



Technical Capacity Gap against Regional Waste Strategy Targets in Musi Rawas Regency, Indonesia

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SUBMITTED: 8 September 2026; REVISED: 17 September 2026; ACCEPTED: 20 September 2026

ABSTRACT: Waste management at the regency level is determined not only by the availability of regulations and infrastructure but also by the alignment among waste generation, transport capacity, processing capacity, and policy targets. This study evaluated the technical capacity gap in the waste management system of Musi Rawas Regency against the 2025 Regional Waste Management Policy and Strategy (Jakstrada) targets using a quantitative evaluative approach based on secondary data. Population data for 2020–2025 were used to estimate waste generation through sensitivity analysis using coefficients of 0.30, 0.35, and 0.40 kg/capita/day. The estimates were then compared with the vehicle fleet inventory, daily collection trips, 3R Waste Processing Facilities (TPS 3R), human resources, service routes, and the Jakstrada targets of 30% waste reduction and 70% waste handling. The population increased from 395,570 in 2020 to 415,744 in 2025. Under the moderate scenario, waste generation in 2025 was estimated at 145.51 t/day. The nominal capacity of seven active dump trucks completing a total of eight trips per day was 40 t/day, equivalent to 27.49% of the estimated waste generation and only 39.27% of the capacity required to meet the 70% handling target. This resulted in a nominal capacity gap of 61.86 t/day. Three of the four TPS 3R units were active, but their recorded throughput was only approximately 0.79 t/day, compared with an active design capacity of 4 t/day. The results indicated that regulatory readiness had not yet been fully supported by adequate technical capacity and facility utilization. Based on the identified gaps, the most appropriate policy measures included strengthening tonnage-based operational records, optimizing collection routes and trip frequencies, revitalizing TPS 3R facilities, integrating waste banks into the waste management system, expanding decentralized organic waste treatment, and upgrading final disposal standards.

KEYWORDS: Jakstrada; collection fleet; TPS 3R; resource recovery; policy implementation

1. Introduction

Growth in waste generation was a direct consequence of demographic change, consumption patterns, urbanization, and intensifying economic activity. However, the challenge faced by

local governments was not merely the increasing quantity of waste but also the capacity of the system to collect, transport, process, recover resources from, and safely manage residual waste. Global analyses showed that the quality of waste management services often lagged behind the expansion of service coverage, particularly in areas with lower socioeconomic and institutional capacity [1]. Studies in developing countries likewise emphasized that institutional limitations, inadequate financing, constrained technical capacity, and inconsistent implementation were major reasons why waste management systems failed to achieve the expected environmental outcomes despite the existence of formal policy instruments [2, 3]. Accordingly, waste-system evaluation needed to distinguish among policy availability, asset availability, nominal capacity, and actual operational performance.

These challenges became more complex at the regency level. Compared with relatively compact cities, regencies generally had more dispersed settlements and activity centers, longer transport distances, lower waste-generation densities, and more limited fiscal capacity. Studies of small cities and municipalities indicated that sustainable waste management was simultaneously influenced by technical solutions, regulations, financial resources, human-resource capacity, information systems, and the engagement of the private sector and communities [4]. Recent governance perspectives further emphasized that regulatory quality did not automatically lead to effective implementation unless monitoring, coordination, financing, and operational accountability developed in parallel [5–7]. This framework was particularly relevant to regencies that already had relatively comprehensive regulations but continued to face infrastructure and service constraints.

From an operational perspective, collection and transportation represented critical components of the waste management system because they consumed recurrent resources and connected waste sources with processing facilities and final disposal sites. Recent studies showed that increasing the number of vehicles was not the only approach to improving operational performance. Dynamic route optimization, the use of spatial data, container-capacity monitoring, and improved trip scheduling could reduce travel distances, fuel consumption, and operating time [8–13]. Fleet capacity therefore needed to be interpreted in conjunction with trip frequency, actual payload, route distance, cycle time, vehicle downtime, and service area. Assessing nominal capacity without corresponding throughput data could provide an overly optimistic representation of actual system capability.

At the upstream end of the system, the waste management paradigm increasingly shifted from a collect–transport–dispose approach toward prevention, source separation, reuse, recycling, and resource recovery within a circular-economy framework. Studies in developing countries identified decentralized organic-waste treatment, stronger recycling systems, and the integration of community-scale facilities as mechanisms for reducing transportation burdens and dependence on final disposal sites [14–19]. Reddy et al. [20] demonstrated the importance of combining centralized and decentralized facilities so that waste management systems could respond effectively to spatial characteristics and waste volumes. In Indonesia, strengthening the recycling industry, waste banks, digitalization, and circular-economy practices was increasingly regarded as an integral component of the waste management system rather than as a set of stand-alone supplementary activities [21–24].

Musi Rawas Regency had a relatively adequate policy foundation. Musi Rawas Regent Regulation No. 66 of 2018 established the Regional Waste Management Policy and Strategy (Jakstrada), with 2025 targets of a 30% reduction in household and household-like waste and

70% waste handling [25]. Musi Rawas Regency Regulation No. 3 of 2021 regulated waste management activities from sorting, collection, and transportation to processing and final disposal [26], while Regent Regulation No. 30 of 2023 assigned these functions to the Waste and Hazardous and Toxic Waste Management Division of the Environmental Agency (DLH) [27]. This regulatory framework was complemented by standard operating procedures for waste transportation and service-fee collection [28], as well as regional tax and service-fee provisions [29, 30]. Therefore, an institutional foundation for waste management had already been established. The scientific question consequently shifted from whether policies existed to the extent to which the available technical capacity was sufficient to support the stated policy targets.

