Industrial Solid Waste Management: A Path to Net Zero Emission for Industrial Estate

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Abstract. The management of industrial solid waste represents a critical element in achieving sustainable development and emission reduction within industrial estates. This research investigates the current utilization of industrial waste, emphasizing low-value residues, and assesses the potential adoption of waste-to-energy approaches in the Jababeka Industrial Estate. The study utilized secondary datasets derived from the Environmental Management (RKL) and Environmental Monitoring (RPL) reports submitted by tenant companies. Through descriptive statistical analysis, the study identified waste categories, generation volumes, prevailing handling methods, and opportunities for resource valorization. Results indicate that a substantial share of industrial waste remains inadequately recovered, as recycling efforts are mainly directed toward high-value materials, while lower-value fractions are predominantly landfilled. Nonetheless, the findings suggest that integrating waste-to-energy systems could substantially lessen landfill reliance and contribute to the reduction of greenhouse gas emissions. The study infers that advancing circular economy practices through industrial symbiosis that is strengthened by institutional support and technological advancement can transform industrial waste into productive resources, reinforcing the role of industrial estates in progressing toward national net-zero emission targets. **Keywords**: Zero Emission, Sustainable Development, Waste Management

1 Introduction

Bekasi Regency faces a serious waste problem. Data from the National Information System for Waste management (*SIPSN*) in 2024 showed that Bekasi District generated the highest amount of waste compared to other district in West Java Province (Figure 1). This is due to the dense industrial estate sector and the increasing number of immigrants interested in settling in areas considered to be the periphery of Jakarta, the economic center. Therefore, Bekasi Regency's population is very diverse, and many people make their living in industrial areas. Consequently, the production pro Bekasi's industrial estates has increased over time, along with the inevitable waste generation.

Industrial activities grow rapidly, especially in urban and special economic zones such as industrial estate, waste generation often exceeds the capacity of available management systems [1]. The increasing amount of waste shows the situation that leads to environmental

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issues such as land and water pollution, declining soil quality, and risks to public health [2]. Human activities will always produce waste, a system is needed to ensure that all solid waste is properly managed without depending only on landfilling [3]. Integrated waste management is therefore an urgent step to protect the surrounding ecosystem and support sustainable industrial growth.

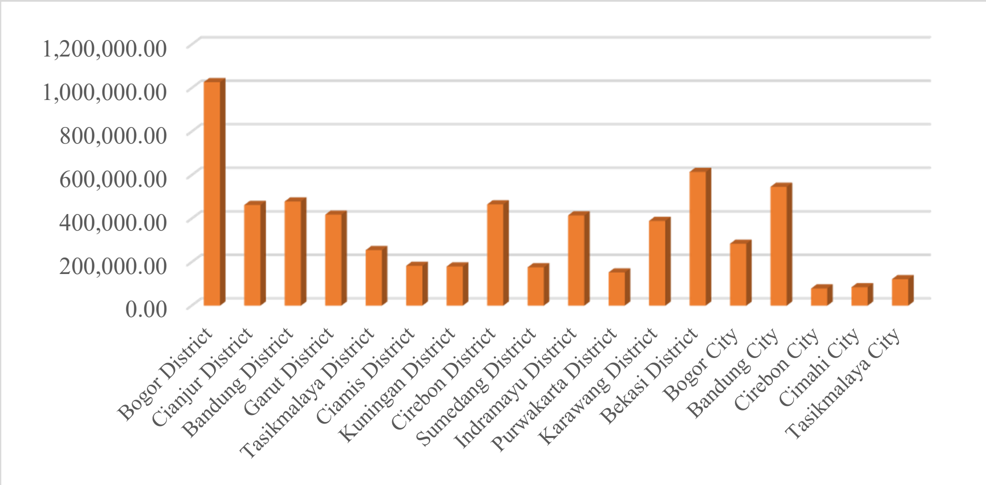

Fig 1. Waste Generation in West Java Province in 2024 (Source: SIPSN (2025)).

In recent years, the focus of waste management has shifted from simple disposal to the use of waste as a resource. The 3R principles (Reduce, Reuse, Recycle) are increasingly applied to minimize raw material consumption and extend the life cycle of industrial inputs [4]. When treated properly, industrial solid waste can become a secondary raw material that supports circular economy practices and brings economic benefits through cost savings and resource recovery, as well as social benefits such as job creation [5]. However, recycling in practice is not optimal yet. A large portion of recyclable waste is handled by informal sectors, and their methods sometimes cause further environmental damage rather than solving the waste problem [4].

