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Green Budgeting Strategy for Waste Sector Greenhouse Gas Mitigation: A QSPM-Based Approach in Bogor City

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Abstract

Background: The waste sector is a local authority emission source whose mitigation depends on structure of public expenditure rather than its size alone.
Objective: This study formulates a budget allocation strategy for the Bogor City Environmental Agency (*Dinas Lingkungan Hidup* [DLH]) to support greenhouse gas (GHG) emission reduction in the waste sector.
Methods: Spending data from 2017–2024 were functionally reclassified into core mitigation, downstream operational, and supporting components to ensure comparability across the 2021 fiscal nomenclature transition. The analysis combined descriptive methods, exploratory multiple linear regression with a COVID-19 dummy variable and a two-year lag (n = 6), and a strategic management framework comprising the Internal Factor Evaluation (IFE) matrix, External Factor Evaluation (EFE) matrix, Internal–External (IE) matrix, Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, and Quantitative Strategic Planning Matrix (QSPM) assessed by nine purposively selected expert respondents.
Results: Core mitigation activities absorbed only approximately one-sixth of total mitigation spending, while downstream operations dominated budget allocation, and proportion allocated to core mitigation tended to shrink after 2018. Exploratory regression indicated that each additional million rupiah allocated to core mitigation was associated with an approximately 3.2-ton reduction in CO_2-equivalent (CO_2eq) emissions two years later (p = 0.021). The strategic position analysis placed DLH in a hold-and-maintain quadrant. Among seven identified strategies, large-scale organic waste processing through partnerships received the highest QSPM score, with the top four strategies forming a complementary priority cluster.
Conclusion: The findings indicate allocative quality, rather than budget volume alone, determines the effectiveness of mitigation spending.

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INTRODUCTION

Indonesia has positioned greenhouse gas (GHG) emission control as part of its low-carbon development commitment, with national emission reduction targets reinforced through the Enhanced Nationally Determined Contribution (NDC) in 2022, namely 31.89% through domestic efforts and 43.20% with international support by 2030. This commitment is cascaded to the regional level through the Regional Action Plan for Greenhouse Gas Emission Reduction (RAD GRK). In low-carbon development, regional fiscal policy serves as an emission control instrument because government spending not only finances operations but also directs behavioral change and strengthens system management capacity (Magno et al., 2015).

The concept of green budgeting provides a theoretical framework for linking fiscal policy to environmental outcomes. The OECD (2020) defines green budgeting as the systematic integration of environmental and climate considerations into budgetary processes through tagging, assessment, and alignment of expenditures with environmental objectives. This concept extends earlier performance-based budgeting frameworks by incorporating an environmental outcome dimension (Rubin, 2020). In developing countries, Environmental Public Expenditure Reviews (EPERs) have been used to evaluate whether government spending effectively addresses environmental priorities (World Bank, 2021). Climate budgeting, as a subset of green budgeting, specifically focuses on tracking expenditures related to climate change mitigation and adaptation. These theoretical foundations underpin the present study's approach of reclassifying expenditures based on their functional contribution to emission reduction rather than relying solely on programmatic or nominal budget categories.

At the city level, the waste sector is a relevant emission source because it falls under the direct authority of local governments, particularly through waste management activities that produce methane from anaerobic decomposition at final disposal sites (IPCC, 2006). Bogor City has conducted GHG inventories since 2013 and established a waste sector emission reduction target in the RAD GRK of 22.28% by 2030 and 29.74% by 2035, which is higher than the average target across all sectors (Bapperida Kota Bogor, 2023). This target includes solid waste management, which is under the authority of the Environmental Agency (Dinas Lingkungan Hidup [DLH]), as well as wastewater management, which is under the authority of the Public Works and Spatial Planning Agency. Therefore, this analysis focuses on the solid waste component within DLH's authority.

The Bogor City Environmental Agency (Dinas Lingkungan Hidup [DLH]) implements waste sector emission reduction programs through regional budget allocations. Although climate planning documents are available, implementation has not been fully realized; therefore, the gap between emission reduction targets and achievements is primarily related to implementation rather than the absence of planning documents. This issue is important because increased budgets do not always lead to emission reductions; in several years, increases in expenditure coincided with rising waste sector emissions. This condition indicates that the effectiveness of DLH expenditure is determined by the direction and structure of spending rather than by its magnitude alone (Halkos & Paizanos, 2017; Kaza et al., 2018).

Previous studies in Bogor City have largely focused on the transportation sector (Lesmana, 2014; Prihartono et al., 2024), while environmental budgeting studies generally remain limited to examining allocation magnitude across the entire regional budget and have not linked the expenditure structure of a specific regional agency with sectoral emission reduction achievements (Pambudi, 2024; Suharyono, 2025). Moreover, existing studies present inconsistent findings regarding the relationship between budget size and environmental outcomes: some suggest that increased allocation improves performance (Magno et al., 2015), while others demonstrate that increased spending may coincide with rising emissions when allocative quality is neglected (Halkos & Paizanos, 2017).