A recent study in Musi Rawas by Laszuardy et al. [31] examined environmentally based waste management strategies through interviews, observations, and document reviews. This approach was important for understanding stakeholder perceptions and implementation challenges, but it did not specifically quantify the gap among estimated waste generation, transport capacity, processing capacity, and Jakstrada targets. International studies likewise highlighted the need to integrate governance indicators with technical performance indicators so that evaluations did not stop at assessing the existence of regulations or programs [32, 33]. Moreover, circular-economy frameworks required clearer measurements of material flows, recovery capacity, and dependence on final disposal [34–36]. Unlike previous Indonesian waste management studies that primarily evaluated stakeholder perceptions, institutional arrangements, or the performance of individual facilities, this study integrated demand estimation, nominal collection capacity, facility throughput, and statutory reduction and handling targets within a single auditable policy-capacity framework. The novelty of this study therefore lay in translating the Jakstrada percentage targets into daily tonnage requirements and identifying the operational variables that needed to be measured before infrastructure expansion could be justified.

Based on this research gap, the present study used official secondary data to construct a quantitative evaluation of both service demand and service capacity. The demand side was represented by population-based estimates of waste generation, whereas the capacity side was represented by the vehicle fleet, daily collection trips, TPS 3R facilities, processing facilities, human resources, and service-route patterns. Both components were evaluated against the Jakstrada targets of 30% waste reduction and 70% waste handling. The study aimed to (1) estimate changes in waste generation from 2020 to 2025 through sensitivity analysis; (2) calculate nominal transport capacity and processing-facility utilization; (3) quantify the technical capacity gap relative to the 2025 Jakstrada targets; and (4) formulate a sequence of managerial interventions based on measurable capacity gaps. The study contributed a quantitative evaluation framework that could be replicated by regency governments where direct weighing data, waste-composition studies, and household surveys were not yet comprehensively available. Importantly, the framework distinguished four quantities that were often conflated in administrative reporting: estimated waste generation, nominal engineering capacity, measured throughput, and policy-target achievement. This distinction provided a transparent and reproducible diagnostic framework for evaluating waste management systems in data-limited regencies.

2. Materials and Methods

2.1. Study Design and Data Sources.

This study employed a quantitative evaluative design based on secondary data, with the waste management system of Musi Rawas Regency as the unit of analysis. The analytical framework was developed in three stages. First, service demand was estimated using population-based waste generation calculations. Second, service capacity was evaluated based on the vehicle fleet, trip frequency, processing facilities, human resources, and operational routes. Third, estimated demand and available capacity were compared with the policy benchmarks established by the 2025 Regional Waste Management Policy and Strategy (Jakstrada). The approach was not intended to provide a complete mass-balance assessment or replace direct field measurements. Rather, it was designed to determine whether the administratively recorded technical capacity was sufficient to support the stated policy targets.

The primary administrative data consisted of official documents obtained from local government institutions. These included population data for 2020–2025 from Statistics Indonesia (BPS) and the Indonesia Population Projections 2020–2050 based on the 2020 Population Census [37]; the 2025 Environmental Agency (DLH) inventory of waste collection vehicles and heavy equipment; the 2025 DLH list of waste management personnel; waste management facility data for 2025; the collection-route schedule for 22 June–4 July 2026; and relevant regional regulations and operational documents [25–30]. The regulatory documents included the Jakstrada Regent Regulation, Waste Management Regional Regulation, Regent Regulation concerning the organizational structure of DLH, Regional Regulation on taxes and service fees, Regent Regulation on waste service fees, and standard operating procedures of the Waste and Hazardous and Toxic Waste Management Division.

Data validation was conducted through cross-document triangulation using four reproducible checks. First, vehicle counts, payload capacities, and operational status reported in the asset inventory were compared with vehicle assignments recorded in the collection-route schedule. Second, personnel categories were examined against organizational functions and standard operating procedures. Third, facility operational status and design capacity were distinguished from recorded throughput to avoid interpreting installed capacity as actual performance. Fourth, all policy percentages were independently converted into daily tonnage requirements using the same 2025 waste generation scenarios. When documents differed in their time basis, definitions, or measurement units, the values were not combined. Instead, these discrepancies were retained and reported as sources of uncertainty or study limitations. International literature published between 2023 and 2026 was used as an interpretive and conceptual benchmark rather than as a substitute for local data.

2.2. Estimation of Waste Generation.

Waste generation was estimated using a population-based approach because the available dataset did not contain representative daily weighing data for the entire regency. This approach was consistent with the application of per-capita waste generation factors as preliminary estimates under data-limited conditions, provided that uncertainty associated with the selected coefficients was explicitly acknowledged. Rather than applying a single coefficient as an absolute value, three sensitivity scenarios were used: 0.30 kg/capita/day for the low scenario, 0.35 kg/capita/day for the moderate scenario, and 0.40 kg/capita/day for the high scenario. The

sensitivity analysis was conducted to ensure that the conclusions did not depend on a single assumed coefficient and to determine how changes in the waste generation factor affected the estimated capacity gap.

The coefficient range was selected to represent plausible conditions in small towns and regencies rather than to establish a universal Indonesian waste generation factor. Direct measurements in rural Gunungkidul Regency reported an average waste generation rate of approximately 0.29 kg/capita/day [38], supporting the use of 0.30 kg/capita/day as a defensible lower-bound scenario. The coefficients of 0.35 and 0.40 kg/capita/day were applied as progressively higher planning assumptions to account for uncertainty associated with differences in settlement density, household income, commercial activity, consumption patterns, seasonal variation, and the inclusion of household-like waste. Daily waste generation was calculated using Eq. (1):

$$Q = \frac{P \times q}{1,000} \quad (1)$$

where Q represented estimated waste generation (t/day), P represented the population (persons), and q represented the waste generation coefficient (kg/capita/day). Annual waste generation was subsequently calculated by multiplying Q by 365. The moderate scenario of 0.35 kg/capita/day was used as the reference scenario for the main analysis, while the low and high scenarios were retained to evaluate the robustness of the findings.

Uncertainty in Q varied linearly with q . A change of ± 0.05 kg/capita/day in the coefficient changed the estimated 2025 waste generation by approximately ± 20.79 t/day. However, the sensitivity scenarios did not account for uncertainty associated with population projections, waste composition, unregistered commercial waste, or temporal variations in waste generation. Therefore, the resulting estimates and capacity gaps were interpreted as planning ranges rather than direct measurements.

