Integrated Waste Treatment Facility In Payakumbuh: Performance Evaluation And Technology Selection Using Multi-Criteria Decision Analysis

Siska Fitri[1], Rizki Aziz[1*], Fadjar Goembira[1], Rahmat Wahyudi Putra[2]

[1,2]Department of Environmental Engineering, Faculty of Engineering, Universitas Andalas, Padang, West Sumatra, Indonesia.
[2]Master of Environmental Science, Universitas Negeri Padang, Padang, West Sumatra, Indonesia.
[*] Corresponding Author:
Email: rizkiaziz@eng.unand.ac.id

Abstract.
The collapse of the Payakumbuh regional landfill in December 2023 left the city without a final disposal site, so the integrated waste treatment facility (TPST) commissioned in January 2025 now carries most of the municipal waste load. This study measured the facility's performance, traced its material flows, and identified the most suitable technology combination for its expansion. Performance was assessed with Key Performance Indicators (KPI) covering technical operation, environment, institutions, community participation, and financing, based on direct weighing, three months of operating logs, smoke opacity observation, and interviews. Technology selection applied Multi-Criteria Decision Analysis (MCDA) with the Simple Additive Weighting (SAW) method to five alternatives and nine criteria weighted by four experts. The overall KPI score was only 28% (poor). Productivity and process efficiency were both 27.31%, and the treatment cost reached IDR 720,479 per tonne. The mass balance showed that manual sorting removed only 3.25% of the incoming waste, while 52.02% ended up in the pyrolysis–gasification unit. To close a capacity gap of 71.5 t/day, the combination of mechanical sorting, rotary kiln composting, and conversion of low-value inorganic waste into Refuse-Derived Fuel (RDF) achieved the highest score (0.7557), followed by the option using pyrolysis–gasification (0.7356). The three highest ranks did not change when the weights of the three most important criteria were each reduced by 10%. These findings indicate that upstream sorting and diversion of the inorganic fraction to RDF matter more to facility performance than additional thermal capacity.

Keywords: *key performance indicator; mass balance; multi-criteria decision analysis; refuse-derived fuel and waste treatment facility.*

I. INTRODUCTION

Municipal solid waste in developing countries keeps growing, while the capacity of local governments to collect and treat it lags behind. The World Bank projects that global waste generation will rise from 2.01 billion tonnes in 2016 to about 3.40 billion tonnes in 2050, with the sharpest increase in low- and middle-income countries [1]. In many cities, uncollected waste ends up in open land or is burned without control, causing health problems, air pollution, and plastic leakage into water bodies [2]. Indonesia faces the same situation; weak land-based waste handling is one of the main sources of plastic debris on its coasts and in its seas [3].

Payakumbuh City in West Sumatra shows what happens when a landfill-dependent system loses its end point. In 2024 the city generated 34,821.70 tonnes of waste, or 95.4 t/day on average. Reduction at source reached only 16.04%, while 80.33% of the waste, about 76.63 t/day, was transported for processing [4]. A landslide closed the Payakumbuh Regional Landfill on 20 December 2023, forcing the city to haul its waste to the Air Dingin landfill in Padang throughout 2024. The long hauling distance, high transport cost, and limited fleet left part of the waste stranded in the city. In response, the municipality built an integrated waste treatment facility (*Tempat Pengolahan Sampah Terpadu*, TPST) in 2024 and began trial operation in January 2025. The facility combines manual and mechanical sorting with a pyrolysis–gasification unit, but its installed capacity of about 1 m^3/h means its contribution to total waste generation is still small.

The performance of TPST facilities in Indonesia has been studied extensively, usually with reference to technical operation, institutions, financing, regulation, and community participation. A study at TPST Batununggal Indah in Bandung found that a facility already equipped with several technologies still faced technical and non-technical operational problems [5]. In Cimahi City, community participation consistently emerged as a factor supporting the sustainability of TPST and TPS 3R facilities [6]. Most of these studies, however, are descriptive or perception-based. Quantitatively measured performance indicators have been applied to material recovery facilities (MRF), for example through productivity, process efficiency, and material recovery rate [7], or through flow modelling between separation units [8]. AlHumid et al. [9] went

further and developed an indicator-based performance model for municipal waste systems that covers technical, environmental, economic, and social aspects simultaneously.

