Advance Sustainable Science, Engineering and Technology (ASSET)
Vol. 7, No. 3, July 2025, pp. 02503016-01 ~ 02503016-15
ISSN: 2715-4211 DOI: https://doi.org/10.26877/asset.v7i3.1988

Assessing the Feasibility of Small-Scale RDF Technology in Urban Solid Waste Management Using Cost-Benefit Analysis

Heru Purwanto[1*], Renny Nurhasana[1], Azizah Rohimah[2]

[1]School of Strategic and Global Studies, Universitas Indonesia, Jl. Salemba Raya No. 4 Central Jakarta 10430, Jakarta, Indonesia

[2]Faculty of Medicine, Universitas Indonesia, Jl. Salemba Raya No. 6 Central Jakarta 10430, Jakarta, Indonesia

*heru.purwanto31@ui.ac.id

Abstract. The development of Waste Processing Facilities based on the 3R principles (TPS 3R) with small-scale Refuse Derived Fuel (RDF) technology in Jakarta aims to support waste sorting, composting, reuse, and recycling activities, with locations strategically placed as close as possible to service areas. However, its implementation faces significant challenges, particularly due to high initial investment and operational costs. This study evaluates the feasibility of four TPS 3R facilities using a Cost-Benefit Analysis approach, considering economic, environmental, and social dimensions. The results indicate that all units are economically viable, with TPS 3R Joe demonstrating the highest economic feasibility, marked by a BCR of 1.870, an NPV of IDR 25.81 billion (USD 1.60 million), and an IRR of 15.76%. The study concludes that the successful implementation of small-scale RDF technology is highly influenced by technical efficiency, institutional support, community participation, and policies that are adaptive to local characteristics.

Keywords: Cost Benefit Analysis, Refuse Derived Fuel, Solid Waste Management, TPS 3R

(Received 2025-05-20, Revised 2025-06-16, Accepted 2025-06-19, Available Online by 2025-06-26)

1. Introduction

Urban solid waste management has become an increasingly urgent global issue, in line with the growing global population and improvements in living standards [1]. According to projections by the United Nations Environment Programme, the volume of global solid waste is expected to rise from 2.1 billion tons in 2023 to 3.8 billion tons by 2050 [2]. This increase is primarily driven by rapid urban population growth, which is closely associated with economic advancement, urbanization, and changing consumption patterns.

These socioeconomic transformations have significantly contributed to the escalation of solid waste generation. As a developing market economy, Indonesia faces substantial challenges in managing solid waste, particularly due to accelerated urbanization and a sharp rise in population over the past decade [3]. According to The Atlas of Sustainable Development Goals 2023 published by the World Bank, Indonesia was ranked as the fifth-largest generator of solid waste globally in 2020, with total production reaching 65.2 million tons. This issue not only poses a serious threat to environmental sustainability but also potentially undermines economic resilience and societal well-being [4].

In many cities across Indonesia, solid waste management is generally implemented as a public service that demands substantial financial allocations, including labor requirements, operational equipment, and supporting infrastructure. The cost of solid waste collection alone is estimated to consume between 80% and 90% of the total municipal solid waste management budget [5]. This situation poses serious challenges for local governments in executing waste collection and disposal efficiently, particularly amid limited financial and technical resources. A study revealed that developing countries in Asia and Africa face similar structural constraints, especially in the areas of waste collection, processing, and recycling [6]. These challenges are further exacerbated by rapid population growth in those regions, which directly contributes to the increasing volume of waste and intensifies the pressure on existing waste management systems.

This condition is very relevant to the situation faced by Jakarta, as the capital city of the central government and economy of Indonesia. With a total land area of 661.5 square kilometres and a population reaching 10,672,100 in 2023, Jakarta records an annual population growth rate of 0.38 percent and a population density of 17,152 people per square kilometre, according to data from the Central Statistics Agency of DKI Jakarta Province (2024). The rapid population increase, compounded by the high intensity of economic activities, has significantly accelerated the volume of solid waste generated surpassing the capacity of the existing waste management infrastructure. Furthermore, the limited capacity of landfills and the widespread occurrence of illegal dumping practices have further exacerbated the situation. These conditions underscore the urgent need for the implementation of more adaptive and sustainable solid waste management strategies in Jakarta [7].

As a strategic initiative to address the growing challenge of solid waste management, the Provincial Government of DKI Jakarta has launched the development of Waste Processing Facilities based on the 3R principles (Reduce, Reuse, Recycle), known as TPS 3R. These facilities are equipped with small-scale Refuse Derived Fuel (RDF) processing units, with a handling capacity ranging from 25 to 50 tons per day. The TPS 3R model is designed to support on-site waste segregation, composting, reuse, and recycling, with facilities strategically located near the service areas they support. Construction of these facilities began in 2023, and by the end of 2024, a total of eight TPS 3R units have been successfully established and are operational.

RDF technology has seen increasing adoption due to its capacity to process nearly all types of household waste including plastics, paper, organic matter, and wood into alternative fuel [8]. RDF has been proven effective for use in co-firing processes alongside coal, both in the cement industry and in coal-fired power plants [9], [10]. The advantages of this technology include its ability to significantly reduce the volume of waste, minimize the need for highly specialized personnel, and shorten the construction time required for establishing waste processing facilities.

The adoption of RDF technology in Indonesia represents a significant innovation in solid waste management while simultaneously contributing to the achievement of national climate goals. RDF offers a promising solution to reduce reliance on fossil fuels, minimize the volume of waste sent to landfills, and generate broader positive impacts on environmental protection [10]. Moreover, RDF aligns closely with the principles of the circular economy and the objectives of sustainable development, particularly by avoiding the extraction of non-renewable natural resources [11]. Looking ahead, the utilization of RDF in Indonesia is expected to continue expanding in line with technological advancements and increasing policy pressures aimed at strengthening sustainable waste management practices.

Nevertheless, the implementation of RDF technology, particularly within TPS 3R facilities, still faces several significant challenges. One of the primary obstacles is the high initial investment required to establish supporting infrastructure, including RDF production facilities, waste sorting and processing systems, as well as logistics networks for waste collection and RDF distribution [10]. Additionally, the relatively high estimated operational costs present further constraints to long-term implementation [12]. Therefore, strong investment commitments from both the government and the private sector are essential to ensure the long-term operational sustainability of these facilities.

Building upon this context, the present study aims to analyze the feasibility of RDF processing implementation at TPS 3R using a Cost-Benefit Analysis (CBA) approach from economic, environmental, and social perspectives. CBA serves as a crucial tool for policymakers in selecting the most appropriate and efficient waste management strategies [13]. It is an economic approach used to estimate and compare the total costs and benefits associated with a given policy or alternative scenario. Given that waste management systems often require substantial initial investments and ongoing operational expenditures, it is essential to evaluate not only the economic viability but also the social and environmental implications of such systems [14], [15].