2.3. Technical Capacity Indicators.

Transport capacity was calculated by multiplying the nominal vehicle payload by the recorded number of daily trips. According to the DLH inventory, seven active dump trucks had a nominal payload capacity of 5 t each and collectively completed eight trips per day, resulting in a maximum nominal transport capacity of 40 t/day. This value was treated as an upper-bound engineering proxy rather than actual transported tonnage because data on net payload per trip, vehicle load factors, cycle times, travel distances, and vehicle downtime were unavailable. This distinction was important because transport optimization studies demonstrated that vehicles with identical nominal capacities could produce substantially different actual throughput depending on route configuration, demand, service time, and fleet utilization [8, 10, 12].

The technical assessment included five principal indicators: fleet availability rate, ratio of nominal transport capacity to estimated waste generation, required handling capacity, capacity adequacy relative to the handling target, and nominal capacity gap. Fleet availability was calculated as the number of active vehicles divided by the total number of available vehicles and multiplied by 100%. The ratio of nominal transport capacity to estimated waste generation was calculated by dividing nominal transport capacity by Q and multiplying by

100%. Required handling capacity was calculated as 70% of Q , while capacity adequacy was determined by dividing nominal transport capacity by the required handling capacity and multiplying by 100%. The capacity gap was calculated as the difference between nominal transport capacity and the required handling capacity. A negative value indicated that the available nominal transport capacity remained below the theoretical capacity required to meet the 70% handling target.

For TPS 3R facilities, the proportion of active units and throughput utilization were also calculated. Throughput utilization was determined by dividing the recorded quantity of waste processed by the active design capacity and multiplying the result by 100%. Transport capacity was not interpreted as equivalent to actual waste handling performance because the policy definition of waste handling encompassed a broader sequence of activities than transportation alone. The 70% handling target was converted into a daily tonnage requirement using Eq. (2):

$$H_{70} = 0.70Q \quad (2)$$

where H_{70} represented the daily waste handling requirement. Similarly, the 30% waste reduction target was calculated using Eq. (3):

$$R_{30} = 0.30Q \quad (3)$$

where R_{30} represented the daily waste reduction requirement.

For the moderate 2025 scenario, with Q estimated at 145.51 t/day, the required handling capacity was 101.86 t/day, while the required reduction volume was 43.65 t/day. Based on the nominal transport capacity of 40 t/day, transport capacity adequacy was calculated at 39.27%, with a nominal handling capacity gap of -61.86 t/day. Recorded TPS 3R throughput of 0.79 t/day represented 1.81% of the calculated 30% reduction requirement. However, this percentage was interpreted only as a partial indicator because Jakstrada waste reduction could also occur through waste banks, household composting, producer responsibility programs, reuse, recycling, and informal-sector resource recovery.

2.4. Policy Analysis and Validation.

Policy analysis was conducted using a policy–capacity gap approach in which the numerical Jakstrada targets were compared with the technical capacity derived from administrative records. The analytical framework comprised four domains: regulation and governance, collection and transportation, waste reduction and processing, and final disposal. This structure enabled the assessment to distinguish between regulatory readiness and operational capacity. The local findings were subsequently interpreted using 30 peer-reviewed international journal articles published between 2023 and 2026 that addressed waste management systems in developing countries, governance, fleet optimization, decentralized treatment, waste banks, and circular economy practices. The literature was used to interpret mechanisms that could explain the identified capacity gaps, while recommendations for Musi Rawas Regency were derived only from deficiencies supported by the local administrative data. The overall analytical procedure is summarized in Figure 1. Population data were first converted into low, moderate, and high waste generation scenarios. These estimates were then compared with

recorded transport and processing capacities and converted Jakstrada targets. The resulting capacity and utilization gaps provided the quantitative basis for identifying management priorities and formulating operational interventions.

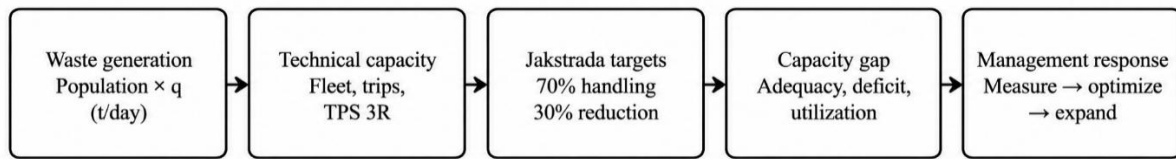


Figure 1. Conceptual and Methodological Flow Used to Translate Estimated Waste Generation Into Technical-Capacity Gaps and Management Interventions.

3. Results and Discussion

3.1. Population Trends and Estimated Waste Generation.

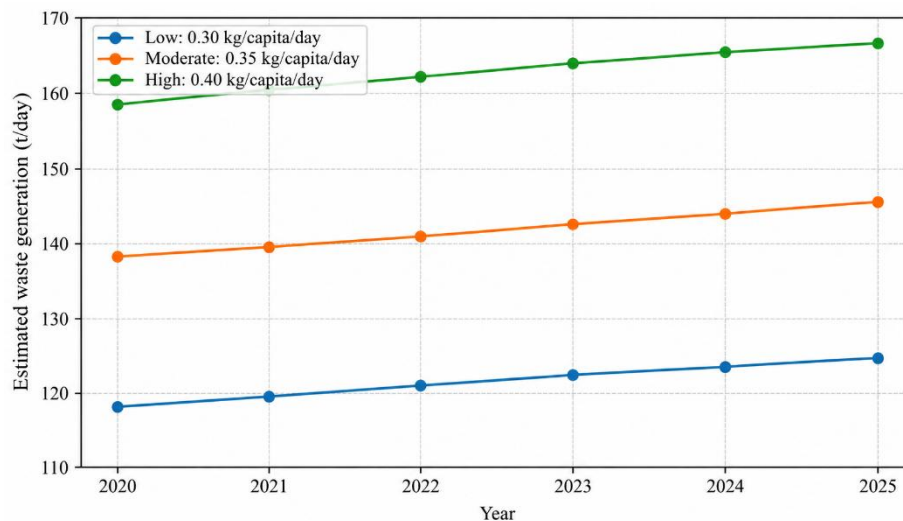
The population of Musi Rawas Regency increased consistently from 395,570 in 2020 to 415,744 in 2025, representing an absolute increase of 20,174 people or 5.10% over the five-year period. This change corresponded to a compound annual growth rate of approximately 1.00%. Although population growth alone did not indicate changes in household consumption patterns or per-capita waste generation, it increased the population base contributing to the municipal waste stream. Consequently, even when the per-capita waste generation coefficient was held constant, the quantity of waste requiring collection, processing, recovery, or final disposal increased over time. Velis et al. [1] showed that socioeconomic development and improvements in waste management performance did not necessarily occur at the same rate, emphasizing the need to align service capacity with increasing material flows. Similarly, Zhang et al. [3] reported that increasing waste generation without corresponding improvements in infrastructure, monitoring, and processing capacity could increase pressure on final disposal systems.