Once performance is known, the next decision is which technology should be added. Waste technology choices almost always involve conflicting criteria: cost, capacity, emissions, and social acceptance rarely move in the same direction. For this reason, Multi-Criteria Decision Analysis (MCDA) is widely used to rank alternatives transparently [10]. Coban et al. [11] used MCDA to select a waste management scenario for Istanbul, Khan and Kabir [12] assessed the sustainability of waste-to-energy technologies in developing economies, and Torkayesh et al. [13] showed that pyrolysis and plasma perform well technically but poorly on economic and social grounds compared with anaerobic digestion. In Bantul Regency, an AHP–TOPSIS approach framed around energy justice placed incineration first [14]. These contrasting results confirm that technology rankings depend strongly on local context and on the criteria weights used.

Studies that combine quantitative performance evaluation, mass balance, and technology selection within one framework for a facility receiving mixed waste in a city without a landfill remain scarce. This study addresses that gap with three objectives: (1) to measure the performance of the Payakumbuh TPST using KPI; (2) to map its mass balance in order to locate the critical point of the process; and (3) to determine the most feasible combination of physical, biological, and thermal technologies for expanding the facility using MCDA with the Simple Additive Weighting (SAW) method. The results are intended to support planning by the city government and by other regions facing similar conditions.

II. METHODS

Study Site and Data Collection

The study was carried out at the Payakumbuh TPST, located in Padang Karambia and Kapalo Koto Ampangan sub-districts, South Payakumbuh District, on a 29,671 m^2 site. The facility receives mixed waste from a single collection vehicle. Waste is unloaded on the working floor, then manually sorted to remove high-value recyclables and items that could disturb the machines, passed through a bag opener, and mechanically separated by an auto sorter into a shredded organic fraction and an inorganic fraction. The low-value inorganic fraction is treated in a pyrolysis–gasification unit fitted with a cyclone.

This was a descriptive quantitative study. Primary data came from direct weighing over three operating days of the incoming waste, the material removed manually, the shredded organics, and the ash, together with records of machine running time and downtime. The weighing results were cross-checked against the facility's operating logs for the previous three months (October–December 2025). Environmental data were obtained from combustion-chamber temperature readings and 24 smoke opacity readings on the Ringelmann scale, while institutional, participation, and cost data were collected through semi-structured interviews with officials of the Payakumbuh Environmental Agency and with the operators. Secondary data included municipal waste composition and generation, facility planning documents, budget realisation for fuel, electricity, and operator wages, and equipment prices from the national e-catalogue.

Performance Evaluation Using Key Performance Indicators

The KPI framework consisted of five aspects and twelve indicators (Table 1). Technical indicators followed the MRF evaluation framework [7] and the municipal waste performance model [9], while scoring parameters and aspect weights were adapted from the technical guideline for TPS 3R facilities [15], Minister of Public Works Regulation No. 03/PRT/M/2013, and the Indonesian national standard for incinerators SNI 8423:2023 [16]. Because the facility is fully government-operated, the regulatory aspect in the guideline was replaced with an environmental aspect weighted at 5%. Each indicator was scored 1, 3, or 5.

Table 1. Structure of the KPI framework, scoring parameters, and aspect weights

Aspect (weight)	Indicator	Score 5	Score 3	Score 1
Technical operation (30%)	Productivity	>80% of target	60–80% of target	<60% of target
	Process efficiency	>80% of target time	60–80% of target time	<60% of target time
	Recycling ratio	>70% of input	60–70%	<60%
	Residue ratio	<30% of input	30–40%	>40%

Aspect (weight)	Indicator	Score 5	Score 3	Score 1
Environment (5%)	Emissions	Stable >800 °C; opacity ≤20%	Unstable; opacity 20–40%	Unstable; opacity >40%
	Air pollution control	>1 device and periodic testing	1 device, no testing	No device
Institutions (30%)	Type of institution	Public service agency	Technical unit	Agency department
	Organisational structure	Complete and active	Incomplete	None
	Human resources	Competent, sufficient	Competent, insufficient	Less competent, insufficient
	Administration	Good records	Records kept, poorly	No records
Community participation (20%)	Source separation	All households	Some households	Almost none
Financing (15%)	Treatment cost per tonne	<IDR 300,000	IDR 300,000–500,000	>IDR 500,000

Technical indicators were calculated using Equations (1) to (4). The daily processing target was obtained by multiplying the measured hourly capacity of the equipment by an operating time of 6 h/day.