Several studies have explored the economic feasibility of developing waste processing facilities for RDF, highlighting its potential to reduce non-recyclable waste [16], [17], [18]. However, these studies predominantly focus on large-scale facilities located near landfill sites, which may not fully capture the complexities of waste management in densely populated urban areas. To provide a more original scientific contribution, this study emphasizes the analysis of small-scale RDF processing facilities situated in close proximity to service areas, while also underscoring the critical role of multi-stakeholder engagement in the planning and implementation process. This approach distinguishes the present study from prior research, as integrated assessments encompassing economic, environmental, social, and institutional dimensions within a localized context remain limited in the existing literature.

2. Methods

This study aims to evaluate the feasibility of TPS 3R facilities through a Cost-Benefit Analysis CBA) approach, which serves to measure and assess relevant economic costs and benefits, particularly in the context of social and environmental development in urban areas [19]. The analysis incorporates economic, environmental, and social dimensions to yield comprehensive results that can serve as an objective foundation for decision-making in the planning of sustainable development within the solid waste management sector.

2.1 Study Location and Research Object

This study was conducted in the Special Capital Region of Jakarta, Indonesia, which serves as the national center for governance, economic activity, and urban development. The selection of Jakarta as the research location is based on the complexity of the solid waste management issues faced by the city, driven by rapid population growth and increasing economic intensity. In response to these challenges, Jakarta has initiated a decentralized approach to waste management through the development and operation of TPS 3R equipped with *Refuse* RDF technology, as part of a broader strategy for circular economy-based waste processing.

The objects of this study are four TPS 3R units that have been operational since 2024, selected based on their processing capacity and the availability of supporting RDF infrastructure. These units are considered to represent early-stage implementation of RDF technology at the municipal level in Indonesia and are regarded as potential models for replication in other regions. This study analyzes the economic, environmental, and social feasibility of RDF implementation in these facilities using a *Cost-Benefit Analysis* approach.

2.2 Data Collection

This study employed two types of data sources: primary and secondary data. Primary data were obtained through in-depth interviews with TPS 3R facility managers and relevant stakeholders, as well as direct observations of operational activities at the TPS 3R sites. These methods were employed to gain a comprehensive understanding of the management practices and challenges associated with the implementation of RDF technology.

Secondary data included information on the construction, operational, and maintenance costs of TPS

3R facilities, comprising Capital Expenditure (CAPEX) and Operational Expenditure (OPEX), along with the revenue generated from the operation of these facilities. In addition to financial aspects, secondary data also covered the environmental and social benefits resulting from RDF implementation. All secondary data were collected from official documents, government reports, academic publications, and relevant and credible statistical databases.

2.3 Data Analysis

The analysis in this study employs the Cost-Benefit Analysis (CBA) method, a project or investment evaluation technique that compares the economic benefits of an activity with its associated economic costs. This approach provides a comprehensive analytical framework for assessing the efficiency, sustainability, and overall impact of a project [20]. In the context of this research, the feasibility of developing a TPS 3R is evaluated using three key indicators: Economic Benefit-Cost Ratio (BCR), Economic Net Present Value (NPV), and Economic Internal Rate of Return (IRR). These indicators enable a holistic assessment of the economic effectiveness of implementing RDF technology within TPS 3R facilities.

BCR is calculated by dividing the present value of all benefits generated by the project by the present value of all costs incurred. Here, B_t represents the benefits at time t, and C_t denotes the costs at time t. As a general convention, the calculation begins from the present period, with $t = 0$. A project is considered economically feasible if the BCR value exceeds 1. The formula used to calculate the BCR is as follows:

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}} \tag{1}$$

NPV is an indicator that reflects the present value of a project's total net benefits over its implementation period. NPV is calculated by summing the difference between benefits (B) and costs (C) for each time period, which are then discounted to their present value using a specified discount rate (r). If the resulting NPV is greater than zero, the project is considered economically viable, as it generates a positive net benefit relative to the resources invested. Accordingly, this indicator provides critical insight into the project's potential real profitability over time. The formula used to calculate NPV is as follows:

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t} \tag{2}$$

Meanwhile, IRR is the discount rate at which the present value of all project benefits equals the present value of all costs incurred—essentially, the rate that makes the NPV equal to zero. This indicator represents the maximum rate of return that can be achieved from the use of project resources while still ensuring full recovery of the investment without incurring losses. IRR serves as a benchmark for the financial efficiency of a project; if the IRR exceeds the applied discount rate, the project is considered feasible, as it yields a return greater than its cost of capital.

$$PV\ (Benefits) - PV\ (Costs) = 0 \tag{3}$$

2.4 Assumptions and Parameters

CAPEX data utilized in this study were primarily obtained from the Environmental Agency of DKI Jakarta Province, except for TPS 3R Joe, which employed a combination of data from the Environmental Agency and references from the Ministry of Home Affairs Regulation No. 7 of 2021 concerning the Procedures for Calculating User Charges. This was due to the unavailability of certain CAPEX data for that specific TPS 3R unit. Meanwhile, the operational cost estimates were also based on the same regulation, with necessary adjustments made according to the processing capacity and the technological characteristics of each TPS 3R unit. The discount rate applied in the feasibility analysis refers to the Ministry of Public Works Regulation No. 03/PRT/M/2013, calculated based on the average inflation rate over the past two decades, which stands at 5.25%.

The economic benefits are calculated based on two main components: revenue from product sales and income from sanitation service fees. The products sold include RDF, recyclable or reusable materials, and compost. The economic value of these products, along with the solid waste service fees, is determined in accordance with Regional Regulation No. 1 of 2024 on Regional Taxes and Levies. Meanwhile, environmental benefits are estimated through two approaches: the reduction of greenhouse gas (GHG) emissions resulting from the use of RDF as co-firing fuel in the cement industry, and the reduction of organic waste volumes sent to landfills. The monetary value of GHG emission reduction is calculated based on the carbon tax rate stipulated in Law No. 1 of 2021, amounting to IDR 30,000 (USD 1.86) per ton of CO_2 equivalent. Additionally, the reduction in waste management costs is calculated based on the waste treatment service rate at the landfill, which is set at IDR 468,100 (USD 29.74) per ton as stipulated in Regional Regulation No. 1 of 2024.

Social benefits are analyzed based on the increased employment opportunities generated by the operation of TPS 3R facilities, particularly for communities residing in the vicinity of the development sites. The monetary value of these social benefits is estimated by calculating the total income earned by workers employed at each TPS 3R unit. For financial variables denominated in USD, currency conversion is conducted using the exchange rate assumption stated in the 2025 State Budget (APBN), which is set at IDR 16.100 per USD.