The effect of population growth on estimated waste generation is presented in Table 1. Across all three scenarios, estimated waste generation increased progressively between 2020 and 2025. Under the low-generation scenario of 0.30 kg/capita/day, estimated waste generation increased from 118.67 t/day in 2020 to 124.72 t/day in 2025. Under the moderate scenario of 0.35 kg/capita/day, it increased from 138.45 to 145.51 t/day, while under the high scenario of 0.40 kg/capita/day, it increased from 158.23 to 166.30 t/day. These results indicated that demographic growth alone produced a gradual increase in the waste load that needed to be accommodated by the existing waste management system. Under the moderate scenario, estimated waste generation increased by approximately 7.06 t/day between 2020 and 2025, equivalent to an additional 2,577 t/year. This increase was directly attributable to population growth because the per-capita coefficient remained constant within each scenario. However, a more important finding emerged from the sensitivity analysis. As shown in Table 1 and Figure 2, the estimated waste generation for 2025 ranged from 124.72 t/day under the low scenario to 166.30 t/day under the high scenario, producing a difference of 41.58 t/day. This range was substantially larger than the 7.06 t/day increase associated with population growth under the moderate scenario between 2020 and 2025. Thus, uncertainty in the assumed per-capita waste generation coefficient had a greater influence on the estimated waste load than the demographic increase observed during the study period.

Table 1. Population Trends and Estimated Waste Generation in Musi Rawas Regency, 2020–2025.

Year	Population (persons)	0.30 kg/capita/day (t/day)	0.35 kg/capita/day (t/day)	0.40 kg/capita/day (t/day)
2020	395,570	118.67	138.45	158.23
2021	399,094	119.73	139.68	159.64
2022	403,466	121.04	141.21	161.39
2023	407,694	122.31	142.69	163.08
2024	411,787	123.54	144.13	164.71
2025	415,744	124.72	145.51	166.30

Figure 2 further illustrates that all three scenarios followed similar upward trajectories because population was the common underlying variable, while the separation among the lines reflected differences in the assumed per-capita generation coefficients. The moderate scenario remained between the low and high estimates throughout the study period and was therefore retained as the reference scenario for subsequent capacity analysis. For 2025, the moderate estimate of 145.51 t/day corresponded to approximately 53,111 t/year. This value should not be interpreted as measured waste generation but as a planning estimate against which the adequacy of existing transport and processing capacity could be evaluated.

**Figure 2.** Estimated Waste Generation in Musi Rawas Regency, 2020–2025, Under Three Coefficient Scenarios.

The relatively wide interval between the low and high scenarios also demonstrated the importance of improving primary waste data. Previous study [38] showed that governance arrangements and data quality could influence the interpretation of waste generation and service performance, while Fernando and Zutshi [2] identified information systems as an important component of institutional improvement in waste management. In the present study, relying exclusively on the moderate estimate without sensitivity analysis could have created a false impression of precision. The scenario-based approach instead provided a range within which transport, processing, and policy capacity could be evaluated under different plausible levels of waste generation.

From a planning perspective, these results also indicated that future capacity assessments should not rely solely on population projections. Periodic weighing and waste characterization would allow the assumed generation coefficients to be replaced with locally measured values and would help distinguish demographic effects from changes associated with consumption patterns, commercial activity, seasonal variation, and waste composition. Therefore, the

population-based estimates presented in Table 1 and Figure 2 served as a transparent baseline for the subsequent assessment of transport capacity, processing-facility utilization, and the capacity required to achieve the 2025 Jakstrada targets, rather than as a substitute for direct waste-generation measurements.

3.2. Fleet Condition and Transport Capacity.

The 2025 DLH inventory recorded eight dump trucks, consisting of seven active units and one unit in severely damaged condition, resulting in an availability rate of 87.5% for the main collection fleet. All dump trucks had a nominal payload of 5 t (Table 2). Trip records showed that six vehicles made one trip per day and one vehicle made two trips per day, producing an aggregate total of eight trips per day. From an asset perspective, the 87.5% availability rate appeared high because most vehicles could be operated. However, availability was not equivalent to productivity. Productivity was also influenced by load factor, the spatial distribution of waste generation points, route length, loading and unloading times, queues at the final disposal site, road conditions, and the alignment of schedules with waste generation patterns. Recent waste transport studies showed that route and vehicle allocation improvements could increase service coverage without a proportional increase in fleet size [8–10].

Table 2. Summary of Waste Collection Vehicles and Heavy Equipment in 2025.

Component	Total	Active	Capacity/trip	Remarks
Dump truck	8 units	7 units	5 t	1 unit severely damaged; total of 8 trips/day
Three-wheeled vehicle	3 units	2 units	300 kg	1 unit inactive
Excavator	1 unit	1 unit	0.93 m ³	Active
Mini excavator	1 unit	1 unit	0.25 m ³	Active
Bulldozer	1 unit	1 unit	4.28 m ³	Active
Arm-roll truck	0	0	–	Not available

Assuming that each trip carried a full 5 t load, the nominal dump-truck transport capacity was 40 t/day. This was equivalent to 32.07% of estimated generation under the low scenario, 27.49% under the moderate scenario, and 24.05% under the high scenario. These ratios were not described as the “waste-handling rate” because vehicle capacity was only one component of handling and did not account for the actual weight transported on each trip. Instead, the contrast between high fleet availability and the low ratio of capacity to estimated generation suggested a potential structural bottleneck: trip frequency and total system capacity had not increased in proportion to the volume requiring service. Petchrompo et al. [11] showed that operational data could support more efficient collection schedules, while Ghoreishi et al. [12] emphasized the importance of evaluating fleet utilization and fleet structure together. For Musi Rawas, additional vehicle decisions should therefore have been evaluated only after data on weight per trip, kilometers traveled, cycle time, and load factor became available, allowing optimization of the existing system to be compared with new investment options.