$$\text{Productivity (\%)} = (\text{waste processed} / \text{processing target}) \times 100 \quad (1)$$

$$\text{Process efficiency (\%)} = (\text{machine running time} / \text{target operating time}) \times 100 \quad (2)$$

$$\text{Recycling ratio (\%)} = [(\text{shredded organics} + \text{high-value inorganics}) / \text{waste input}] \times 100 \quad (3)$$

$$\text{Residue ratio (\%)} = [(M_{input} - M_{recycled} - M_{untreatable}) / M_{input}] \times 100 \quad (4)$$

The indicator score was the parameter value multiplied by the aspect weight and divided by the number of indicators in that aspect; the aspect value was the sum of its indicator scores, and the overall KPI score was the sum of aspect values divided by five. The achievement of each aspect was expressed as a percentage of its maximum value and classified as very good (≥80%), good (60–<80%), fair (40–<60%), poor (20–<40%), or very poor (<20%).

Mass Balance Analysis

The mass balance followed the principle of material flow analysis, in which the mass entering a system equals the mass leaving it plus any change in stock [17]. The system boundary covered waste reception, manual sorting, mechanical sorting, and the thermal unit. Outputs comprised high-value inorganics (O_1), untreatable glass, hazardous, or special items (O_2), shredded organics (O_3), ash (O_4), and mass released as gas and water vapour from the thermal unit (O_5), giving Equation (5). O_5 was calculated by difference because it was not measured directly.

$$M_{in} = M_{O1} + M_{O2} + M_{O3} + M_{O4} + M_{O5} \quad (5)$$

Technology Selection Using MCDA–SAW

The additional capacity required was calculated as the difference between the waste delivered to the TPST area and the optimum capacity of the existing facility under a two-shift scenario (12 h/day). This requirement was then allocated to sorting, composting, and residue treatment according to the mass balance proportions. Based on a municipal waste composition dominated by food waste (48.25%), plastics (17.47%), and paper (15.45%), five technology combinations were defined. All alternatives share the same mechanical sorting package (hopper, bag opener, sorting conveyor, feeder conveyor, and sorting machine) but differ in the biological and residue treatment units: A1 (open windrow + pyrolysis–gasification), A2 (rotary kiln composter + pyrolysis–gasification), A3 (rotary kiln composter + plastic melting and paving block moulding), A4 (rotary kiln composter + incinerator), and A5 (rotary kiln composter + RDF).

Nine criteria were adapted from a sustainability framework for waste technologies [13] and grouped into economic, technical, environmental, and social aspects (Table 2). Criteria weights were set by four academics specialising in solid waste management and air pollution using a 1–9 scale. Their judgements were aggregated with the geometric mean and then normalised so that the weights summed to one.

Table 2. Criteria used to assess the technology alternatives

Code	Criterion	Aspect	Type	What is assessed
C1	Investment cost	Economic	Cost	Total cost of equipment and facilities
C2	Operation and maintenance cost	Economic	Cost	Energy, labour, and maintenance cost per tonne
C3	Treatment capacity	Technical	Benefit	Ability to treat daily waste and to scale up

Code	Criterion	Aspect	Type	What is assessed
C4	Revenue potential	Technical	Benefit	Market value of the products
C5	Technology accessibility	Technical	Benefit	Spare-part availability and ease of operation
C6	Emissions	Environmental	Cost	Process characteristics and emission control
C7	Job creation	Social	Benefit	Skilled and unskilled job opportunities
C8	Public acceptance	Social	Benefit	Public perception of the technology
C9	Skilled labour requirement	Social	Cost	Level of special skills required of operators

Each alternative was scored on a 1–5 scale from three sources: technical study, literature, and the judgement of the four experts. For quantifiable criteria (investment and operating cost), technical-study scores were calculated with Equation (6) for benefit criteria and Equation (7) for cost criteria. Scores from the three sources were averaged arithmetically, normalised by dividing by five, and multiplied by the weights to obtain the final score of each alternative (Equation 8).

$$r_{ij} = (x_{ij} / x_{max}) \times 5 \quad (6)$$

$$r_{ij} = (x_{min} / x_{ij}) \times 5 \quad (7)$$

$$S_i = \Sigma\, w_j \cdot r_{ij} \quad (8)$$

The robustness of the ranking was tested through sensitivity analysis. The weights of the three most important criteria (C8, C6, and C2) were reduced by 10% in turn, while the other weights were increased proportionally so that their sum remained one.