This study acknowledges certain limitations within the analytical model, particularly in the determination of macroeconomic parameters that are dynamic and subject to change over time. Although the discount rate and exchange rate have been established based on official and widely accepted references, potential deviations remain that could influence the overall outcomes of the analysis. Therefore, the findings of this study should be interpreted within the framework of the assumptions applied.

3. Results and Discussion

To conduct a comprehensive evaluation of urban solid waste management options through TPS 3R facilities, accurate estimation and collection of data on the costs and benefits of each alternative are essential. This evaluation must consider a range of key determinants that influence the effectiveness of solid waste management implementation.

3.1 Municipal Solid Waste Generation

The characteristics, volume of waste generation, and composition of solid waste have a significant influence on waste-to-energy (WtE) management strategies [21]. Therefore, a comprehensive analysis of the composition and characteristics of municipal solid waste is essential as an initial step to determine the most appropriate and efficient treatment technology. Based on the waste sampling activities conducted in Jakarta in 2022, the following findings were obtained:

Table 1. Characteristics of Solid Waste in DKI Jakarta Province

No.	Categories	Value	RDF Standards for the Cement Industry
1	Actual Moisture Content	44,93 %	22 %
2	Ash Content	15,67 %	< 20 %
3	Chlorine Content	0,17 %	≤ 0,5
4	Higher Heating Value (HHV)	2.145,06 kcal/kg	Min. 3000 kcal/kg
5	Lower Heating Value (LHV)	1.368,79 kcal/kg	-

Source: Environmental Agency of DKI Jakarta Province (2023); National Standardization Agency of Indonesia (2024).

Based on Table 1, the average Higher Heating Value (HHV) of municipal solid waste in Jakarta is recorded at 2,145.06 kcal/kg, with an average Lower Heating Value (LHV) of 1,368.79 kcal/kg and an average moisture content of 44.93%. These figures indicate that the energy content of the waste remains below the minimum threshold required for RDF production. RDF technology typically requires high-calorific components such as plastics, paper, cardboard, wood, textiles, leather, and rubber. According to the Indonesian National Standard (SNI), in order for a waste fraction to be utilized as an alternative fuel in the cement industry, a minimum calorific value of 3,000 kcal/kg is required, with a maximum actual moisture content of 22%. Consequently, the current characteristics of solid waste in Jakarta suggest the need for additional preprocessing steps [22] to ensure that the waste meets the technical specifications necessary for RDF feedstock.

As shown in Figure 1, the largest fraction of municipal solid waste in Jakarta is composed of readily biodegradable organic waste, accounting for 49.87%, followed by plastic waste at 22.95%, and paper waste at 17.24%. This composition reflects the typical waste profile of urban areas in developing countries, where the organic fraction tends to be predominant. These findings are consistent with previous studies which indicate that in high-income countries and cities, the dominant waste fraction is primarily composed of paper and cardboard, while food waste and green waste represent a smaller proportion. As a result, the production of RDF in developed countries generally requires less intensive preprocessing. In contrast, in developing countries such as Indonesia, the high proportion of organic waste characterized by elevated moisture content presents a significant challenge in RDF processing. This is due to the need for additional treatment steps aimed at reducing moisture levels and enhancing the calorific value of the waste [11].

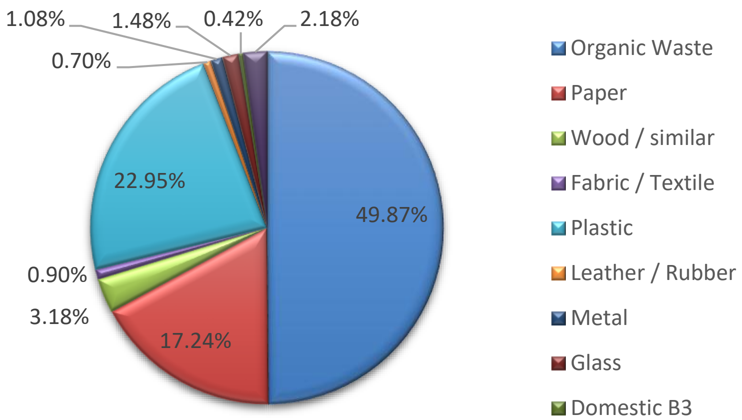

Figure 1. Composition of Solid Waste in DKI Jakarta Province
Source: Environmental Agency of DKI Jakarta Province (2023)

Based on current conditions, municipal solid waste does not yet fully meet the technical criteria required for use as feedstock in RDF production, primarily due to its high moisture content and the predominance of readily biodegradable organic fraction. Although the waste stream contains high calorific components such as plastics and paper, their proportion remains insufficient to meet industry standards without further preprocessing. These findings highlight the need for initial treatment strategies, such as source segregation and drying, to enhance RDF production efficiency and ensure conformity with industrial specifications particularly for use as an alternative fuel in the cement sector. In this context, technological advancement plays a critical role, both in pre-treatment stages and in automated waste sorting systems, to support the transition towards a more sustainable and integrated waste management system [23], [24].

3.2 Profile of TPS 3R

All TPS 3R examined in this study implement a similar core treatment technology, namely the processing of waste into RDF. However, there are notable differences in terms of processing capacity, availability of supporting facilities, and the overall effectiveness of operations at each site. These variations are detailed in Table 2, while an overview of the waste processing systems applied at each TPS 3R is illustrated in Figure 2.

Table 2. Capacity of TPS 3R and Estimated MSW Generation Based on Population in 2025

No.	TPS 3R	Capacity (tons/day)	Location	Area (Km^2)	Population	Waste Generation (tons/day)
1.	Asrama Ciracas	25	Ciracas	3,93	82.187	62,462
2.	Joe	37	Lenteng Agung	2,28	67.778	51,511
3.	Moa	25	Pejagalan	3,23	87.534	66,526
4.	Siaga	50	Pejaten Barat	2,90	44.685	33,961

Source: Author's compilation based on various data sources (2025)