Cross-country studies likewise indicate that the environmental effect of public spending depends on its composition and targeting rather than on its total amount (Lopez et al., 2011; Adewuyi, 2016; Jin et al., 2022). This inconsistency reinforces the need to move beyond aggregate budget analysis toward functional expenditure reclassification that distinguishes core mitigation activities from downstream operational spending. No previous research has analyzed the relationship between the budget allocation of a single sectoral regional organization and GHG emission reduction achievements in the waste sector under its authority. This study addresses this gap by reclassifying DLH expenditures according to their contribution to mitigation and subsequently formulating prioritized allocation strategies.

The primary novelty of this study lies in the integration of three analytical approaches—functional budget reclassification, exploratory regression analysis, and the Quantitative Strategic Planning Matrix (QSPM)—to support emissions-based budget decision-making at the local government level. Previous studies have generally focused on budget magnitude or employed a single analytical approach, providing limited insight into how expenditure composition influences environmental outcomes. By combining expenditure–emission analysis with strategic management tools, this study not only examines the relationship between budget allocation and emission reduction but also develops prioritized strategies for improving green budgeting in the waste sector.

Accordingly, this study aims to analyze the development of waste sector greenhouse gas (GHG) emissions and trends in Environmental Agency (DLH) budget allocation in Bogor City during the 2017–2024 period. It also examines the relationship between budget allocation and waste sector GHG emission reduction achievements and formulates prioritized budget allocation strategies to strengthen the effectiveness of emission mitigation in the waste sector.

This study contributes to the green budgeting literature by demonstrating that functional expenditure reclassification can be used to evaluate the allocative quality of environmental spending at the subnational government level. The integration of expenditure analysis, exploratory regression, and QSPM also provides a practical analytical framework for linking fiscal allocation with strategic decision-making. The findings provide evidence-based recommendations to support more effective and cost-efficient budget allocation for waste sector mitigation, thereby assisting local governments in strengthening climate policy implementation through green budgeting.

METHOD

The research was conducted in Bogor City, West Java, selected purposively because it has implemented various GHG emission reduction efforts, with the Environmental Agency (*Dinas Lingkungan Hidup*/DLH) as the main actor. Data collection and processing took place from December 2025 to May 2026. Quantitative data included DLH budget allocations and realizations for the 2017–2024 period, as well as waste sector GHG emissions from inventory results, sourced from regional budgets, budget realization reports, the Regional Action Plan for Greenhouse Gas Emission Reduction (*Rencana Aksi Daerah Penurunan Emisi Gas Rumah Kaca*/RAD GRK), inventory reports, and GHG Monitoring, Evaluation, and Reporting (*Pemantauan, Evaluasi, dan Pelaporan*/PEP) documents. Two emission series were used for distinct purposes and were never combined arithmetically: the annual GHG inventory series served as actual emission data for trend analysis and regression, whereas the RAD GRK projections and PEP GRK reports provided Business as Usual (BAU) assumptions and reported achievement figures for the formulation of strategic factors. Qualitative data were obtained through interviews with expert respondents selected purposively from DLH, the Regional Development Planning Agency (*Badan Perencanaan Pembangunan, Riset, dan Inovasi Daerah*/Bapperida), and the Regional Finance and Asset Agency (*Badan Keuangan dan Aset Daerah*/BKAD), serving as the basis for formulating strategic factors.

Respondent selection did not rely on large numbers but rather on relevance and authority in planning, budgeting, and implementing emission reduction programs (expert judgment). The number of expert respondents was nine, which was considered adequate for determining weights, ratings, and strategy attractiveness scores (Sugiyono, 2016).

Before analysis, DLH expenditure data required harmonization due to the transition in regional financial nomenclature from Minister of Home Affairs Regulation Number 13 of 2006 to Government Regulation Number 12 of 2019, which became effective in the preparation of regional budgets starting from the 2021 fiscal year. As a result of this transition, program and activity names during 2021–2024 differed from those in the previous period and could not be directly used as cross-period analysis units. Therefore, DLH expenditures were regrouped according to the functional classification of activities, with adjustments to sub-activity titles under the new nomenclature to maintain consistency across periods.

Despite these changes, activities were mapped into core mitigation expenditures, waste operational expenditures, and supporting expenditures, following the review of core and supporting activities in the RAD GRK and the concepts of climate budgeting and green budgeting (OECD 2020). Core mitigation expenditures cover activities that reduce waste generation at its source and are therefore directed at future emission reductions, such as community education and empowerment, cleanliness competitions, technical guidance, and waste reduction through TPS 3R facilities, waste banks, and 3R-based management. Waste operational expenditures handle waste that has already been generated and accumulates downstream, namely transportation, the provision and maintenance of facilities, and landfill operations, which keep services running but do not reduce generation at the source. Supporting expenditures are complementary, covering document preparation and studies, GHG inventories, environmental quality monitoring and testing, and compliance guidance, which provide data and oversight without directly reducing emissions. This functional grouping became the unit of analysis for examining expenditure trends and their relationship with emission reduction achievements.