One approach that shows promise for industrial estates is industrial symbiosis [7]. Within this framework, companies collaborate to exchange materials, by-products, energy, or water. For example, waste from one company can be used as input for another. This cooperation reduces waste, improves efficiency, and creates new value chains. Industrial symbiosis not only supports sustainability goals but also improves competitiveness for companies involved. More importantly, it helps reduce reliance on new raw materials and lowers emissions, making it an important step toward achieving net-zero targets [7].

Solid waste management in industrial estates employs multiple complementary strategies, including hierarchical waste management, technological approaches, and stakeholder involvement. The hierarchical approach prioritizes actions that minimize environmental impact. Prevention focuses on reducing waste generation at the source through optimized production planning and resource-efficient designs. Reduction involves minimizing material use and avoiding unnecessary by-products. Reuse and recycling enhance resource efficiency by repurposing waste into new applications or converting it into raw materials for other production cycles [8]. Energy recovery transforms non-recyclable waste into alternative energy sources, such as biomass, refuse-derived fuel (RDF), or biogas. Finally, disposal entails safe handling of residual waste through engineered landfill or incineration systems [9].

Technological approaches integrate mechanical, biological, and thermal methods. Mechanical and biological treatment (MBT) combines sorting, shredding, and composting to reduce mixed waste volume while generating energy or compost. Composting converts organic waste into nutrient-rich soil amendments, whereas recycling targets materials such as metals, plastics, and paper. Thermal technologies, including incineration, pyrolysis, and gasification, harness waste calorific content to produce electricity, syngas, or bio-oil [10]. RDF production enhances fuel value from sorted and processed waste streams, though proper pre-sorting is critical for efficiency. Biological treatment methods, such as anaerobic digestion and fermentation, convert organic waste into biogas or bioethanol, providing renewable energy while minimizing landfill burden.

The success of industrial solid waste management relies heavily on stakeholder engagement. Government authorities provide regulatory frameworks, incentives, and infrastructure support. Industrial operators implement on-site waste minimization and recycling programs. Private sectors contribute through technology adoption and resource recovery, while local communities participate in waste segregation, recycling, and awareness campaigns. Such a shared-responsibility approach ensures integrated solid waste management systems, aligning industrial productivity with environmental sustainability [11] [12].

Meanwhile the application of circular economy principles promote waste valorization, such as upcycling, organic waste composting, and energy recovery, reducing dependency on virgin resources. Ecological balance ensures that waste management practices maintain ecosystem integrity, preventing soil, water, and air contamination while preserving biodiversity [13]. Efficiency and sustainability principles focus on optimizing resource use, adopting modern environmentally friendly technologies, and ensuring long-term viability of SWM systems [14].

Industrial solid waste represents a significant potential energy source, especially in efforts to reduce reliance on fossil fuels. Organic and carbon-rich waste possess calorific values that can be harnessed for electricity, heat, or alternative fuels. Biogas production via anaerobic digestion converts organic residues into methane-rich gas suitable for energy generation. Thermal processes, including incineration, pyrolysis, and gasification, transform waste into electricity, syngas, or bio-oil. RDF production provides a high-calorific fuel for cement plants or power stations, whereas bioethanol production through fermentation of sugar- and starch-rich waste contributes to sustainable transport fuels. These approaches reduce landfill burden while providing economic and environmental benefits [15].

One of the notable and successful example of industrial waste management technology application is the *Bantargebang* Landfill Site (TPST) or *PLTSa Merah Putih* that has one Landfill Gas to Energy (LFGTE) Powerhouse with an installed capacity of 14 MW. This 24-hour operating facility is designed to utilize landfill gas generated from waste disposal activities [5].

While the existing research about waste-to-energy mainly focus to context of what method is suitable or what type of waste-to-energy applicable to industrial estate, this study provides a beneficial data and pattern on waste generated by the biggest industrial estate in ASEAN, Jababeka.