The distinction between nominal and realized capacity was therefore central. Nominal capacity assumed a full payload on every recorded trip and uninterrupted operation, whereas actual collection depended on average load factor, cancelled trips, loading time, route length, queuing, vehicle downtime, and the fraction of generated waste located within the formal service area. In practical terms, a fleet could appear adequate in an asset register while delivering much lower tonnage because the reported capacity represented engineering potential rather than measured throughput.

3.3. Gap Relative to the 70% Waste-Handling Target.

The Jakstrada waste-handling target of 70% implied required handling volumes of approximately 87.31 t/day under the low scenario, 101.86 t/day under the moderate scenario, and 116.41 t/day under the high scenario. When the nominal transport capacity of 40 t/day was used as an upper-bound proxy, capacity adequacy relative to the target volume was only 45.82%, 39.27%, and 34.36%, respectively. The resulting nominal gap ranged from 47.31 to 76.41 t/day; under the moderate scenario, the gap was 61.86 t/day. Because 40 t/day was itself a theoretical maximum, the actual operational gap could have been larger if average vehicle loads were below capacity, vehicles were not operated every day, or cycle times limited the number of trips. These findings showed that achievement of the 70% policy target depended strongly on the ability to translate a macro-level target into specific and measurable daily capacity requirements (Table 3).

Table 3. Sensitivity Analysis Of The Transport-Capacity Gap Relative to the 2025 Jakstrada Target.

Scenario	Waste generation (t/day)	70% target (t/day)	Capacity/generation (%)	Capacity adequacy relative to 70% target (%)	Gap (t/day)
Low (0.30)	124.72	87.31	32.07	45.82	−47.31
Moderate (0.35)	145.51	101.86	27.49	39.27	−61.86
High (0.40)	166.30	116.41	24.05	34.36	−76.41

The operational schedule for 22 June–4 July 2026 showed that seven dump trucks were repeatedly allocated across six service routes and trips to the final disposal site. The existence of this schedule was an important management asset because the system already had an established pattern for assigning vehicles, drivers, and collection crews. However, the available information did not include the distance of each route, coordinates for all waste sources, travel time, stopping time, payload weight, fuel consumption, or the percentage of the population or households served. Without these variables, route efficiency could not be evaluated causally. The literature showed that dynamic routing could adapt vehicle deployment to changes in waste volume at collection points [8], IoT technologies could improve route decisions based on container-fill conditions [9], and GIS-based route optimization could reduce travel distance and fuel demand under certain configurations [10]. Moussavi et al. [13] further demonstrated that collection networks could be formulated as multi-criteria optimization problems. Thus, the most rational next step for Musi Rawas was not to alter schedules normatively without evidence but to build a route dataset that enabled objective optimization.

As an external triangulation source, Laszuardy et al. [31] reported approximately 19–21 t/day of collected waste under normal conditions. This figure was lower than the nominal 40 t/day capacity calculated from the asset inventory. The difference could not automatically be interpreted as inefficiency because the definitions, observation periods, and recording bases of the two values differed; nevertheless, it reinforced the need to distinguish theoretical capacity from actual throughput. Possible explanations included incomplete load factors, cycle-time constraints, long route distances, dispersed service points, operating-day limitations, downtime, and waste handled outside the formal system. From a management perspective, actual tonnage data by route would have been a key variable for determining whether the main bottleneck lay in fleet size, route configuration, trip productivity, or service coverage.

The approximately 19–21 t/day previously reported for Musi Rawas [31] corresponded to only about 48–53% of the 40 t/day nominal upper bound, illustrating why asset-based capacity should not have been used as a proxy for service achievement. This type of difference was consistent with collection-system evidence from developing-country settings, where nominal payload multiplied by maximum trips could substantially overstate actual collected mass when weighing and load-factor records were absent. Accordingly, the principal performance metrics for subsequent monitoring should have been measured tonnes per vehicle-trip and tonnes per route-day, rather than nominal tonnes per day alone.

3.4. Processing-facility Capacity and the 30% Waste-Reduction Target.

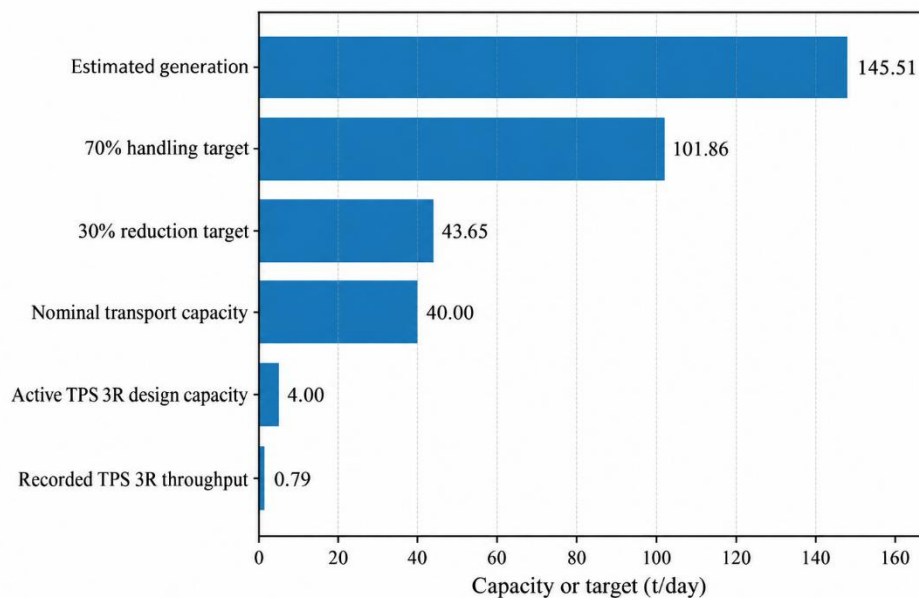
The 2025 facility inventory recorded four TPS 3R units. One unit procured in 2021 had a design capacity of 2 t/day, while three units procured in 2022 each had a design capacity of 1 t/day. Of the three units procured in 2022, two were active but not yet operating optimally, while one was inactive. The facility activity rate was therefore 75%, with an estimated active design capacity of approximately 4 t/day. A relatively high proportion of active units may create the impression that basic infrastructure is already available, but the more important indicator is the quantity of material actually sorted, processed, and diverted from final disposal. Literature on decentralized treatment emphasizes that the performance of community-scale facilities depends on source separation, stable feedstock supply, process control, product quality, and links to users or markets for recovered products, rather than on the mere existence of infrastructure [14, 15, 17].