The pattern of the relationship between expenditures and emissions was examined exploratorily using multiple linear regression with the ordinary least squares (OLS) method (Gujarati & Porter, 2009), incorporating a pandemic-period dummy variable and a two-year lag alignment between expenditure realization and emission outcomes:

$$\text{Emissions}^{t} = \alpha + \beta^{1}\text{CM}^{t-2} + \beta^{2}\text{D} + \varepsilon$$

where Emissions^{t} represents waste sector GHG emissions (tons CO_2eq) as the dependent variable, CMt−2 represents core mitigation expenditures two years earlier (million rupiah), and D represents the pandemic dummy variable. The two-year lag alignment was based on the time interval between expenditure realization and its measurable impact on annual emission inventories. Activities such as 3R temporary waste collection sites (*Tempat Pengolahan Sampah* Reduce-Reuse-Recycle / TPS 3R) construction generally begin with socialization activities in the first year and physical implementation in the second year; therefore, emission reductions may only become observable several years later (Hocherman et al., 2025).

This alignment paired expenditure realizations for 2017–2022 with emissions for 2019–2024, resulting in six observations (n = 6) with three degrees of freedom for error. Because the number of observations was very limited, the regression was positioned as an exploratory examination to identify the direction and strength of the observed pattern rather than as a causal test, and the results were interpreted together with the qualitative expenditure classification analysis. With only six observations, statistical significance indicates that the model demonstrates a statistical fit with the available data but is insufficient to establish a causal relationship.

The descriptive and regression results served as inputs for strategic analysis following the three stages of the David et al. (2017) framework: the input stage through the Internal Factor Evaluation (IFE) and External Factor Evaluation (EFE) matrices; the matching stage through the Internal–External (IE) matrix and SWOT analysis; and the decision stage through the Quantitative Strategic Planning Matrix (QSPM). This analysis was based on strategic logic aimed at maximizing strengths and opportunities while minimizing weaknesses and threats (Rangkuti, 2016). The list of strategic factors was compiled from a review of regional performance documents and relevant literature, then validated by expert respondents. Weights were determined using the paired comparison method (Kinnear & Taylor, 1991), while ratings followed the David et al. (2017) scale ranging from 1 to 4. In the QSPM, attractiveness scores (AS) provided by respondents were multiplied by the assigned weights to obtain total attractiveness scores (TAS), which were then averaged across respondents to determine strategy priorities.

RESULTS AND DISCUSSION

Results

Waste Sector GHG Emission Development

Bogor City's waste sector GHG emissions fluctuated and showed an increasing trend toward the end of the observation period. Calculated following the IPCC Guidelines (2006) and the 2019 Refinement, emissions rose steadily from 2017 to 2020, declined slightly in 2021 in line with reduced activity during the pandemic, and then increased again to reach their peak in 2024. Over the 2017–2024 period, the emission inventory recorded an increase from approximately 241,439.09 tons CO_2eq to 289,101.99 tons CO_2eq, consistent with population growth and increasing economic activity. The waste sector's contribution to total city-level emissions ranged from 10.91% to 12.70%, showing a fluctuating pattern; however, its role in greenhouse gas emission mitigation remains substantial.

Table 1. Bogor City waste sector GHG emissions, 2017–2024

Year	Waste sector emissions (ton CO_2eq)	Total emissions (ton CO_2eq)	Contribution (%)
2017	241,439.09	2,018,361.70	11.96
2018	252,485.65	1,988,816.17	12.70
2019	258,579.37	2,041,107.38	12.67
2020	261,770.23	2,280,278.40	11.48
2021	258,495.58	2,040,589.79	12.67
2022	274,054.80	2,282,797.07	12.01
2023	281,090.88	2,456,021.34	11.44
2024	289,101.99	2,649,585.77	10.91

Source: Bogor City GHG Inventory 2018–2025 (processed)

All figures in Table 1 are actual data from the annual GHG inventory rather than projections or model outputs. Emission changes were associated with several interrelated factors: increased waste generation due to population growth and consumption; the dominance of landfill disposal as a methane source, a gas with a global warming potential far exceeding that of CO_2; limited infrastructure and processing technologies; fluctuations in socioeconomic activity due to the pandemic; and suboptimal integration of policies and budget allocation (Kaza et al., 2018). The persistent upward trajectory despite mitigation programs underscores the structural limitations of relying on downstream waste management approaches rather than implementing source reduction interventions.