III. RESULT AND DISCUSSION

Performance of the Existing Facility

The average amount of waste processed during the three weighing days was 708 kg/day, with wide daily variation (416–1,024 kg). The auto sorter ran for only 98.33 min/day, or 1.64 h/day, giving an actual equipment capacity of about 432 kg/h. With a 6 h/day operating target, the facility should be able to process 2,592 kg/day. The measurements and the score of each indicator are summarised in Table 3.

Table 3. Measured conditions and KPI scores of the Payakumbuh TPST

Aspect	Indicator	Measured condition	Score	Aspect achievement
Technical operation	Productivity	708 of 2,592 kg/day target (27.31%)	1	20% (poor)
	Process efficiency	1.64 of 6 h/day (27.31%)	1	
	Recycling ratio	333.34 kg/day (47.08%)	1	
	Residue ratio	368.33 kg/day (52.02%)	1	
Environment	Emissions	600–1,001 °C, unstable; mean opacity 39.17%	3	60% (good)
	Air pollution control	Cyclone only; never tested	3	
Institutions	Type of institution	Run directly by the agency	1	40% (fair)
	Organisational structure	No dedicated structure	1	
	Human resources	4 trained operators; at least 5 needed	3	
	Administration	Records kept, no weighbridge	3	
Community participation	Source separation	Incoming waste mostly mixed	1	20% (poor)
Financing	Cost per tonne	IDR 720,479/t	1	20% (poor)
Overall KPI score				**28% (poor)**

Productivity and process efficiency share the same value (27.31%) because both are compared with targets derived from the 6 h/day operating time. This equality is telling: the poor technical performance is caused less by small equipment capacity than by the short time the machines actually run. Field observation identified several causes. The bag opener did not work, so operators tore bags open by hand on the feeder conveyor; there was no dedicated picking conveyor for manual sorting; and the auto sorter frequently jammed on wet, oily, bulky, or long textile items. This agrees with the MRF evaluation by Mastellone et al. [7], who recommended improving the layout and sorting units as the main route to better facility performance.

The recycling ratio (47.08%) and residue ratio (52.02%) both fell into the lowest class. Much of the inorganic fraction could not be recovered because it was mixed and contaminated, and Payakumbuh has neither the technology nor an off-taker for low-value plastics. For comparison, the residue at TPST

Batununggal Indah in Bandung is only about 10% [5], showing that facilities with better upstream separation can cut their residue load considerably.

The environmental aspect was the only one rated good (60%), but this result must be read with care. The combustion chamber temperature fluctuated between 600 and 1,001 °C, and the reading was sometimes lost because of a faulty sensor. Opacity ranged from 20% to 80%, with a mean of 1.96 on the Ringelmann scale, equivalent to 39.17%, above the 20% limit used as reference. The temperature swings were caused by manual feeding: the feeder conveyor to the reactor was not used for fear that fire would spread to the belt, so the chamber door had to be opened each time waste was loaded. The inflow of cold air lowered the temperature and produced black smoke, particularly in the first five minutes of each burn. Because pollutant concentrations were not measured, the 60% score reflects only the visual character of the emissions and the presence of control equipment, not compliance with emission standards.

For institutions (40%), the TPST has no dedicated management unit and is still run directly by a division of the Environmental Agency. The four operators have completed an internship and training, but their number is below the minimum of five needed to staff every work point. Community participation (20%) was also low. Programmes for source-separation assistance, distribution of composter bags, training of motorised waste-cart workers, and separation instructions in schools are already running, yet in practice most households only set aside items that can be sold. Hutabarat and Mulyani [18] showed that separation behaviour depends strongly on residents' understanding, while Knickmeyer [19] highlighted convenience, feedback, and social norms as conditions for separation to last. This weak source separation is what shifts the burden of the TPST onto its machines.

Treatment costs from October to December 2025 amounted to IDR 46,929,120, or IDR 720,479 per tonne. About 86% of this was operator wages (IDR 40,428,000), while electricity and fuel accounted for only about 8% and 6%, respectively. This breakdown confirms that the high unit cost stems from the small volume processed rather than from excessive energy use. If operating time were extended to two shifts with ten operators, the capacity of the existing facility is projected to rise to 5.184 t/day at about IDR 278,683 per tonne, which falls into the best cost class of the KPI matrix. The overall evaluation is summarised in Fig. 1.