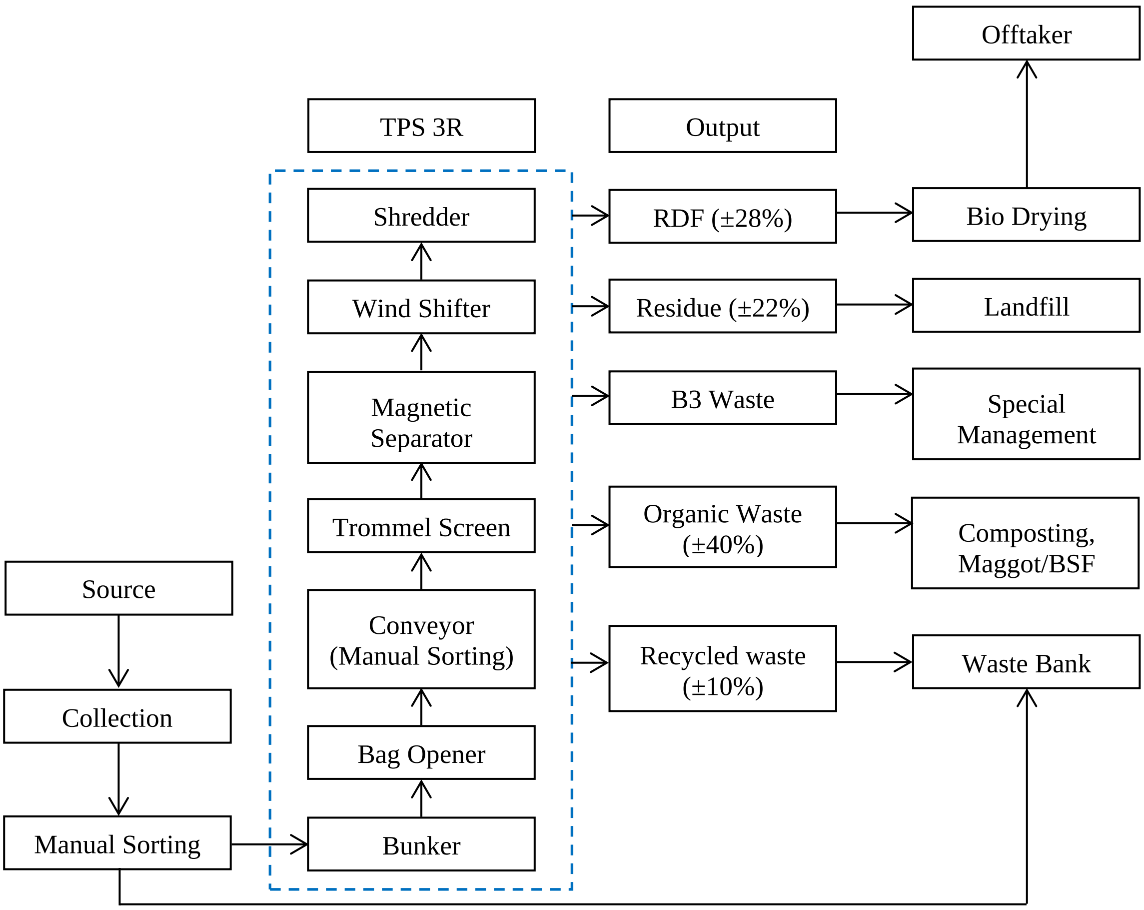

Figure 2. Operational Workflow of TPS 3R
Source: Compiled by the author based on field observation (2025)

The TPS 3R facility at Asrama Ciracas has a processing capacity of 25 tons per day and is equipped with facilities for organic waste composting, along with an integrated waste bank located within the same compound. The presence of this integrated waste bank has contributed positively to the management of inorganic waste by the surrounding community, thereby supporting the implementation of source-based waste reduction programs [25]. In contrast, although the TPS 3R facility at Moa possesses the same processing capacity, it lacks essential treatment facilities and supporting systems. This condition has led to low operational effectiveness and limited the unit’s capacity to manage waste optimally.

The TPS 3R facility at Joe has a relatively large processing capacity, reaching up to 37 tons per day, and is equipped with two conveyor lines and three waste processing units. This equipment configuration enables a more efficient waste sorting process, resulting in a higher volume of recyclable materials recovered compared to other TPS 3R facilities. At this site, the collected organic waste fraction is further processed into organic RDF as a means of utilizing waste with energy potential. Additionally, a portion of the organic waste is sent for treatment using a maggot cultivation system, offering a biological alternative for waste processing. The processing effectiveness at TPS 3R Joe demonstrates that equipment configuration plays a critical role in enhancing output and improving the overall efficiency of the waste management system [26]. This facility is the result of a collaborative initiative between the government, the private sector, and non-governmental organizations (NGOs) aimed at realizing a sustainable waste management system.

Meanwhile, the TPS 3R facility at Siaga is the unit with the highest processing capacity among all study locations, reaching up to 50 tons per day. Despite this, the facility is equipped with only a single processing line, resulting in suboptimal sorting of recyclable materials and lower operational efficiency compared to other TPS 3R units. Furthermore, although a waste bank is available, TPS 3R Siaga does not yet have a dedicated system for organic waste treatment. Consequently, biodegradable waste is categorized as residual and is not further utilized. This condition contributes to an increase in final disposal volumes, which may pose negative environmental impacts [27], and ultimately reduces the sustainability performance of the waste processing system at this site.

3.3 Cost Analysis

Cost analysis is a critical component in evaluating the economic feasibility and operational sustainability of solid waste processing facilities [28]. In the context of developing and managing TPS 3R, cost structures are generally classified into two main components: CAPEX and OPEX. CAPEX includes all initial investments required, such as the procurement of mechanical equipment, civil works, utility installations, supporting infrastructure development, and pre-operational expenses. Notably, all TPS 3R units examined in this study required no budget allocation for land acquisition, as the facilities were constructed on land owned by the Provincial Government of DKI Jakarta. This initiative was part of a broader program to enhance existing waste management infrastructure. As a result, no land acquisition, resettlement, or compensation for new environmental impacts was necessary. The use of public assets not only generated significant efficiencies in terms of planning and financing, but also reflected the local government's strategic approach to optimizing existing infrastructure in support of more efficient and sustainable waste management systems.

Meanwhile, OPEX represents the recurring operational costs, which include labour wages, energy consumption, equipment maintenance, residual waste management, and co-processing expenses. The analysis reveals that both CAPEX and OPEX vary significantly across TPS 3R units, as illustrated in Figure 3. These variations are primarily influenced by the processing capacity and the technological complexity implemented at each facility. The largest component of CAPEX is attributed to the procurement of core equipment, which also serves as the main differentiating factor among the sites. TPS 3R Siaga recorded the highest CAPEX, amounting to IDR 21.93 billion (USD 1.36 million), along with the highest OPEX over a 20-year operational period, reaching IDR 69.98 billion (USD 4.35 million) both figures aligning with its status as the facility with the largest waste processing capacity among all units analysed.