DLH Budget Allocation Trends and Reclassification

DLH budget allocations during 2017–2024 fluctuated, with a sharp decline in 2020 due to pandemic-related budget refocusing, followed by recovery and further strengthening in 2024. The observation period includes the COVID-19 pandemic, during which activity refocusing and budget reallocation policies from 2020 to 2022 altered regional expenditure patterns based on Presidential Instruction Number 4 of 2020 and the Joint Decree of the Minister of Home Affairs and the Minister of Finance Numbers 119/2813/SJ and 177/KMK.07/2020 (Suparman, 2021). Not all DLH expenditures were used as the analysis unit, as some consisted of administrative and routine operational spending that was not directly related to emission reduction efforts.

The identification process referred to the DLH Strategic Plan 2019–2024, the Regional Action Plan for Greenhouse Gas Emission Reduction (RAD GRK), and the Monitoring, Evaluation, and Reporting of Greenhouse Gas Emission Reduction (PEP GRK) 2025. Activities were categorized as mitigation expenditures if they were directly related to reducing waste disposal to landfills, organic waste processing, methane emission reduction, and community-based waste management. Because DLH's authority is limited to solid waste management, wastewater treatment plant activities were excluded from the scope of DLH expenditures, consistent with the reporting of three solid waste management activities in the Aksara application (Galuga Landfill, TPST/TPS3R, and Waste Banks).

The reclassification results (Table 2) show that the proportion of mitigation expenditures relative to total DLH expenditures ranged from 12.44% to 28.43% throughout 2017–2024, with the lowest proportion recorded in 2020 at 12.44%. Following the pandemic period, the proportion stabilized within the range of 21%–22%. This stability indicates increased attention toward the mitigation agenda; however, it has not yet been accompanied by improvements in the quality of the expenditure structure, as examined in the subsequent discussion.

Table 2. Reclassification of waste sector GHG mitigation spending, 2017–2024

Year	Total DLH spending (Rp)	GHG mitigation spending (Rp)	Mitigation (%)
2017	111,009,315,380	31,560,858,552	28.43
2018	112,254,647,505	22,886,506,986	20.39
2019	126,844,416,881	20,490,722,947	16.15
2020	109,769,551,901	13,654,145,310	12.44
2021	116,927,980,646	26,183,860,273	22.39
2022	120,495,777,456	26,790,506,254	22.23
2023	108,538,993,259	23,200,993,283	21.38
2024	127,098,030,817	27,772,098,175	21.85

Source: Bogor City regional regulations on budget realization accountability (P2APBD) 2017–2024, 2026 (processed)

Identification and Classification of Mitigation Activities

Mitigation activities listed in the RAD GRK were classified according to their relevance to emission reduction (Table 3). Core activities are those that directly reduce the amount of waste entering landfills and suppress methane emissions, particularly 3R-based waste management and waste reduction at the source. Supporting activities contribute through supervision, monitoring, inventory development, and institutional strengthening, including landfill operations, which are important but remain responsive to waste generation volumes. This classification applies specifically to activities included within the RAD GRK framework; administrative and routine operational expenditures outside this framework are excluded from the classification.

Table 3. Classification of activities according to level of relevance to GHG emission reduction

Level	Example activities	Role in emissions
Core	Construction of community-based 3R waste reduction facilities; 3R waste management; community empowerment in waste management; coaching and technical guidance on waste management; cleanliness competitions	Reduces waste to landfill and suppresses methane emissions from source
Supporting	GHG inventory; climate village development; water, air, and soil quality testing and analysis; landfill facility management and maintenance; procurement and rejuvenation of waste facilities	Monitors, supervises, and supports the system; association with emissions is indirect

Source: secondary data, 2026 (processed)

Composition of Mitigation Spending

Total mitigation spending was divided into three components: core mitigation spending, which directly contributes to emission reductions; waste operational spending, which responds to downstream waste volumes; and non-waste supporting spending. As defined in the Method section, core mitigation spending is the component that reduces waste generation at its source, in contrast with operational spending that responds to waste already accumulating downstream. In aggregate, from 2017 to 2024, operational spending accounted for 79.4% of total mitigation spending, followed by core spending at 16.3% and supporting spending at 4.4%. The average operational spending (Rp19,108.50 million per year) was 4.9 times higher than core spending (Rp3,911.66 million), with a range of 1.7 to 10.8 times. The proportion of core spending declined from 34.9% in 2017 and 24.5% in 2018 to approximately 8%–15% during 2019–2024. Therefore, the low allocation of core spending represents a deteriorating condition rather than a permanent absence; activities that directly contribute to emission reductions are increasingly constrained by reactive downstream operational expenditures. This pattern is consistent with previous findings that end-of-pipe approaches have limited effectiveness compared with source reduction strategies (Hoornweg & Bhada-Tata, 2012; Kaza et al., 2018).