This study aims are to analyzing the utilization of industrial waste especially for the un-value waste, and to analyzing the potential of waste to energy in industrial estate to evaluate existing solid waste management systems in industrial estates and to identify opportunities for improvement. The details objectives are: (a) to review current practices from storage, collection, and transportation to processing and final disposal; (b) to analyze the quantity and quality of both hazardous and non-hazardous solid waste; and (c) to explore collaboration between industrial and municipal waste management systems. These objectives reflect an effort to connect daily operations with long-term strategies for waste management at both estate and regional levels.

The scope of the study focuses on industrial estates in Bekasi Regency, with Jababeka Industrial Estate as the main study case. Data collection includes surveys of waste types and volumes, distinguishing between hazardous and non-hazardous waste, and assessing material properties relevant for recycling or energy recovery.

2 Research Method

2.1 Population and Sample

In this study, the population used is companies in the Jababeka Industrial Estate. Companies located in the Jababeka Industrial Estate that submit RKL (Environmental Management Plan) or RPL (Environmental Monitoring Plan) reports to PT Jababeka Infrastruktur, as a industrial estate management. From 641 company RKL/RPL documents, data was obtained regarding the waste or solid waste produced by the companies. From all the data obtained, data that can be used for analysis was selected. The consideration in selecting data or companies that can be sampled is the waste data from the companies that can be converted into the same unit (kg/month). This is done so that the amount of waste generated from a company can be added according to the type of waste. After converting the unit of each type of company's waste, 635 companies were obtained as samples. With only a 0.9 percent reduction in the sample from the entire population, it can be said that this study was conducted on the entire population.

2.2 Data Collecting

The data collection method used in this study was documentation, utilizing data from the Environmental Management Plan (RKL/RPL) documents provided by the companies to PT Jababeka Infrastruktur. Therefore, the data used is secondary data. The RKL/RPL documents summarize the types and quantities of waste generated by each company.

In addition to the company waste generation data summarized in the RKL/RPL documents, regulations and policies, both from the government and from the Jababeka industrial estate, concerning waste management in the industrial area were also collected. Existing regulations and policies constitute the initial regulatory framework, providing insight into the regulations currently in effect and implemented in the Jababeka industrial estate. Furthermore, these existing regulations are important considerations when developing further plans or strategies for industrial waste management.

2.3 Data Analysing

Data collected through secondary data collection was analyzed descriptively to determine the quantity and types of waste generated by companies located in the Jababeka industrial area. This descriptive analysis began with converting the weight units of each type of waste and making several assumptions to simplify the high data variation.

The secondary data is derived from the Environmental Management Plans (RKL) and Environmental Monitoring Plans (RPL) submitted by companies operating within Jababeka Industrial Estate. These reports are mandated by Indonesian environmental regulations and are subject to government oversight, which ensures a minimum level of reliability and consistency in the data.

After RKL/RPL data collection, the classification of waste types was performed, which was expected to facilitate identifying which types of waste were large or sufficiently large in quantity and could be used for specific purposes. This company classification was based on the type of primary product they produced. From the collected data, all companies could be grouped into 19 groups, shows at Table 1.

Table 1. Industry classification of Jababeka's industrial estate.

Industrial Classification	
Automotive accessories	Healthcare and pharmacy
Electronic	Printing
Computer hardware	Property and real estate
Chemical	Cosmetics
Plastic	Gas
Food and beverages	Textile
Manufacturer	Waste management
Packaging	Rubber component
Warehouse and storage	Technology
Machine and steel component	Pest control
Pipe and accessories	

(Source: Data analysing)

After the weight of waste generated by companies is equalized to kg/unit, the waste generation from specific industrial types and its weight will be obtained. The obtained waste generation conditions are displayed using descriptive statistics, including frequency distribution, percentage contribution, and weight proportions of waste types, were employed to summarize the data. This approach was considered sufficient because the aim of the study was not to test causal relationships but to map waste generation patterns, highlight underutilized waste streams, and identify potential candidates for waste-to-energy application.

3 Result

Bekasi Regency, as one of the buffer zones for the capital city and an industrial hub in West Java, faces significant challenges in waste and solid waste management. With a growing population and high industrial activity, waste management in Bekasi Regency requires special attention to ensure environmental sustainability and community well-being. Waste and solid waste management in Bekasi Regency faces various challenges that require serious attention. The following is a current overview of waste management in the region.