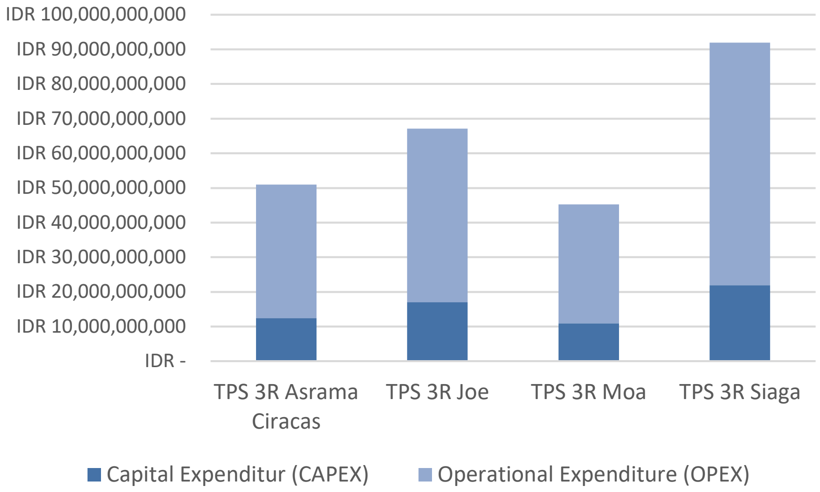

Figure 3. Comparison of Total Costs
Source: Author's data processing (2025)

3.4 Benefit Analysis

Waste-to-energy initiatives, such as the utilization of RDF at TPS 3R facilities, make significant contributions to the economic, environmental, and social dimensions of urban waste management systems. Economically, benefits are generated through revenue from sanitation service fees, RDF sales, recycling outputs, and other by-products [17], [29]. From an environmental perspective, the use of RDF as an alternative fuel particularly in the cement industry helps reduce dependence on fossil fuels and contributes to lower greenhouse gas emissions [16]. Socially, these initiatives foster the creation of new employment opportunities and promote local economic empowerment by engaging communities in the waste management value chain [30].

An analysis of the four TPS 3R units, as illustrated in Figure 4, reveals that economies of scale and the availability of supporting facilities are the primary determinants of the overall benefits generated. TPS 3R Siaga recorded the highest total benefits, amounting to IDR 132.30 billion (USD 8.22 million), primarily driven by its largest processing capacity and the substantial contribution from sanitation service fees. TPS 3R Joe ranked second, with total benefits reaching IDR 125.42 billion (USD 7.79 million), supported by a relatively balanced contribution from product sales, service fees, and environmental benefits. Meanwhile, TPS 3R Asrama Ciracas demonstrated the highest benefit efficiency per ton of waste, achieving a total of IDR 87.10 billion (USD 5.41 million). This was largely attributed to the presence of complementary facilities such as a waste bank and a composting unit. In contrast, TPS 3R Moa generated only IDR 64.96 billion (USD 4.03 million) in benefits, despite having the same processing capacity as TPS 3R Asrama Ciracas, due to the absence of supporting facilities. These findings underscore the critical role of complementary infrastructure in enhancing environmental impact and increasing the added value of RDF-based waste processing systems.

Overall, economic benefits constitute the primary contributor to the total benefits generated by the TPS 3R facilities, followed by social and environmental impacts. These findings affirm that the performance success of TPS 3R facilities is not solely determined by technical capacity, but also critically depends on the integration of supporting infrastructure and the effectiveness of operational management [31], [32]. Accordingly, future policies for the development and replication of TPS 3R facilities should adopt an integrative approach, oriented toward the sustainable achievement of multidimensional benefits.

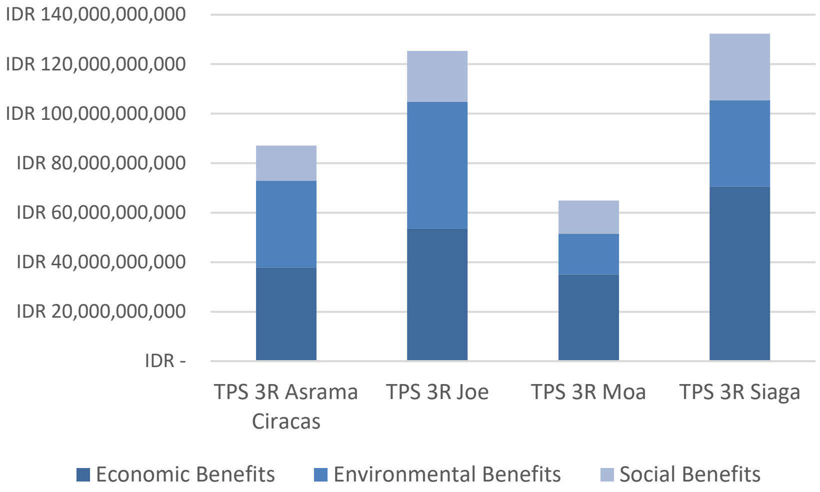

Figure 4. Comparison of Total Benefits
Source: Author’s data processing (2025)

3.5 Feasibility Assessment

Table 3. Summary of Total Costs and Benefits

Type	Component	TPS 3R Asrama Ciracas		TPS 3R Joe		TPS 3R Moa		TPS 3R Siaga	
		Present Value (IDR)	**%**	**Present Value (IDR)**	**%**	**Present Value (IDR)**	**%**	**Present Value (IDR)**	**%**
Cost	CAPEX	12.410.502.637	24	16.995.000.000	25	10.945.855.015	24	21.934.630.833	24
	OPEX	38.553.100.913	76	50.080.818.170	75	34.294.831.182	76	69.975.685.455	76
	Total Cost	**50.963.603.550**	100	**67.075.818.170**	**100**	**45.240.686.197**	**100**	**91.910.316.288**	**100**
Benefit	**Economic**								
	Product Sales	17.029.820.845	20	37.059.660.000	18	13.405.760.739	21	28.211.858.302	21
	Service Fee for SWM	20.908.786.297	24	50.738.676.213	25	21.612.744.776	33	42.321.496.398	32
	Sub Total	**37.938.607.141**	**44**	**53.566.742.029**	**43**	**35.018.505.515**	**54**	**70.533.354.700**	**53**
	Environmental								
	GHG Emission Reduction	2.704.454.854	3	2.108.115.764	2	1.236.710.511	2	2.663.684.178	2
	Reduction of Landfill Operational Costs	32.232.028.178	37	49.196.253.535	39	15.267.802.821	23	32.232.028.178	24
	Sub Total	**34.936.483.032**	**40**	**51.304.369.298**	**41**	**16.504.513.332**	**25**	**34.895.712.356**	**26**
	Social								
	Job Creation	14.224.135.449	16	20.545.973.426	16	13.433.905.702	21	26.867.811.404	20
	Total Benefits	**87.099.225.622**	**100**	**125.417.084.754**	**100**	**64.956.924.549**	**100**	**132.296.878.459**	**100**
Net Value		36.135.622.072		58.341.266.584		19.716.238.352		40.386.562.171	
BCR		1,709		1,870		1,436		1,439	
NPV		14.775.241.966		25.806.710.758		5.382.887.307		10.907.675.838	
IRR		13,60%		15,76%		8,83%		8,77%	

Source: Author’s data processing (2025)

Based on the total cost-benefit calculations presented in Table 6, all TPS 3R facilities are deemed economically feasible. However, performance disparities exist across the different sites. TPS 3R Joe demonstrated the highest level of feasibility, reflecting optimal economic efficiency and effectiveness. TPS 3R Asrama Ciracas, despite its smaller processing capacity, also exhibited strong economic viability due to the presence of complementary facilities. In contrast, TPS 3R Siaga and Moa showed lower feasibility levels, indicating the need to improve operational effectiveness and strengthen supporting infrastructure to approach the performance of higher-performing units.