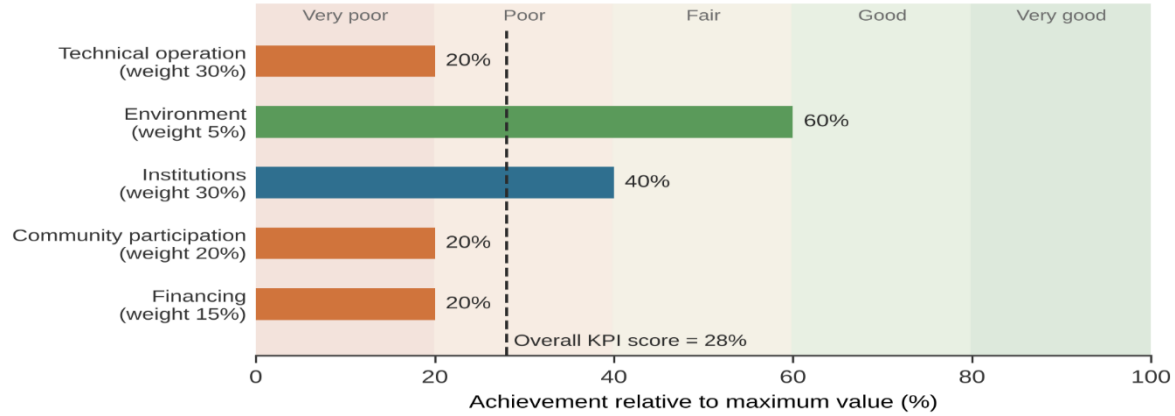


Fig. 1. Achievement of each KPI aspect against the performance classes and the overall score of the Payakumbuh TPST

Mass Balance and Process Bottleneck

The mass balance shows where waste goes after it enters the TPST (Table 4 and Fig. 2). Of the 708 kg/day received, manual sorting removed only 23 kg (3.25%), consisting of 16.67 kg of high-value inorganics and 6.33 kg of untreatable glass, hazardous, or special items. The remaining 685 kg (96.75%) had to pass through the auto sorter, which produced 316.67 kg of shredded organics and 368.33 kg of low-value inorganics, all of which were fed into the pyrolysis–gasification unit.

Table 4. Daily mass balance of the Payakumbuh TPST

Process unit	Input (kg/day)	Output	kg/day	% of input
Reception	708.00	—	—	100.00
Manual sorting	23.00	High-value inorganics (O_1)	16.67	2.35
		Glass/hazardous/special (O_2)	6.33	0.90

Process unit	Input (kg/day)	Output	kg/day	% of input
Mechanical sorting	685.00	Shredded organics (O_3)	316.67	44.73
		Low-value inorganics to thermal unit	368.33	52.02
Pyrolysis–gasification	368.33	Ash (O_4)	39.00	5.51
		Gas and water vapour (O_5)	329.33	46.51
Total system output		$O_1 + O_2 + O_3 + O_4 + O_5$	**708.00**	**100.00**

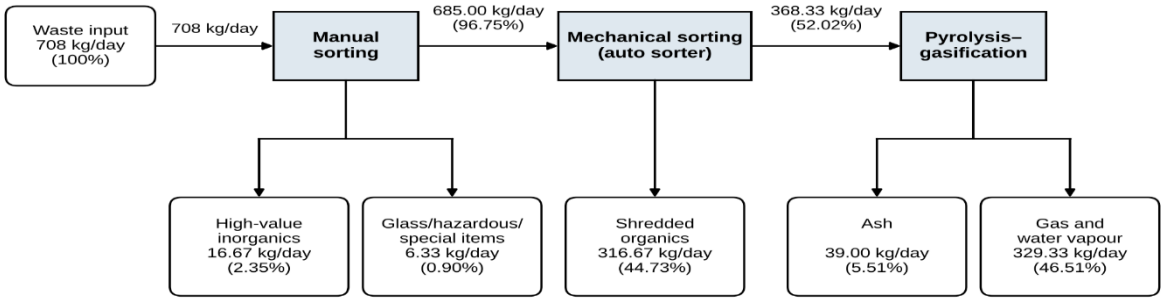


Fig. 2. Daily mass flow diagram of the Payakumbuh TPST

The measured solid outputs totalled only 378.67 kg/day, leaving a difference of 329.33 kg/day. This difference was treated as mass released from the thermal unit as gas and water vapour, since thermal decomposition converts most of the solid organic matter into gases and vapour. A small share of the difference may also come from moisture evaporation and transfer of fine particles during sorting, but this was not measured and is treated as measurement uncertainty. The thermal unit reduced its feed to only 10.59% ash and was therefore effective at shrinking the residue volume. From the standpoint of the waste hierarchy, however, relying on thermal treatment for more than half of the flow indicates that upstream material recovery is not working.