Table 4. Composition of GHG mitigation spending by component, Bogor City 2017–2024 (million Rp)

Year	Core mitigation	Waste operations	Supporting	Total
2017	11,015.45	18,940.40	1,605.01	31,560.86
2018	5,612.16	15,847.69	1,426.66	22,886.51
2019	3,107.20	15,833.52	1,550.00	20,490.72
2020	1,159.20	12,494.95	0.00	13,654.15
2021	3,489.82	21,694.40	999.63	26,183.86
2022	2,418.32	23,466.71	905.48	26,790.51
2023	2,160.01	20,057.35	983.64	23,200.99
2024	2,331.10	24,532.96	908.04	27,772.10
Average	3,911.66	19,108.50	1,047.31	23,015.39

Source: secondary data, 2026 (processed)

Pattern of Relationship between Spending and Emissions

The exploratory regression model produced the equation $\text{Emissions}_{(t)} = 294{,}313 - 3.201\ \text{CM}_{(t-2)} - 19{,}000\ \text{D}$ (Table 5). The negative coefficient of core mitigation spending indicates a tendency for higher core spending to be associated with lower emissions two years later, a direction consistent with mitigation logic and the presence of an impact lag. The negative dummy coefficient also indicates lower emissions during pandemic-period observations. The overall model was statistically significant ($F = 13.45$; $p = 0.032$), with all three coefficients significant at the 20% level adopted a priori given the very small sample and a VIF value of 1.15, indicating no symptoms of multicollinearity. The Anderson-Darling test on residuals ($AD = 0.247$; $p = 0.517$) did not reject the assumption of residual normality.

The core mitigation spending coefficient of −3.201 indicates that, holding the pandemic effect constant, each additional one million rupiah of core spending two years earlier is associated with an estimated reduction of approximately 3.2 tons of CO_2eq in current-year emissions. The constant value of 294,313 tons represents the estimated emission level when core spending is zero during a non-pandemic period and should be interpreted as a mathematical intercept outside the observed data range rather than as an actual condition.

The dummy coefficient of −19,000 indicates that estimated emissions during pandemic-period observations were approximately 19,000 tons lower than those in normal periods at the same spending level, which is consistent with reduced economic activity and lower waste generation during 2020–2022. Separating the pandemic effect through the dummy variable prevents emission reductions caused by reduced activity levels from being misinterpreted as the direct impact of spending. Figure 1 illustrates this relationship: the slope of the regression line represents the spending coefficient, whereas the vertical distance between the lines represents the estimated pandemic-related shift. All emission values implied by the equation are model estimates rather than measured data and should be read within the exploratory scope of the analysis.

The R^2 value of 89.97% should be interpreted cautiously. Given the limited sample size of only six observations and three degrees of freedom for error, the statistical power is low, and the results are not intended for broad generalization. With only six years of observation and no additional control variables, the estimates remain sensitive to individual data points, and the results are positioned as exploratory findings that are not intended for generalization. Therefore, the coefficient value of −3.201 should be interpreted as an indication of the direction and approximate magnitude of the relationship rather than as a precise elasticity estimate. The regression results are considered supporting evidence that strengthens the analytical direction rather than providing causal proof; therefore, the primary basis for the strategic argument remains the reclassification of spending and the strategic prioritization analysis. Nevertheless, the consistently negative association between core spending and emissions provides preliminary empirical support for the proposed spending reorientation strategy toward core mitigation activities discussed in the following section.

Table 5. Exploratory multiple linear regression estimation results (n=6)

Predictor	Coefficient	T	p-value
Constant	294,313	57.99	0.000
Core mitigation spending (t−2)	−3.201	−4.45	0.021
Pandemic dummy (D)	−19,000	−4.10	0.026
R^2 = 89.97%; R^2 Adjusted = 83.28%; F = 13.45 (p = 0.032); VIF = 1.15			

Source: primary data, 2026 (processed)