Recorded throughput was approximately 670 kg/day at the 2021 unit and 60 kg/day at each of the two active 2022 TPS 3R units, producing a measured total of approximately 0.79 t/day. Compared with an active design capacity of 4 t/day, utilization was only about 19.75%. Under the moderate generation scenario, the 30% reduction target is equivalent to 43.65 t/day; recorded TPS 3R throughput represents only about 1.81% of the volume that would need to be diverted to meet that target. The 1.81% value is not the regency-wide waste-reduction achievement because data from waste banks, the informal sector, source separation, household composting, and producer activities are incomplete. Nevertheless, the substantial gap between design capacity and recorded throughput clearly indicates a utilization problem. Amato-Lourenço et al. [18] show that community-based composting can enhance sustainability when participation and operational governance are adequate, while Zhu et al. [19] demonstrate that decentralized performance should be assessed jointly in environmental and cost terms. The revitalization of TPS 3R facilities in Musi Rawas should therefore include audits of material flows, operator capacity, receiving schedules, sorting practices, product markets, and operating costs. Comparable Indonesian studies suggest that low diversion is not unique to Musi Rawas, although denominators and facility contexts differ. In Magelang, four active TPS 3R facilities processed approximately 2.29% of total municipal waste generation and overall service coverage remained limited. In Sleman Regency, analysis of 42 TPS 3R units found that facilities in urban areas were more consistently operational, whereas some rural facilities were inactive; accessibility, population density, managerial capacity, operator welfare, and operational financing were identified as important contextual factors [40]. These comparisons reinforce that infrastructure availability alone does not guarantee throughput (Table 4).

Table 4. Condition of Waste-Management Facilities in Musi Rawas Regency in 2025.

Facility	Number/status	Capacity/processed	Remarks
TPS 3R	4 units; 3 active	Active design capacity 4 t/day; recorded throughput 0.79 t/day	Active but not yet optimal; 1 unit inactive
TPST	Not available	–	Not available
Final disposal site (TPA)	1 active unit	Recorded capacity 61,540.61 t; recorded processed amount 13,140 t	Operational status: open dumping; period for processed amount not specified
Waste bank	2 active units	Capacity 100 kg/unit; recorded processed amount 25 kg/unit	Underperforming; time basis for processed amount not specified
Composting house	Not available	–	Not available
Recycling center	Not available	–	Not available
Biodigester	Not available	–	Not available

The facility data also showed that no integrated waste processing facility (TPST), composting house, recycling center, or biodigester was available, while two waste banks were active but underperforming. This situation left a relatively narrow range of processing options between the waste source and final disposal. As illustrated in Figure 3, the available technical and processing capacities remained substantially below the volumes associated with the 2025 Jakstrada targets, particularly when compared with the estimated waste generation under the moderate scenario.

**Figure 3.** Comparison of Moderate Waste Generation, Jakstrada Targets, and Key Technical Capacities in 2025.

Within a circular-economy framework, waste reduction did not simply require the addition of facilities; rather, it required the development of an integrated material network in which waste was separated at the source, waste banks aggregated valuable materials, TPS 3R facilities sorted and processed waste, recyclers absorbed recovered materials, and residual waste was transferred to final disposal. Studies in Indonesia indicated that waste banks had potential as nodes for community participation and resource recovery, but their performance varied across regencies and was influenced by governance, institutional arrangements, and market linkages [24]. Kurniawan et al. [21] emphasized the importance of strengthening the recycling industry and information technology, while Kurniawan et al. [23] and Wikurendra et al. [22] positioned digitalization and the circular economy as mechanisms for integrating

collection, resource recovery, and environmental mitigation. Musi Rawas therefore needed to transform these facilities from separate operational units into an integrated waste-reduction service chain.

As further reflected in Figure 3, the low utilization of existing processing capacity represented an additional constraint beyond the availability of infrastructure itself. For Musi Rawas, the 19.75% utilization level could plausibly have resulted from interacting constraints across four domains that should be examined during the proposed operational audit: technical factors, including equipment condition, sorting layout, power and fuel availability, and unsuitable processing technology; operational factors, including irregular feedstock, limited operating hours, weak source separation, residual contamination, and maintenance downtime; institutional and financial factors, including operator incentives, budget continuity, recordkeeping, market contracts, and coordination between DLH and community operators; and community and market factors, including household participation, willingness to separate waste, collection reliability, and demand and prices for compost and recyclable materials. These mechanisms were presented as testable explanations rather than causal findings because the secondary-data design of the present study did not directly observe them.

3.5. Human Resources and Institutional Readiness.

The 2025 human-resources dataset recorded 43 waste-management personnel. Approximately 30 employees (69.77%) were involved in field operations, including seven drivers, 14 collection assistants, two heavy-equipment operators, one final-disposal-site supervisor, two security officers, and four final-disposal-site cleaning workers; the remainder performed management, administrative, and service-fee functions. This structure indicates that most personnel are allocated to downstream operations, particularly transportation and final disposal. Such a composition is understandable for a system still centered on collect–transport–dispose practices, but a transition toward 3R requires additional competencies in source separation, organic-waste treatment, facility management, material-flow recording, marketing of recovered products, route analysis, and performance control. Kadhila et al. [4] explicitly identify human-resource and information capacity as prerequisites for sustainable systems, while Filimonova and Birchall [6] likewise show that local institutional capacity can remain a constraint even when environmental objectives are formally recognized.