TPS 3R Joe demonstrated the highest level of economic feasibility among all units, with a BCR of 1.870, a NPV of IDR 25.81 billion (USD 1.60 million), and an IRR of 15.76%. These three indicators confirm that the project is highly economically viable and generates a substantial net benefit surplus. This superior performance is supported by the presence of two sorting lines and three RDF processing machines, which enhance technical efficiency, as well as a multi-stakeholder operational strategy involving collaboration between the government, private sector, and non-governmental organizations (NGOs) in integrated waste management particularly in the treatment of organic waste.

TPS 3R Asrama Ciracas ranks second in terms of economic feasibility, with a BCR of 1.709, a NPV of IDR 14.78 billion (USD 0.92 million), and an IRR of 13.60%. Despite its limited processing capacity, the presence of supporting facilities such as a composting unit and a waste bank effectively offsets the limitations of scale. These facilities not only enhance both economic and environmental benefits but also strengthen community participation in the waste management system. The consistency of all three CBA indicators confirms that the project is highly viable, particularly as a model for community-based solid waste management in medium-scale urban areas.

In contrast, TPS 3R Siaga and TPS 3R Moa exhibit relatively lower levels of economic feasibility compared to the other two units. TPS 3R Siaga recorded a BCR of 1.439, a NPV of IDR 10.91 billion (USD 0.68 million), and an IRR of 8.77%, while TPS 3R Moa reported a BCR of 1.436, an NPV of IDR 5.38 billion (USD 0.33 million), and an IRR of 8.83%. Although TPS 3R Moa has a processing capacity equivalent to that of TPS 3R Asrama Ciracas, its limited infrastructure for organic waste treatment serves as a major constraint on the realization of optimal economic benefits. While these values are theoretically still within the feasible range, the IRR falling below the commonly accepted threshold of 10–12% indicates that the rate of return does not yet fully correspond to the expected long-term benefits. This shortfall is primarily attributed to the high proportion of unprocessed organic waste that is directly sent to the landfill, which in turn reduces the potential for generating added economic and environmental value.

Overall, TPS 3R Joe and Asrama Ciracas demonstrate strong economic feasibility, as indicated by BCR values exceeding 1.5, significant NPV, and IRR levels that surpass the standard discount rate threshold (10–12%). These three indicators reflect high technical and operational efficiency, as well as promising long-term socio-economic returns. In contrast, TPS 3R Moa and Siaga fall into the category of marginal feasibility, characterized by lower IRR and BCR values approaching the minimum acceptable limit. These findings underscore the need for strategic interventions, including improvements in technical capacity, the integration of organic waste treatment systems, and the strengthening of cross-stakeholder coordination, in order to enhance the overall effectiveness and efficiency of waste management operations at these facilities.

3.6 Discussion

Feasibility evaluation results indicate that the successful implementation of small-scale RDF technology at TPS 3R facilities is strongly influenced by a combination of technical efficiency, availability of supporting infrastructure, and adaptive governance mechanisms. All units were found to be economically viable based on Cost-Benefit Analysis indicators (BCR > 1, NPV > 0, and IRR exceeding the discount rate), although performance across units exhibited significant disparities. The conversion of conventional waste transfer stations into TPS 3R facilities not only represents a potential for fiscal efficiency through reduced CAPEX, but also contributes to limiting built-up land expansion and reducing vegetation degradation. These outcomes indirectly generate positive impacts on urban environmental quality, which is a key indicator of sustainable development [33].

Given the potential of small-scale RDF technology implementation, there is an urgent need for the Provincial Government of DKI Jakarta to revise the existing Governor Regulation concerning the Roadmap for Waste Management. This policy review is critical, as the development of large-scale waste treatment facilities requires a more comprehensive consideration of technical, environmental, and socio-economic aspects [34]. On the other hand, strengthening collaboration between government and the private sector in the development and management of TPS 3R facilities may serve as a more adaptive alternative strategy [35]. Such a collaborative model also aligns with efforts to accelerate the implementation of Extended Producer Responsibility (EPR) policies, which demand active stakeholder participation [36], as mandated by Law No. 18 of 2008 on Waste Management and Regulation of the Minister of Environment and Forestry No. P.75/MENLHK/SETJEN/KUM.1/10/2019. To date, the implementation of EPR remains suboptimal; therefore, integrating private sector roles in community-level waste management is considered a viable approach to enhancing the effectiveness of producer responsibility realization.

Although this model demonstrates significant potential, large-scale replication still requires sustained regulatory support. The establishment of a stable user fee scheme, the provision of fiscal incentives for the adoption of organic waste processing technologies, and the facilitation of cross-sector partnerships are essential components in ensuring the operational sustainability of such facilities. The findings of this study also reinforce previous research [26], [32], which emphasizes that the effectiveness of waste management systems is not solely determined by input volume or technical capacity, but is strongly influenced by the quality of governance and the presence of an integrated support ecosystem, such as waste banks. The existence of waste banks in close proximity to TPS 3R facilities has been shown to significantly enhance the overall effectiveness and efficiency of solid waste management [37].

Therefore, the future development strategy for TPS 3R facilities should adopt an integrative approach that encompasses the optimization of technological efficiency, the implementation of community-based operational strategies, and the formulation of adaptive policies tailored to the local characteristics of urban waste generation. This approach is particularly crucial in areas with high volumes of solid waste to ensure more effective and sustainable waste management [38]. Community-based strategies have been proven to enhance the efficiency of waste collection processes and contribute to the achievement of sustainability goals [39]. Furthermore, the high proportion of organic waste necessitates more efficient utilization alternatives, one of which is biogas production. Biogas generated through the anaerobic fermentation of organic materials offers a clean and environmentally friendly energy solution, while simultaneously supporting the transition toward a more sustainable waste management system [40].

4. Conclusion

This study concludes that the feasibility and performance of 3R TPS 3R utilizing small scale RDF technology in Jakarta are determined not only by technical capacity, but also crucially by institutional integration, policy support, and the local characteristics of waste generation. The results of the Cost-Benefit Analysis indicate that although all units were deemed economically viable (BCR > 1, NPV > 0, and IRR > discount rate), there are significant variations in performance across the different sites.