The critical point of the system therefore lies in the initial sorting stage. Weak sorting has three consequences at once: little valuable material is recovered, the pyrolysis–gasification unit is heavily loaded, and energy demand and costs rise. The same pattern has been reported at TPST Kebon Kongok in West Nusa Tenggara, which processes only about 30 t/day of its 120 t/day design capacity and still sends about 26 t/day of residue to landfill [20]. A material flow study in Biak Numfor likewise showed that residue can be brought below 10% only when strict source separation is applied and an RDF facility is added [21]. In the short term, the quickest gains would come from restoring the bag opener, cleaning and maintaining the auto sorter routinely, extending operation to two shifts, and fitting the thermal unit with a wet scrubber, an improved feeding system, and emission testing at least every six months. On the institutional side, establishing a regional technical unit for waste as a first step towards a public service agency, drafting standard operating procedures, and adding operators for each work point should proceed in parallel.

Capacity Requirement and Technology Alternatives

Waste delivered to the TPST area in 2024 averaged 76.63 t/day, whereas the optimum capacity of the existing facility with two shifts is only 5.184 t/day. The resulting gap of about 71.5 t/day must be closed by the expansion. Using the mass balance proportions, this translates into roughly 70 t/day of mechanical sorting, 32 t/day of composting, and 38 t/day of treatment for the low-value inorganic fraction.

The choice of composting unit is strongly influenced by land. An open windrow system for 32 t/day with a 50-day retention time and a shredded organic density of 312 kg/m^3 [22] requires 19 windrows and a total area of about 10,124 m^2 including the drying area. Rotary kiln composters of 2 t capacity with a 5-day retention time require 80 units and about 3,103 m^2 in total, roughly 30% of the windrow requirement. This difference agrees with the review by Lim et al. [23], who noted that in-vessel systems need far less land and time than windrows, although they cost more. Purwono et al. [24] even reported that a rotary kiln composter produced stable food-waste compost within three days without generating leachate. In theory both systems fit on the TPST site, but its sloping terrain and its history as a former dumping area make a smaller footprint a real advantage. The number of units and estimated investment of each alternative are summarised in Table 5.

Table 5. Configuration and estimated investment of the technology alternatives

Alternative	Organic treatment (32 t/day)	Low-value inorganic treatment (38 t/day)	Investment (IDR billion)
A1	Open windrow, 2 windrow turners, 8,624 m^2 area	Pyrolysis–gasification, 3 m^3/h and 5 m^3/h	40.08
A2	80 rotary kiln composters	Pyrolysis–gasification, 3 m^3/h and 5 m^3/h	22.30
A3	80 rotary kiln composters	21 plastic melting and paving block moulding machines	26.78
A4	80 rotary kiln composters	4 incinerators of 600–1,000 kg/h	24.05
A5	80 rotary kiln composters	2 RDF facilities of 50 t/day	44.85

Note: all alternatives include the same mechanical sorting package (IDR 2.81 billion) and a 1,500 m^2 compost drying area. Prices follow the national e-catalogue and exclude the TPST building.

Criteria Weights

The four experts produced fairly even weights, but with a clear order of priority (Fig. 3). Public acceptance (C8) received the highest weight (0.1309) and was the only criterion rated 9 by every expert. Emissions (C6) ranked second (0.1229), followed by operation and maintenance cost (C2, 0.1198) and treatment capacity (C3, 0.1193). Revenue potential (C4, 0.0866) and job creation (C7, 0.0828) occupied the two lowest positions. The widest spread of judgements was found for skilled labour requirement (C9), with scores from 5 to 9, indicating differing expert views on how much the limited local workforce should count.