Institutionally, Musi Rawas already has an organizational structure, defined waste-management functions, standard operating procedures for transportation and service-fee collection, management regulations, and a legal basis for service-fee collection. This indicates relatively strong regulatory readiness. However, regulatory readiness differs from government effectiveness. Sasahara et al. [5] show that the quality of waste governance should be assessed through the dimensions of rules, institutional capacity, information, participation, and implementation effectiveness. Novais and Tavares [7] likewise emphasize that governance models are associated with differences in service performance. In developing countries, Iqbal et al. [32] underline the importance of aligning governance structures, economic objectives, and financing, while Hezardastan and Shmelev [33] show that circular-economy policy instruments must be translated into mechanisms capable of changing behavior and material flows. Thus, the challenge in Musi Rawas is not an absence of norms, but the still-weak linkage among normative targets, operational data, technical capacity, and performance evaluation.

3.6. Policy and Management Implications.

The findings support a sequence of evidence-based interventions rather than a perception-based ranking. The first priority is to establish a minimum operational-data system. Performance indicators should shift from “number of assets available” to “actual throughput and service quality.” Ideally, every trip should record the date, vehicle, route, starting and ending odometer readings, departure and return times, payload weight/volume, fuel consumption, service points, and downtime. Such data would allow calculation of t/km, t/trip, cost/t, load factor, vehicle productivity, and service coverage. Velis et al. [1] emphasize the importance of indicators that distinguish service coverage from service quality, while Sasahara et al. [5] identify information quality as an element of governance. Without this database, the government risks adding assets without knowing the actual bottleneck.

The second step is to optimize routes and trip frequencies before deciding to expand the fleet. Under the moderate scenario, the 70% handling target is equivalent to 101.86 t/day. If the entire volume were assumed to be transported using 5-t dump trucks, the theoretical requirement would be approximately 20.37, rounded to 21 full-load trips per day, far above the eight trips currently recorded. This calculation is not a direct operational recommendation because part of the waste should be reduced or processed upstream, but it illustrates the scale of the gap. Priyadarshi et al. [8], Das et al. [10], Petchrompo et al. [11], and Moussavi et al. [13] consistently show that data-driven optimization can improve collection-network efficiency. Only after an optimal route pattern is established can the government more accurately determine how many additional vehicles are genuinely required.

The third step is to activate existing waste-reduction capacity before constructing numerous new facilities. The three active TPS 3R facilities have a combined design capacity of approximately 4 t/day but a measured throughput of only 0.79 t/day; thus, roughly 80% of active design capacity remains unused based on the available data. An operational audit should assess the quality of source separation, daily input volume, operating hours, operator competence, equipment condition, electricity/fuel costs, residual output, compost/material quality, and market certainty. Liao et al. [14] and Rao and Parsai [15] show that decentralized organic-waste processing can reduce system burdens when process conditions and feedstock quality are properly managed. Ashraf et al. [17] demonstrate the importance of life-cycle cost in comparing treatment options, while Amato-Lourenço et al. [18] emphasize the value of community-based models. For a regency context, a combination of centralized and decentralized facilities, as discussed by Reddy et al. [20], may be more appropriate than complete dependence on a single downstream facility.

The fourth step is to build a material-recovery network linking waste banks, TPS 3R facilities, informal actors, aggregators, and secondary-material markets. The two waste banks recorded as active but underperforming should not be treated merely as educational programs; they should function as nodes in a material supply chain. Budiarto et al. [24] demonstrate variation in waste-bank implementation across Indonesian regencies and the need for institutional strengthening. Sondh et al. [16], Monfared et al. [34], and Gajera et al. [35] emphasize that a circular economy requires connectivity among reduction, source-separated collection, recycling, recovery, and market mechanisms. Digital recording of material transactions could help DLH determine how many tonnes of waste are genuinely diverted from final disposal and incorporate this value into waste-reduction performance indicators.

The fifth step is to reduce dependence on final disposal while simultaneously improving final-disposal standards. The 2025 DLH facility dataset records an active final disposal site operating under an open-dumping system. This condition should be regarded as a systemic risk because any shortfall in reduction and processing capacity ultimately becomes an additional burden on the disposal site. Zhang et al. [3] note that open dumping remains a major performance barrier in many parts of Asia and Africa, while Rashad et al. [36] identify segregation, context-appropriate recovery technologies, waste-to-energy, and circular-economy strategies as elements of system transformation. Upgrading the final disposal site should therefore not be pursued in isolation; it should proceed in parallel with source reduction and intermediate processing. The principle is to minimize residual waste entering final disposal and ensure that remaining residuals are managed under more controlled conditions.

3.7. Phased Transition Framework for Waste Management in Musi Rawas.

Based on the quantitative diagnosis, the transition can be divided into three time horizons. The 0–12 month horizon should focus on measurement and efficiency: recording tonnage per trip, mapping service points, auditing routes, auditing TPS 3R facilities, and integrating the service-fee/customer database with service-delivery data. The 1–3 year horizon should focus on increasing diversion: improving TPS 3R utilization, developing decentralized organic-waste treatment in suitable markets and settlements, strengthening waste banks and recycling off-takers, and adjusting fleet size after actual requirements are quantified. The 3–5 year horizon should focus on system consolidation: integrating centralized and decentralized facilities, establishing more transparent financing and cost-recovery mechanisms, and upgrading final disposal. This framework is consistent with the circular-economy perspective that system change requires integration across policy, infrastructure, material markets, and user behavior [22–34]. Each horizon should be accompanied by measurable implementation indicators rather than activity counts alone. The proposed indicators are summarized in Table 5.

Table 5. Phased Transition Framework and Measurable Implementation Indicators.