3.1 Existing Condition of Bekasi Regency's Waste Management

In general, waste management within the Bekasi Regency service area is still carried out using the collect-transport-dispose or end-of-pipe method, as follows: Firstly, waste is collected, the implementation of which depends on the source of the waste. Waste in residential areas is collected independently in mini dumpsters/TPS (trash cans). In high-income housing areas, such as the Gardenia Cluster in Jababeka, waste is managed by the private sector. Waste in markets is collected by market managers, and waste on the streets and dumpsters are collected by sweepers from each Technical Implementation Unit (UPTD) of the Bekasi Regency Environmental Agency.

The collected waste is disposed of at the nearest Temporary Waste Disposal Site (TPS) or directly onto dump trucks and taken to the final disposal site (TPA). In some locations, waste is first sorted at the Waste Bank and TPS3R, which are then disposed of at the nearest TPS or transported directly by dump trucks to the final disposal site (TPA). Waste at the TPS is routinely and periodically transported to the TPA by garbage trucks for large roads in the city area and by garbage trucks for small roads or alleys that cannot be reached by trucks. From a waste-source perspective, the waste management process begins at the source and continues through the final stage at the final disposal site (TPA). Here's an explanation of each stage:

Waste that has been placed in its designated bins is then collected at a designated point and then transported to a larger collection point. These collection points have been established with community involvement, such as through waste banks or TPS3R (Temporary Disposal Sites for Reduce, Reuse, and Recycle). The collection and transportation processes at waste banks have educated the community to separate their waste from the source. Waste bank customers transport their waste independently to the waste banks, and the waste bank administrators receive the waste from the customers and provide the benefits to the customers. However, these waste bank activities are not always continuous and sustainable.

At Bekasi Regency, there are 27 TPS3R (3R waste processing facility), and only 12 TPS3R (44%) still give a services. It was found that the TPS3R reduced waste by 25 tons/day and the Waste Bank by 2.08 tons/day. Of the total waste generation in Bekasi Regency in 2020, which was 1,211.07 tons/day, the waste bank contributed 0.11 percent, while the TPS3R contributed 0.45 percent (RISPS Report, Ministry of Public Works and Public Housing, 2024).

3.2 Analysis of Waste Management Existing Condition in Jababeka Industrial Estate

The Jababeka Cikarang Industrial Estate (KIJC), located in Bekasi Regency, is the oldest and largest industrial area in Indonesia. Construction began in 1989 and has continued to expand. It now encompasses 3,628 hectares of licensed and built-up area and has a land bank of 1,219 hectares, making it one of the largest integrated industrial areas in Southeast Asia.

Fig 2. Map of Jababeka City.

Waste Management Existing Condition

In this study, 804 companies were identified as having hazardous waste, while 635 companies reported non-hazardous waste. This company waste data was obtained from the Environmental Management Efforts (UKL) and Environmental Monitoring Efforts (UPL) documents, as well as the Environmental Management Plan (RKL) and Environmental Monitoring Plan (RPL). These documents are stored at PT Jababeka Infrastruktur until September 2024.

Potential Quality and Quantity of Waste

The previously presented waste generation conditions represent waste generation in Indonesia, and then in Bekasi Regency. Next, we will show the composition of waste generation from the Jababeka Industrial Estate, as shown in Figure 8.

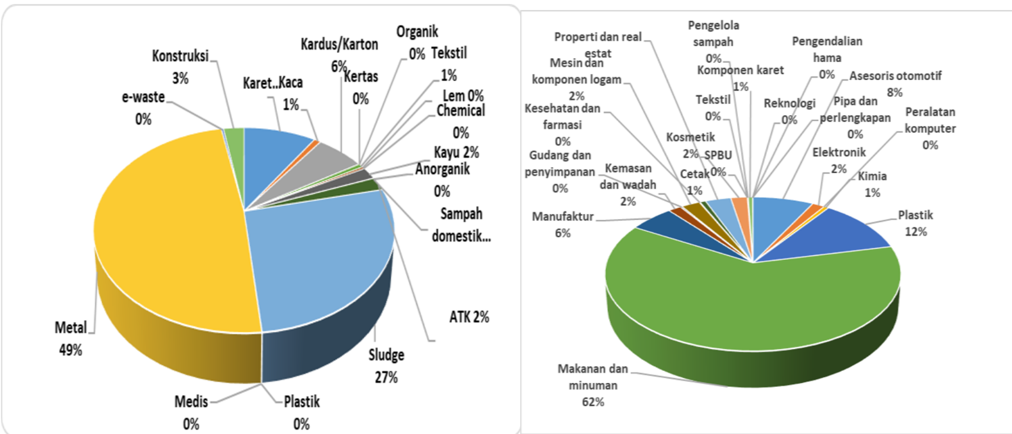

Fig 3. Solid Waste Composition by Type from 635 Companies in the Jababeka Industrial Estate and Waste Contribution from Industrial Classification in the Jababeka Industrial Estate, 2025 (Source: Secondary data processing).