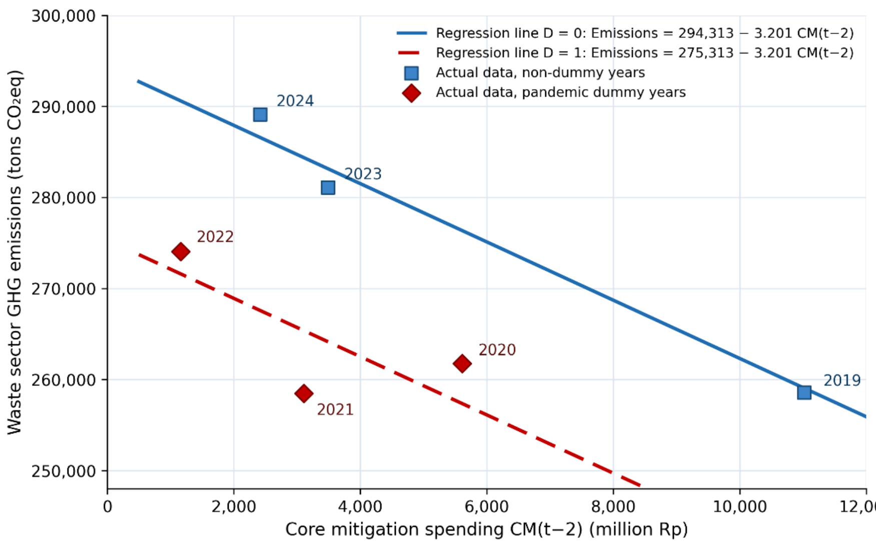

Figure 1. Relationship between core mitigation spending (t−2) and waste sector GHG emissions according to the regression model

Strategic Position: IFE, EFE, and IE Matrices

Identification of strategic factors focused on activities with direct impacts on emission reduction was based on traceable evidence from regional performance documents and subsequently validated by expert respondents (David et al., 2017). The identified strategic factors emphasized activities with direct contributions to emission reduction and were validated and assessed by nine expert respondents. Internally, five strengths and five weaknesses were identified, with the weighted scores of internal factors presented in Table 6.

Table 6. Internal Factor Evaluation (IFE) Matrix

Code	Internal Factor	Weight	Rating	Score
	Strengths			
S1	Achievement of waste sector GHG emission reduction in 2024 exceeded the target, reaching 25.05% from the Business as Usual (BAU) projection.	0.099	3.56	0.351
S2	The waste reduction percentage indicator in the RPJMD was consistently achieved throughout 2021–2024.	0.094	3.67	0.346

Code	Internal Factor	Weight	Rating	Score
S3	Availability of community-based 3R infrastructure including TPST, TPS 3R, and Waste Banks.	0.104	3.78	0.392
S4	Availability of complete planning and GHG emission inventory documents, including DLH Strategic Plan, RAD GRK, and PEP GRK.	0.110	3.89	0.427
S5	Maintained level of waste sector mitigation spending, with a proportion to total DLH spending stable in the range of 12–22% throughout 2020–2024.	0.091	3.44	0.315
	Weaknesses			
W1	Mitigation budget allocation is not guided by cost-effectiveness considerations for emission reduction (cost per ton CO_2eq), so it may not be directed at the most impactful interventions.	0.094	1.33	0.126
W2	DLH spending structure is still dominated by downstream waste management operational activities, especially transportation and landfill operations.	0.102	1.22	0.124
W3	Low budget support for waste prevention and source reduction activities, such as sorting, composting, and behavioral education, which also have not become sustainable priority programs.	0.109	1.44	0.158
W4	The proportion of mitigation spending to total DLH spending fluctuated throughout 2017–2024 in the range of 12.44%–28.43%, with a sharp decline in 2020 due to pandemic budget refocusing.	0.092	1.56	0.143
W5	No implementation of waste-to-energy technology in Bogor City waste management.	0.104	1.44	0.151
Total		**1.000**		**2.533**

Source: primary data, 2026 (processed)

The total IFE score of 2.533 places DLH in a moderate internal position. The highest strengths are the availability of comprehensive planning documents and GHG emission inventory records, including the DLH Strategic Plan, RAD-GRK, and PEP-GRK (S4; 0.427), as well as community-based 3R infrastructure, including TPST, TPS 3R, and Waste Banks (S3; 0.392). Meanwhile, the highest weaknesses are limited budget support for waste prevention and source-reduction activities, such as waste sorting, composting, and behavioral education, which have not yet been established as sustainable priority programs (W3; 0.158), and the absence of waste-to-energy technology implementation in Bogor City's waste management system (W5; 0.151). This pattern indicates that although planning documents and basic infrastructure are already available, the budget allocation structure has not been effectively organized to transform these existing resources into significant emission reduction impacts. On the external side, six opportunities and five threats were identified, as presented in Table 7.

Table 7. External Factor Evaluation (EFE) Matrix

Code	External Factor	Weight	Rating	Score
	Opportunities			
O1	Regulatory mandate for PEP GRK implementation (Minister of Environment and Forestry Regulation 72/2017) aligned with NDC commitments	0.099	3.22	0.319
O2	Availability of 22 waste sector mitigation activities in Bogor City RAD GRK	0.088	3.11	0.275
O3	Community participation in waste reduction shows an increasing trend	0.099	3.00	0.297
O4	Potential for utilizing organic waste as raw material for	0.101	2.67	0.269