These findings underscore that future development of TPS 3R facilities must prioritize an integrated approach, encompassing technological efficiency through equipment and process optimization, community based operational strategies to enhance participation, adaptive policy frameworks aligned with local waste composition, and cross sector institutional synergy to ensure the long term sustainability of RDF based systems.

Given the high moisture content and the dominance of organic waste in Jakarta’s urban areas, investment in pre-treatment infrastructure such as source separation, drying, and organic waste processing is crucial to improve the calorific value and meet industrial RDF standards. Future policies should focus on generating multidimensional benefits economic, social, and environmental as the foundation for strengthening a resilient and sustainable waste management system.

The small-scale RDF processing model implemented through TPS 3R facilities in Jakarta demonstrates strong potential for replication in other cities across Indonesia, particularly in areas facing land constraints and increasing waste generation pressures. However, the success of such replication efforts largely depends on adjustments tailored to the socio-economic conditions and waste characteristics specific to each region. Therefore, the development of small-scale RDF systems should be positioned as an integral component of the national strategy to strengthen waste management system resilience, while also supporting the transition toward a sustainable circular economy.

Acknowledgements
The author would like to express sincere gratitude to the Provincial Government of DKI Jakarta for the support and facilitation provided during this research. Special appreciation is extended to the Human Resources Development Agency (BPSDM) of DKI Jakarta Province and the Environmental Agency of DKI Jakarta Province for their cooperation, provision of data, and access to research facilities, all of which significantly contributed to the successful completion of this study.

References
[1] K. D. Sharma and S. Jain, 'Municipal solid waste generation, composition, and management: the global scenario', *Soc. Responsib. J.*, vol. 16, no. 6, pp. 917–948, Jun. 2020, doi: 10.1108/SRJ-06-2019-0210.
[2] UNEP, Ed., *Beyond an age of waste: turning rubbish into a resource*. in Global waste management outlook, no. 2024. Nairobi: UNEP, 2024.
[3] E. A. Wikurendra, A. Csonka, I. Nagy, and G. Nurika, 'Urbanization and Benefit of Integration Circular Economy into Waste Management in Indonesia: A Review', *Circ. Econ. Sustain.*, vol. 4, no. 2, pp. 1219–1248, Jun. 2024, doi: 10.1007/s43615-024-00346-w.
[4] Y. A. Fatimah, K. Govindan, R. Murniningsih, and A. Setiawan, 'Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia', *J. Clean. Prod.*, vol. 269, p. 122263, Oct. 2020, doi: 10.1016/j.jclepro.2020.122263.
[5] F. Melakessou, P. Kugener, N. Alnaffakh, S. Faye, and D. Khadraoui, 'Heterogeneous Sensing Data Analysis for Commercial Waste Collection', *Sensors*, vol. 20, no. 4, p. 978, Feb. 2020, doi: 10.3390/s20040978.
[6] L. Zhang *et al.*, 'The reduction of the carbon footprint of municipal solid waste management via source classification and supporting strategies: An analysis for the megacity of Shenzhen', *Waste Manag.*, vol. 187, pp. 145–155, Oct. 2024, doi: 10.1016/j.wasman.2024.07.012.
[7] I. W. K. Suryawan and C.-H. Lee, 'Achieving zero waste for landfills by employing adaptive municipal solid waste management services', *Ecol. Indic.*, vol. 165, p. 112191, Aug. 2024, doi: 10.1016/j.ecolind.2024.112191.
[8] H. Rezaei, F. Yazdan Panah, C. J. Lim, and S. Sokhansanj, 'Pelletization of Refuse-Derived Fuel with Varying Compositions of Plastic, Paper, Organic and Wood', *Sustainability*, vol. 12, no. 11, p. 4645, Jun. 2020, doi: 10.3390/su12114645.
[9] M. Stričík, L. Kuhnová, M. Variny, P. Szaryszová, B. Kršák, and Ľ. Štrba, 'An Opportunity for Coal Thermal Power Plants Facing Phase-Out: Case of the Power Plant Vojany (Slovakia)', *Energies*, vol. 17, no. 3, p. 585, Jan. 2024, doi: 10.3390/en17030585.
[10] Wiharja *et al.*, 'Research on the matching relationship of municipal solid waste management and alternative fuel in Indonesia's cement industry', *Case Stud. Chem. Environ. Eng.*, vol. 11, p. 101098, Jun. 2025, doi: 10.1016/j.cscee.2025.101098.
[11] J. A. M. Chavando, V. B. Silva, L. A. C. Tarelho, J. S. Cardoso, and D. Eusébio, 'Snapshot review of refuse-derived fuels', *Util. Policy*, vol. 74, p. 101316, Feb. 2022, doi: 10.1016/j.jup.2021.101316.
[12] A. Siddiqi, M. Haraguchi, and V. Narayanamurti, 'Urban waste to energy recovery assessment simulations for developing countries', *World Dev.*, vol. 131, p. 104949, Jul. 2020, doi: 10.1016/j.worlddev.2020.104949.
[13] A. H. Khan *et al.*, 'Evaluation of cost benefit analysis of municipal solid waste management systems', *J. King Saud Univ. - Sci.*, vol. 34, no. 4, p. 101997, Jun. 2022, doi: 10.1016/j.jksus.2022.101997.
[14] C. Ghinea and M. Gavrilescu, 'Costs Analysis of Municipal Solid Waste Management Scenarios: Iasi – Romania Case Study', *J. Environ. Eng. Landsc. Manag.*, vol. 24(3), pp. 185–199, 2016, doi: https://doi.org/10.3846/16486897.2012.721784.

[15] T. Jamasb and R. Nepal, ‘Issues and options in waste management: A social cost–benefit analysis of waste-to-energy in the UK’, *Resour. Conserv. Recycl.*, vol. 54, no. 12, pp. 1341–1352, Oct. 2010, doi: 10.1016/j.resconrec.2010.05.004.

[16] G. De Lorena Diniz Chaves, R. R. Siman, G. M. Ribeiro, and N.-B. Chang, ‘Synergizing environmental, social, and economic sustainability factors for refuse derived fuel use in cement industry: A case study in Espirito Santo, Brazil’, *J. Environ. Manage.*, vol. 288, p. 112401, Jun. 2021, doi: 10.1016/j.jenvman.2021.112401.

[17] D. Prihandoko, C. W. Purnomo, P. K. Widyaputra, and N. Nasirudin, ‘Application of Refuse-Derived Fuel (RDF) Plant in Piyungan Landfill Municipal Solid Waste Management’, *ASEAN J. Chem. Eng.*, vol. 22, no. 2, p. 296, Dec. 2022, doi: 10.22146/ajche.75560.