The waste generated by companies located in the Jababeka Industrial Estate is collected by a third party. To see the weight of each type of waste, the composition of waste from the Jababeka Industrial Estate is shown in Figure 6.

Figure 6 show that the heaviest types of solid waste are metal waste and sludge. This is understandable, given that these two types of waste are heavier than other types. Metal waste has been utilized and has a selling value, especially for metal companies. While the most contributing industry to solid waste is food and beverages, commonly due to the amount of food packaging and food process producing solid waste, metal and sludge from food and beverage process is potential for waste-to-energy. The high organic or biodegradable content link to Circular Economy Principles in Indonesia's Low-Carbon Development Strategy (RPJMN 2020–2024, Bappenas) and Presidential Regulation No. 35/2018 on Acceleration of Waste-to-Energy Facilities (PLTSa) that pre-exquisite the waste-to-energy to convert high-volume, high-moisture organic waste (like F&B sludge) into energy.

Waste Collection, Storage, and Processing System in the Area

The waste management system in industrial areas is a crucial component in supporting environmental sustainability and increasing waste management efficiency. This system encompasses several key stages: waste collection, transportation, and processing, designed to minimize negative impacts on the environment and support the concept of a circular economy. Waste management in Jababeka Industrial Estate follows a structured process consisting of collection, transportation, treatment, and monitoring. Companies first collect waste at designated Temporary Storage Sites (TPS), where domestic and production waste are separated from hazardous and toxic materials. The collected waste is then transported to processing facilities by third-party partners, with route selection generally based on efficiency; however, organic and inorganic waste are often transported together due to the lack of partner differentiation, and not all transport partners guarantee proper treatment. On-site waste processing is limited, with only a few companies implementing 3R practices as part of their Kaizen initiatives, while most rely on disposal or external handling. Monitoring and evaluation of these practices are under the responsibility of PT Jababeka Infrastruktur, the estate developer, which can establish continuous oversight mechanisms to improve system effectiveness. For optimal performance, a sustained monitoring framework and targeted improvement strategies are required. Several strategies that can be implemented is shown in the figure 4.

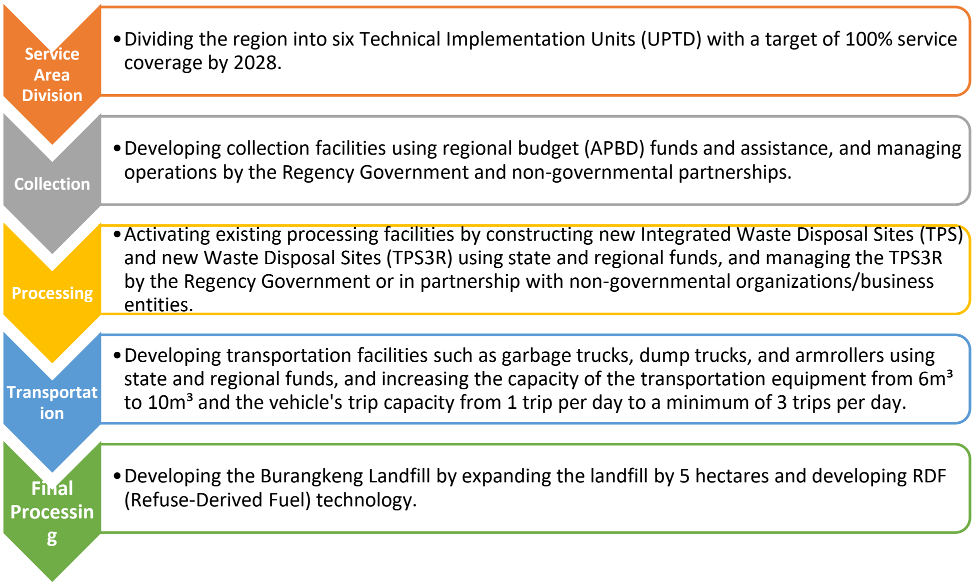

Fig 4. The masterplan of industrial estate waste management from area division to final processing waste-to-energy.