Code	External Factor	Weight	Rating	Score
	large-scale waste processing			
O5	Availability of access to climate funding outside the regional budget (national budget, DAK LH, provincial budget, climate finance)	0.103	2.67	0.273
O6	Partnership potential aligned with circular economy development trends	0.096	3.11	0.300
	Threats			
T1	Waste sector GHG emissions show a consistently increasing trend throughout 2017–2024	0.087	2.22	0.194
T2	An average of 20.01% of waste generation was not optimally managed throughout 2020–2024	0.091	2.56	0.232
T3	Limited land availability for expansion of 3R infrastructure, TPS, and landfill	0.081	2.44	0.199
T4	Behavior of disposing waste into water bodies and low participation in safe sanitation services	0.080	2.11	0.168
T5	Time-lag risk between implementation of mitigation activities and impact on annual inventory	0.074	2.56	0.190
Total		**1.000**		**2.717**

Source: primary data, 2026 (processed)

The total EFE score of 2.717 places DLH in a moderate external position. The highest opportunities are the regulatory mandate for PEP GRK implementation and NDC commitments (O1; 0.319) and the potential for circular economy partnerships (O6; 0.300), while the highest threat is unmanaged waste generation (T2; 0.232). Regulatory foundations and partnership opportunities are available; however, quantitative pressures arising from waste generation and land limitations remain the main obstacles.

The combination of an IFE score of 2.533 on the horizontal axis and an EFE score of 2.717 on the vertical axis places DLH in Cell V of the IE matrix, namely the hold-and-maintain quadrant. In the public sector context, this position is interpreted as strengthening the reach of existing community-based mitigation activities and innovating waste management governance, with a focus on optimizing existing resources and refining expenditure structures rather than pursuing large-scale expansion that is not supported by implementation capacity.

Strategy Formulation through SWOT Matrix

The SWOT matrix breaks down the hold-and-maintain position into four strategy types that integrate internal and external factors (Table 8). S-O strategies utilize strengths to capitalize on opportunities, W-O strategies address weaknesses through opportunity support, S-T strategies employ strengths to mitigate threats, and W-T strategies minimize weaknesses while avoiding potential threats. The analysis generated seven alternative strategies: two S-O strategies, two W-O strategies, one S-T strategy, and two W-T strategies.

Table 8. SWOT Matrix for DLH Bogor City budget allocation strategies

	Strengths (S): S1–S5	**Weaknesses (W): W1–W5**
Opportunities (O): O1–O6	**S-O Strategies** • Development of large-scale organic waste processing through partnerships (S3, S4, O4, O6) • Replication of supporting activities for mitigation achievements through RAD GRK acceleration (S1, S2, O2)	**W-O Strategies** • Reorientation of DLH spending from downstream to source prevention (W2, W3, W4, O2, O3) • Strengthening access to non-regional-budget climate funding for mitigation spending stabilization (W4, O5)
Threats (T): T1–T5	**S-T Strategy** • Waste-to-energy initiation through landfill partnership (S4, T1, T3)	**W-T Strategies** • Strengthening community behavioral education and safe sanitation services (W3,

Strengths (S): S1–S5	Weaknesses (W): W1–W5
	T2, T4) • Marginal Abatement Cost (MAC) audit for mitigation spending prioritization (W1, W2, W4, T1, T5)

Source: primary data, 2026 (processed)

The uneven composition, particularly the presence of only one S-T strategy, is consistent with the Cell V position, which emphasizes the consolidation of internal weaknesses and the utilization of opportunities rather than aggressive maneuvering of strengths against threats. Forcing the addition of a second S-T strategy solely for numerical balance risks producing overlapping formulations. Descriptions of each strategy are presented below.

S-O Strategies

The development of large-scale organic waste processing through partnerships focuses on organic waste, which dominates waste generation and serves as the main contributor to methane emissions when disposed of anaerobically in landfills. Intervention in the organic fraction therefore addresses the primary point of emission generation. Existing assets in the form of 3R infrastructure (S3) and comprehensive planning documents (S4) are combined with the potential for large-scale organic waste utilization (O4) and circular economy partnerships (O6). Partnership schemes are necessary because the construction and operation of high-capacity facilities, such as controlled composting systems, anaerobic digesters, or Black Soldier Fly (BSF) processing facilities, require investment and technical expertise beyond the independent fiscal capacity of the city government.

The replication of supporting activities for mitigation achievements through RAD GRK acceleration is based on the achievement of emission reductions in 2024, which exceeded the target (S1), and the consistency of waste reduction indicators within the RPJMD (S2). The substance of this strategy involves systematically identifying intervention types that contributed to the achievement, followed by the preparation of replication and scaling-up plans to support the implementation of 22 RAD GRK mitigation activities that have not yet been fully completed (O2). This approach aligns with the principles of evidence-based policy, which recommend designing interventions based on outcomes that have already demonstrated effectiveness within the local context (Cairney, 2016).

