be insufficient during periods of higher waste accumulation. However, because the complete original date-level dataset was unavailable for independent verification, minimum daily values, standard deviations, coefficients of variation, and annual exceedance probabilities were not calculated.

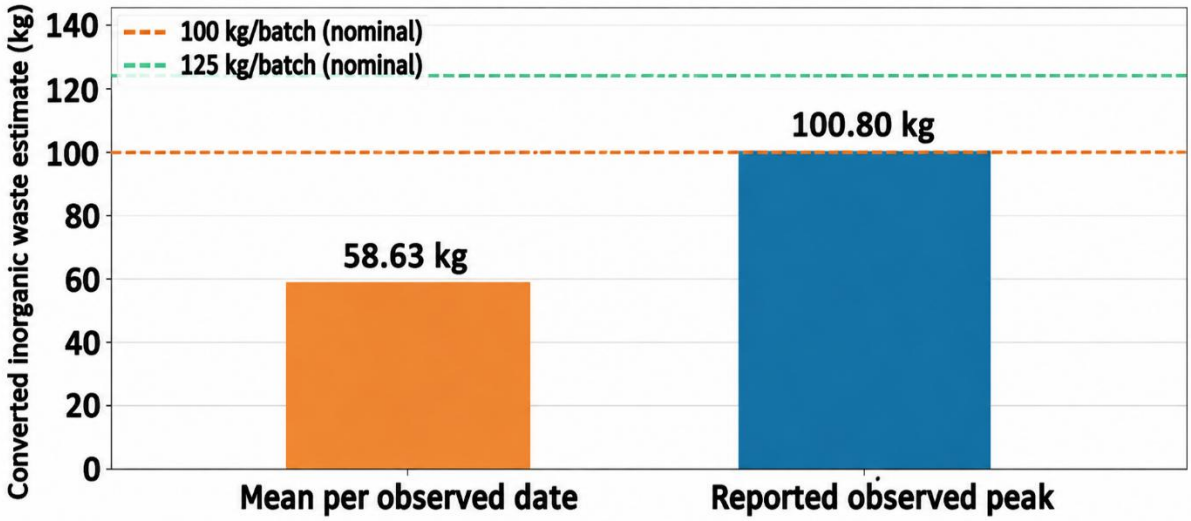

Figure 3. Original-Source Mean Inorganic Mass Per Observed Day (820.8/14 = 58.63 Kg) and Reported Peak (100.8 Kg). Reference Lines at 100 and 125 Kg Indicate Nominal Mass-Per-Batch Screening Thresholds, not Validated Operating Limits.

Four preliminary batch-capacity scenarios were evaluated using the reported peak inorganic waste mass of 100.8 kg. Table 3 compares the nominal capacities of 80, 100, 125, and 180 kg/batch and their corresponding theoretical batch requirements.

Table 3. Preliminary Screening of Nominal Batch Capacities Against the Reported Peak Inorganic Waste Load.

Nominal capacity	Peak load/capacity	Screening interpretation
80 kg/batch	1.26 batches	Below peak; additional batch or alternative treatment required
100 kg/batch	1.01 batches	Slightly insufficient for a single batch
125 kg/batch	0.81 batches	Covers peak on a mass basis; suitability unverified
180 kg/batch	0.56 batches	Greater nominal reserve; economic and environmental implications unverified

An 80-kg batch capacity would require approximately 1.26 theoretical batches to accommodate the reported peak, whereas a 100-kg capacity would be marginally insufficient for a single batch. A nominal capacity of 125 kg/batch would provide a reserve of 24.2 kg, while 180 kg/batch would provide 79.2 kg of additional nominal capacity. Applying an illustrative 20% reserve to the reported peak produces a requirement of approximately 121.0 kg/batch, making 125 kg/batch a possible preliminary screening scenario. Nevertheless, this result does not establish an optimal equipment capacity. The actual mass requiring thermal treatment may be substantially lower after segregation and recycling. Moreover, moisture content, lower heating value, loading density, emissions, operating schedules, and maintenance requirements may significantly influence equipment suitability [5, 18−22].

The difference between average and peak waste generation also has implications for operational planning. Under the conservative assumption that all inorganic waste requires treatment, a 100-kg unit could nominally accommodate the mean daily load but not the reported peak within a single batch. Although larger equipment could reduce peak-day accumulation, it may also operate below its intended loading capacity during ordinary periods. Consequently, temporary storage, transfer to authorised external treatment facilities, and multiple permitted operating cycles should be evaluated as alternatives. Batch capacity must not be interpreted as hourly throughput because actual treatment performance depends on heating rates, residence time, start-up fuel requirements, emission controls, cooling periods, and operating cycles.

Therefore, claims regarding processing durations of 30–60 minutes or guaranteed daily throughput cannot be justified without technical verification [5, 19−25].

4. Conclusions

This study provides a preliminary assessment of waste generation, treatment capacity requirements, and educational opportunities at a maritime vocational institution. Across 14 nonconsecutive observation dates, 154 equivalent 120-L containers were recorded from five campus zones, corresponding to an estimated total waste mass of 3,697.8 kg, comprising 2,877.0 kg of organic waste and 820.8 kg of inorganic waste. The mean inorganic waste generation was 58.63 kg per observed date, with a reported peak of 100.8 kg. Waste generation varied across functional zones, highlighting the importance of location-specific management strategies. Questionnaire findings also indicated cadets' interest in practical environmental training. Preliminary capacity screening identified 125 kg/batch as an illustrative option incorporating a 20% reserve above the reported peak; however, this estimate does not represent a validated equipment specification. The findings support an integrated, segregation-first waste management approach that prioritises resource recovery and environmentally appropriate residual treatment. Nevertheless, the reliance on unvalidated volume-to-mass conversion factors, limited observation periods, and self-reported questionnaire responses restricts the reliability and generalisability of the results. Future investigations should incorporate direct gravimetric measurements, detailed waste characterisation, technology-specific feasibility assessments, emission and ash evaluations, life-cycle cost analysis, and regulatory compliance verification. Objective competency assessments are also necessary to establish educational effectiveness. Overall, the study offers a preliminary decision-support framework for sustainable campus waste management rather than evidence of validated incinerator performance or technical feasibility.

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Author Contributions

Hendi Prasetyo: Conceptualization, methodology, formal analysis, writing – original draft. Pierre Marcello Lopulalan: Investigation, data curation, validation, writing – review and editing. Rahmat Santoso: Supervision, methodology, project administration, writing – review and editing. Alvian Demaz Peramutya: Investigation, data curation, visualization, writing – review and editing. Tiara Shintawati: Investigation, questionnaire administration, data curation, writing – review and editing.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The dataset underlying the reported calculations consists of the original daily source records and the initial recapitulation, as summarized in the original research report. The original tabulation is the numerical basis for Tables 1–3 and Figures 1 and 3. The original day-level observations are necessary for independent recalculation of variability statistics and should be retained with the project documentation.

Use of Artificial Intelligence

The authors used QuillBot to improve the language and take full responsibility for the content of this manuscript.

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