3.3 Applicable Strategy to Achieving Net Zero Emissions in Industrial Estates with Waste Management

The master plan for developing a waste management system in Bekasi Regency includes several sections

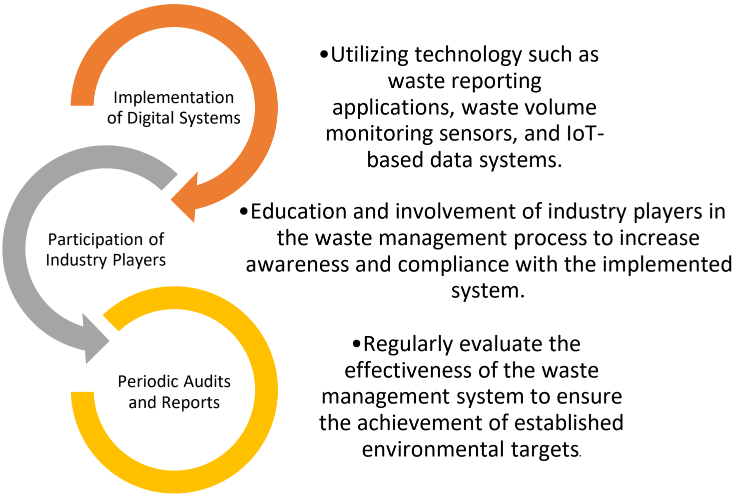

Fig 5. The strategy that can be implemented for continuous monitoring and evaluation mechanism.

Monitoring and evaluation of waste and solid waste management by companies in the Industrial Estate can be carried out by the developer company. For the Jababeka Industrial Estate, the developer or manager of the Jababeka Industrial Estate, in this case PT Jababeka Infrastruktur, can establish a monitoring and evaluation system for waste management by companies in the Jababeka Industrial Estate. For the waste management system in the industrial estate to run optimally, a continuous monitoring and evaluation mechanism is required.

Stakeholder Mapping in Waste Management in Bekasi Regency

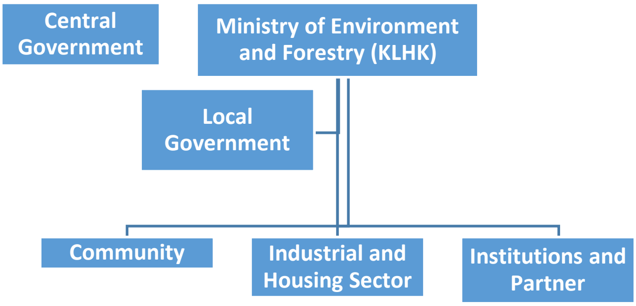

Fig 6. Overview of Stakeholder Mapping for the Construction of Burangkeng Landfill.

In early 2025, the Bekasi Regency Government accelerated the development of the Burangkeng Landfill (TPA) in accordance with the Ministry of Environment's directive to create a modern and environmentally friendly waste management system by the end of 2024. This will focus on technology-based waste management, eliminating open dumping and replacing it with Landfill Residue (LUR) to accommodate residual waste.

4 Conclusion

This study shows that the existing solid waste management at Bekasi Regency system, still dominated by a collect-transport-dispose approach, is inadequate to address the increasing volume of waste. While the contribution of TPS3R (Recycling Waste Management System) and Waste Banks (Waste Banks) remains limited, both demonstrate the potential of upstream and community-based management models to complement centralized systems.

The Jababeka Industrial Estate case highlights sludge and metal as the most dominant types of waste, with the food and beverage industry contributing the largest proportion overall. This potential waste contribution can be utilized to circular economy principle and organic energy management as set by Presidential Regulation No. 35/2018 to achieve an acceleration of waste-to-energy as a path to net zero emission in industrial estate.

Stakeholder mapping further confirms that effective waste management and emissions reduction require collaborative governance. The central government (KLHK) plays a role in providing regulatory guidance, the Bekasi Regency Government provides infrastructure and financing, industries and industrial estates implement minimization and recovery practices, while communities, schools, and NGOs support sorting and education at the source level.

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