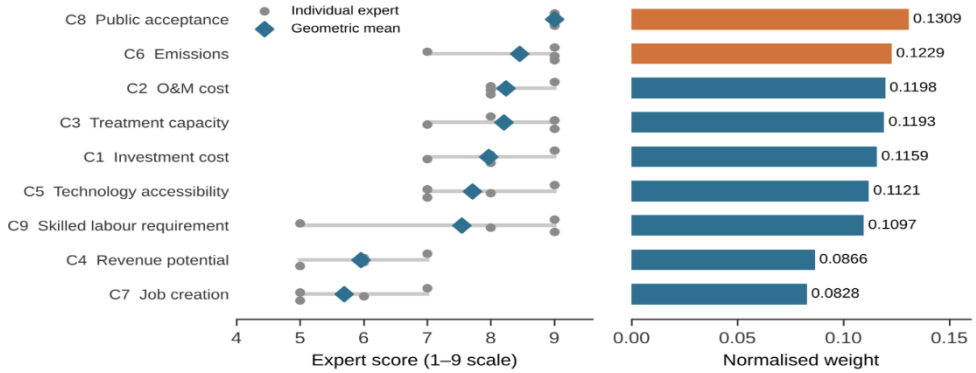


Fig. 3. Distribution of expert judgements, geometric mean, and normalised weight of each criterion

This weighting reflects the Payakumbuh context. Losing the landfill and seeing waste pile up across the city made social acceptance and air impacts appear more decisive for the success of a facility than the economic value of its products. A similar framework was used by Khan and Kabir [12] to assess waste-to-energy technologies in developing economies with technical, economic, environmental, and social criteria together, underscoring that the feasibility of a waste technology cannot be judged on financial grounds alone.

Ranking of Alternatives and Robustness

The normalised score matrix and the final score of each alternative are shown in Fig. 4. Alternative A5 achieved the highest score (0.7557), followed by A2 (0.7356), A1 (0.7073), A3 (0.6539), and A4 (0.6517). The advantage of A5 comes mainly from heavily weighted criteria: public acceptance (r = 0.97), treatment capacity (0.92), and emissions (0.72, the highest of the five alternatives). Its weakness is investment cost (0.46), because the RDF facility is the most expensive component of the package.

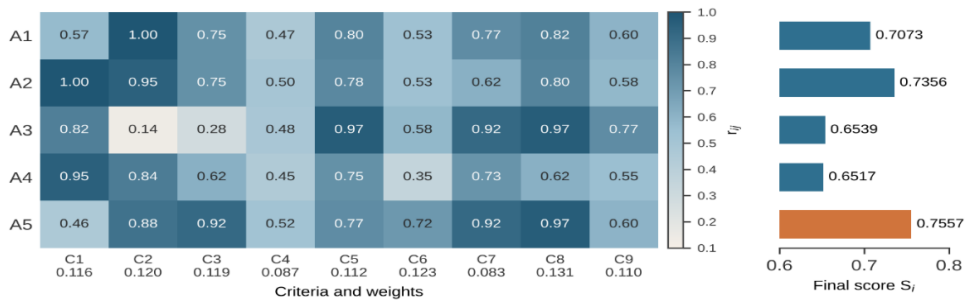


Fig. 4. Normalised score matrix (r_{ij}) and final SAW score of each alternative

A2 ranked second mainly because it has the lowest investment (r = 1.00) and a low pyrolysis–gasification operating cost based on data from the existing facility. However, its emission score is only moderate (0.53) and its skilled labour score is relatively low (0.58). A1 uses the same thermal unit but is held back by the high investment of the windrow system, owing to the large land and building area required. A3 is well accepted by the public and its technology is easy to access, but it has the highest operating cost (r = 0.14), and 21 melting machines still struggle to match the 38 t/day requirement. A4 received the lowest scores for emissions and public acceptance because incineration involves direct combustion with emissions released through a stack.

The results of the sensitivity analysis are presented in Table 6 and Fig. 5. When the weight of C8, C6, or C2 was reduced by 10%, the score of any alternative shifted by at most 0.0070. The order A5, A2, A1 did not change in any of the three scenarios, so the main recommendation can be regarded as robust. A change occurred only in the two lowest positions: A4 slightly overtook A3 when the weight of C8 or C6 was reduced, because the difference between their baseline scores was only 0.0022. In other words, A3 and A4 are practically equivalent and both less feasible than the other three alternatives.

Table 6. Final scores and ranks of the alternatives under baseline weights and sensitivity scenarios

Alternative	Baseline	C8 −10%	C6 −10%	C2 −10%
A1	0.7073 (3)	0.7056 (3)	0.7097 (3)	0.7033 (3)
A2	0.7356 (2)	0.7346 (2)	0.7384 (2)	0.7327 (2)
A3	0.6539 (4)	0.6492 (5)	0.6549 (5)	0.6609 (4)
A4	0.6517 (5)	0.6523 (4)	0.6560 (4)	0.6492 (5)
A5	**0.7557 (1)**	**0.7525 (1)**	**0.7562 (1)**	**0.7540 (1)**

Numbers in brackets indicate the rank.