Horizon	Primary focus	Key actions	Measurable indicators
0–12 months	Measurement and operational efficiency	Install/standardize weighing and trip logs; map service points; route and TPS 3R audits; link customer and service databases.	≥90% of collection trips with payload and cycle-time records; 100% active vehicles with monthly availability/downtime logs; all TPS 3R units with daily input-output records; baseline service-coverage map completed.
1–3 years	Diversion and productivity improvement	Increase TPS 3R utilization; develop decentralized organic treatment; strengthen waste banks/off-takers; adjust routes and fleet using measured demand.	TPS 3R utilization progressively increased from the 19.75% baseline; tonnes diverted/day reported by facility and material type; tonnes/trip and fuel/tonne improved against the year-1 baseline; formal service coverage increased annually.
3–5 years	System consolidation and disposal upgrading	Integrate centralized/decentralized facilities; strengthen financing and cost recovery; upgrade final disposal and residual-waste control.	Auditable annual reduction and handling rates reported in tonnes/day and %; residual waste to TPA per capita declines; cost/tonne and cost-recovery ratio reported; open-dumping practices eliminated or formally transitioned to controlled/sanitary disposal standards.

This sequence also avoids two policy risks. First, physical investment may be undertaken before operational bottlenecks are measured, causing new facilities to be underutilized. Second, target achievement may be assessed only from the number of facilities or activities rather than from the actual mass of waste reduced and handled. Governance literature emphasizes that

effectiveness arises from the relationship among targets, instruments, implementing capacity, data, financing, and accountability [2, 6, 32, 33]. Post-2025 Jakstrada strategy should therefore use a new quantitative baseline and auditable annual indicators.

This study has several limitations that define the boundaries of interpretation. First, waste generation is estimated from population rather than from field sampling and direct weighing; therefore, three sensitivity scenarios were used and all values are explicitly labeled as estimates. Second, the 40 t/day figure is nominal capacity based on vehicle payload and trip frequency rather than actual tonnage; it cannot be used to state a collection rate. Third, several “processed” values in the facility dataset do not consistently specify the measurement period, so only TPS 3R throughput expressed on a daily basis was used quantitatively. Fourth, data on waste composition, route distance and travel time, fuel consumption, cost per tonne, household coverage, realized service-fee revenue, informal-sector capacity, and emissions were not available. Fifth, the secondary-data design does not test behavioral factors or stakeholder perceptions and therefore cannot causally explain why facilities are underperforming. The results are therefore most appropriately treated as a baseline policy–capacity assessment. Future research should conduct waste characterization according to the latest SNI standard [39–44], actual weighing across at least multiple seasons, GPS-based route tracking, service-cost analysis, and material-recovery measurement to transform this baseline into a full mass-balance and optimization model. The uncertainty analysis further shows that the choice of generation coefficient alone changes the estimated 2025 capacity gap from 47.31 to 76.41 t/day. Thus, investment sizing should not rely on the moderate scenario as a point estimate. A minimum validation program should include seasonal direct weighing, stratified waste-generation sampling, measured payload per trip, GPS-derived cycle time, route-level service coverage, and facility input/output mass balances.

4. Conclusions

Musi Rawas Regency has relatively strong regulatory readiness through Jakstrada, the Waste Management Regional Regulation, the DLH organizational structure, standard operating procedures, service fees, collection vehicles, human resources, TPS 3R facilities, waste banks, and a final disposal site. Nevertheless, the evaluation indicates a substantial technical-capacity gap. Under the moderate scenario, estimated waste generation in 2025 is 145.51 t/day, while nominal transport capacity is 40 t/day, equivalent to 27.49% of estimated generation. The 70% handling target corresponds to 101.86 t/day, resulting in a nominal capacity gap of 61.86 t/day. Because this capacity estimate is not based on actual weighing, the result should be interpreted as a strong indication that system capacity and productivity need to be verified and improved, rather than as an estimate of the actual collection rate. On the reduction side, three of the four TPS 3R facilities are active, but recorded throughput is only 0.79 t/day compared with an active design capacity of 4 t/day, giving utilization of approximately 19.75%. This finding shows that the challenge is not only a lack of infrastructure, but also underutilization of facilities that already exist. The sequence of improvements derived from the results is to: establish tonnage data and service indicators; optimize routes and trip frequencies; activate TPS 3R capacity; integrate waste banks and recycling markets; expand decentralized organic-waste treatment; and improve final-disposal standards. The main contribution of this study is to shift waste-management evaluation away from an approach based merely on the existence of regulations and the number of assets toward a quantitative relationship among waste generation, capacity,

utilization, and policy targets. The framework can serve as a baseline for setting post-2025 targets and can be replicated in other regencies facing similar limitations in primary data. More broadly, the analysis indicates that the immediate planning problem is not simply an insufficient number of assets, but the absence of a verified mass-flow and productivity baseline linking policy targets to daily operations. The most defensible post-2025 strategy is therefore to make measured throughput, diversion, and service coverage the basis for investment decisions. If direct weighing confirms a gap of the same order as the scenario analysis, route optimization alone will be insufficient and additional collection and upstream treatment capacity will be required; if measured tonnage is substantially lower, the policy response should prioritize service coverage, participation, and material-flow capture before expanding downstream assets.

Acknowledgments

The authors acknowledge the Environmental Agency of Musi Rawas Regency and Statistics Indonesia for the administrative data and official documents used in this secondary-data assessment.

Author Contribution

T.L.: Conceptualization, Methodology, Data Curation, Formal Analysis, Investigation, Visualization, Writing – Original Draft. Y.: Conceptualization, Methodology, Validation, Supervision, Writing – Review & Editing. M.M.R.: Methodology, Validation, Formal Analysis, Supervision, Writing – Review & Editing. Y.: Validation, Supervision, Interpretation of Results, Writing – Review & Editing. All authors have read and approved the final manuscript. For clarity, author roles correspond to Teddy Laszuardy (T.L.), Yuwana (Yu.), Muhamad Mustopa Romdhon (M.M.R.), and Yansen (Ya.).

Conflict of Interest

No conflict of interest was reported by all authors.

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