[18] B. H. M. Zahir, R. Nurcahyo, Farizal, and A. D. Wibowo, ‘ECONOMIC ASSESSMENT OF REFUSE-DERIVED FUEL (RDF) PRODUCTION AS WASTE MANAGEMENT STRATEGY AND ALTERNATIVE FUEL IN CEMENT KILNS’, *J. Law Sustain. Dev.*, vol. 12, no. 2, p. e3220, Feb. 2024, doi: 10.55908/sdgs.v12i2.3220.

[19] G. Squires, *Urban and Environmental Economics: An Introduction*, 1st ed. Routledge, 2012. doi: 10.4324/9780203825990.

[20] G. Shively, ‘An Overview of Benefit-Cost Analysis’, Jan. 2012.

[21] A. T. Hoang *et al.*, ‘Perspective review on Municipal Solid Waste-to-energy route: Characteristics, management strategy, and role in circular economy’, *J. Clean. Prod.*, vol. 359, p. 131897, Jul. 2022, doi: 10.1016/j.jclepro.2022.131897.

[22] P. Damayanti, S. S. Moersidik, and J. T. Haryanto, ‘Waste to Energy in Sunter, Jakarta, Indonesia: Plans and Challenges’, *IOP Conf. Ser. Earth Environ. Sci.*, vol. 940, no. 1, p. 012033, Dec. 2021, doi: 10.1088/1755-1315/940/1/012033.

[23] H. A. M. Salman, ‘Optimizing Biomass Pre-Treatment Technologies for BBJP Plants in Indonesia: A Multi-Criteria Decision Making Approach’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 6, no. 1, p. 02401021, Jan. 2024, doi: 10.26877/asset.v6i1.17877.

[24] M. Zulhusni, C. A. Sari, and E. H. Rachmawanto, ‘Implementation of DenseNet121 Architecture for Waste Type Classification’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 6, no. 3, p. 02403015, Jul. 2024, doi: 10.26877/asset.v6i3.673.

[25] M. R. Ismiraj, A. Wulansari, Y. Setiadi, A. Pratama, and N. Mayasari, ‘Perceptions of Community-Based Waste Bank Operators and Customers on Its Establishment and Operationalization: Cases in Pangandaran, Indonesia’, *Sustainability*, vol. 15, no. 14, p. 11052, Jul. 2023, doi: 10.3390/su151411052.

[26] G. Gadaleta, S. De Gisi, F. Todaro, G. D’Alessandro, S. Binetti, and M. Notarnicola, ‘Assessing the Sorting Efficiency of Plastic Packaging Waste in an Italian Material Recovery Facility: Current and Upgraded Configuration’, *Recycling*, vol. 8, no. 1, p. 25, Feb. 2023, doi: 10.3390/recycling8010025.

[27] A. S. Bello, M. A. Al-Ghouti, and M. H. Abu-Dieyeh, ‘Sustainable and long-term management of municipal solid waste: A review’, *Bioresour. Technol. Rep.*, vol. 18, p. 101067, Jun. 2022, doi: 10.1016/j.biteb.2022.101067.

[28] B. H. Dastjerdi, V. Strezov, R. Kumar, and M. Behnia, ‘Economic Feasibility and Sustainability Assessment of Residual Municipal Solid Waste Management Scenarios in NSW, Australia’, *Sustainability*, vol. 13, no. 16, p. 8972, Aug. 2021, doi: 10.3390/su13168972.

[29] R. Prateep Na Talang and S. Sirivithayapakorn, ‘Comparative analysis of environmental costs, economic return and social impact of national-level municipal solid waste management schemes in Thailand’, *J. Clean. Prod.*, vol. 343, p. 131017, Apr. 2022, doi: 10.1016/j.jclepro.2022.131017.

[30] W. Ahmad *et al.*, ‘Socio-economic benefits and policy implications of generating sustainable energy from municipal solid waste in Pakistan’, *Energy Clim. Change*, vol. 5, p. 100124, Dec. 2024, doi: 10.1016/j.egycc.2023.100124.

[31] M. Struk and M. Boďa, ‘Factors influencing performance in municipal solid waste management – A case study of Czech municipalities’, *Waste Manag.*, vol. 139, pp. 227–249, Feb. 2022, doi: 10.1016/j.wasman.2021.09.022.

[32] F. M. Tsai, T.-D. Bui, M.-L. Tseng, K.-J. Wu, and A. Sf. Chiu, ‘A performance assessment approach for integrated solid waste management using a sustainable balanced scorecard approach’, *J. Clean. Prod.*, vol. 251, p. 119740, Apr. 2020, doi: 10.1016/j.jclepro.2019.119740.

[33] W. Sidiq, T. Sanjoto, and A. Jabbar, ‘Assessing Environmental Quality Using the Risk Screening Environmental Indicators (RSEI) Method: A Multi-Year Remote Sensing Approach’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 7, p. 0250302, May 2025, doi: 10.26877/pf84qe16.

[34] A. H. Khan *et al.*, ‘Municipal solid waste generation and the current state of waste-to-energy potential: State of art review’, *Energy Convers. Manag.*, vol. 267, p. 115905, Sep. 2022, doi: 10.1016/j.enconman.2022.115905.

[35] S. Mor and K. Ravindra, ‘Municipal solid waste landfills in lower- and middle-income countries: Environmental impacts, challenges and sustainable management practices’, *Process Saf. Environ. Prot.*, vol. 174, pp. 510–530, Jun. 2023, doi: 10.1016/j.psep.2023.04.014.

[36] T. T. Y. Anh, S. Herat, and K. Prasad, ‘A Review on Extended Producer Responsibility Schemes for Packaging Waste Management and Research Gaps in the Field’, *Nat. Environ. Pollut. Technol.*, vol. 24, no. 1, p. D1662, Mar. 2025, doi: 10.46488/NEPT.2025.v24i01.D1662.

[37] V. Arsanti *et al.*, ‘Spatial Analysis of Waste Management Facility Distribution Using GIS’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 6, no. 4, p. 02404013, Sep. 2024, doi: 10.26877/asset.v6i4.996.

[38] M. Labambe, ‘Predicting Waste Production Trends in Palu City Using Linear Regression Analysis’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 6, no. 3, p. 0240306, Jun. 2024, doi: 10.26877/asset.v6i3.523.

[39] S. Purwati, ‘Evaluating Sustainable Waste Collection Models Using the Analytical Hierarchy Process (AHP): A Multi-Criteria Decision-Making Approach’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 7, p. 0250305, May 2025, doi: 10.26877/25x2jy26.

[40] D. I. Setyanansyach, M. Setiyo, and T. Raja, ‘Review and Bibliometric Analysis of Biogas Power Plants in Indonesia’, *Adv. Sustain. Sci. Eng. Technol.*, vol. 5, no. 3, p. 02303015, Oct. 2023, doi: 10.26877/asset.v5i3.16806.