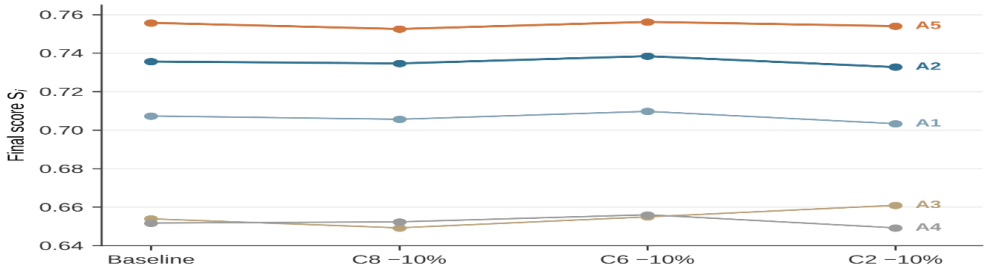


Fig. 5. Change in the final scores of the alternatives under three weight-reduction scenarios

The selection of the RDF route is consistent with several experiences in Indonesia. At the Piyungan landfill, operation of an RDF plant was estimated to reduce the waste entering the landfill by an average of 43% per year [25]. A study of the Cilacap RDF plant showed that biodrying lowered waste moisture from 55.44% to 23.63% with a calorific value of about 15 MJ/kg, although product quality still needed improvement to meet the industrial standard [26]. For this reason, only the low-value inorganic fraction is recommended for the RDF route, while the organic fraction is composted separately. RDF quality must also be controlled for ash, sulphur, and especially chlorine, since high chlorine content can disrupt cement kiln operation [27, 28]. The presence of PT Semen Padang in the same province offers an off-taker opportunity, given that the company already has an alternative fuel substitution target [29].

The RDF route nevertheless has its caveats. The investment for A5 reaches about IDR 44.85 billion, comprising IDR 2.81 billion for mechanical sorting, IDR 15.04 billion for the rotary kiln composting facility, and IDR 27.00 billion for two RDF facilities. Reported RDF operating costs range from IDR 210,765 to 503,000 per tonne, while its selling price is about IDR 300,000–414,000 per tonne and transport to the off-taker is estimated at IDR 112,500 per tonne of baled RDF. These ranges suggest that the operating margin may be thin or even negative, so a more detailed financial feasibility study is still needed before the investment is decided. Alternative A2, which consistently ranked second, can serve as a complementary system for residues that do not meet RDF requirements, particularly because the city has no landfill. Its use must be accompanied by emission control in line with SNI 8423:2023 [16] and adequate tar management, since tar formation is a common problem in the pyrolysis of mixed waste [30].

In terms of permitting, expanding the TPST to 71.5 t/day with technology A5 requires an environmental management and monitoring document (UKL-UPL) because the processes are physical and biological without combustion. The facility still needs technical approval for wastewater discharge because leachate can form during temporary storage, sorting, and composting. Technical approval for emissions would be required only if the pyrolysis–gasification unit is operated as a complement. Given the city's limited fiscal capacity, construction can be phased, with funding beyond the municipal budget such as national budget support for the RDF facility and partnerships with private parties for compost production.

IV. CONCLUSION

The performance of the Payakumbuh TPST is still poor, with a KPI score of 28%. The greatest weaknesses lie in technical operation, community participation, and financing, each reaching only 20%. Low productivity and efficiency (27.31%) are caused more by short machine running time than by limited equipment capacity, while the high treatment cost (IDR 720,479/t) is driven by the small volume processed. The mass balance identifies initial sorting as the critical point: only 3.25% of the waste is removed manually, so 52.02% of the flow depends on the pyrolysis–gasification unit.

To close the capacity gap of about 71.5 t/day, the combination of mechanical sorting, rotary kiln composting, and conversion of low-value inorganic waste into RDF (A5) is the best alternative, with a score of 0.7557. The three highest ranks remained stable in all sensitivity scenarios, whereas the two lowest swapped places because their scores were nearly identical. Pyrolysis–gasification (A2) is worth retaining as a complementary system for residues that cannot enter the RDF route, provided emissions are strictly controlled. Further research should use operating data over a longer period, measure emission concentrations directly, and assess the financial feasibility of the selected alternative using indicators such as net present value, internal rate of return, and payback period.

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