W-O Strategies

The reorientation of DLH expenditure from downstream handling toward source prevention addresses the dominance of downstream operations (W2), limited prevention-oriented spending (W3), and fluctuations in mitigation spending proportions (W4). This reorientation refers to the waste management hierarchy, which places waste reduction at the source as the highest priority. Prevention interventions consistently demonstrate more favorable cost-benefit ratios compared with downstream management approaches for equivalent waste generation volumes (Hoornweg & Bhada-Tata, 2012). Implementation should be carried out gradually through budget item reconfiguration, restructuring of activity nomenclature, and integration with the TPS 3R and Waste Bank networks (O3).

Strengthening access to non-regional-budget climate financing addresses the structural vulnerability of mitigation expenditure to annual priority changes (W4) by utilizing funding channels outside the regional budget (O5), including Environmental Special Allocation Funds, sectoral allocations from the national budget, West Java Provincial regional budget financial assistance, and multilateral climate financing schemes (Anggraini et al., 2023). Access to carbon-based funding channels under Presidential Regulation Number 98 of 2021 further requires compliance with the measurement, reporting, and verification (MRV) framework recorded through the National Registry System; the established practice of annual PEP GRK reporting provides DLH with an initial foundation for meeting this standard. Strengthening access requires the preparation of feasibility documents, the assignment of personnel responsible for managing funding opportunities, and vertical coordination with provincial governments and relevant technical ministries.

S-T Strategy

The initiation of waste-to-energy through landfill partnerships responds to the increasing emission trend (T1) and land limitations (T3) by applying a more land-efficient technological approach, while simultaneously addressing the unused intervention space (W5) through the utilization of comprehensive planning documents (S4). The national regulatory framework is supported by Presidential Regulation Number 35 of 2018 and its subsequent update through Presidential Regulation Number 109 of 2025. The initial phase prioritizes a pre-feasibility study to assess technology alternatives, site suitability, investment requirements, and projected emission reductions as a basis for subsequent decision-making. However, this technology requires substantial investment, and the tipping fee burden may become a long-term fiscal pressure for local governments (Qodriyatun, 2021).

W-T Strategies

Strengthening community behavioral education and safe sanitation services addresses unmanaged waste generation (T2), disposal behavior into water bodies, and limited access to safe sanitation services (T4), while also responding to low source prevention expenditure (W3). Effective behavioral interventions require clearly defined behavioral targets and a combination of instruments that address capability, opportunity, and motivation (Michie et al., 2011). Within its institutional authority, DLH should focus its contribution on behavioral education and pollution control, while improving safe sanitation coverage should be positioned as a cross-sectoral agenda involving relevant agencies (World Health Organization & UNICEF, 2021)..

A Marginal Abatement Cost (MAC) audit for mitigation expenditure prioritization addresses the absence of cost-effectiveness considerations (W1), the dominance of downstream expenditure (W2), fluctuations in expenditure proportions (W4), and time-lag risks (T5). The MAC audit calculates the net cost per ton of CO_2 equivalent (CO_2eq) for each intervention option and organizes them into a curve that ranks options from the lowest to the highest cost (Ariani et al., 2016; McKinsey & Company, 2009). The results provide a quantitative basis for ensuring that budget allocation no longer follows previous years' spending patterns but instead prioritizes cost-effectiveness ratios that can be transparently justified.

Strategy Priorities through QSPM

The seven strategies were prioritized using the Quantitative Strategic Planning Matrix (QSPM) approach, incorporating IFE and EFE factor weights and attractiveness scores obtained from nine respondents (Table 9). The strategy of developing large-scale organic waste processing through partnerships achieved the highest priority ranking, with a total attractiveness score (TAS) of 6.185.

Table 9. Strategy priorities based on QSPM

No.	Alternative strategy	Quadrant	Total TAS
1	Development of large-scale organic waste processing through partnerships	SO	6.185
2	Reorientation of DLH spending from downstream to source prevention	WO	6.170
3	Marginal Abatement Cost (MAC) audit for mitigation spending prioritization	WT	6.146
4	Replication of supporting activities for mitigation achievements through RAD GRK acceleration	SO	6.124
5	Strengthening access to non-regional-budget climate funding sources	WO	5.904
6	Waste-to-energy initiation through landfill partnership	ST	5.844

No.	Alternative strategy	Quadrant	Total TAS
7	Strengthening community behavioral education and safe sanitation services	WT	5.818

Source: primary data, 2026 (processed)

The difference between the top four strategies is only 0.061 (the first and second rankings are 0.015 apart), while there is a clearer gap of 0.220 between the fourth and fifth rankings. This density stems from how the Quantitative Strategic Planning Matrix (QSPM) works: the seven strategies are derived from the same set of Strengths, Weaknesses, Opportunities, and Threats (SWOT) factors and assessed using identical Internal Factor Evaluation (IFE) and External Factor Evaluation (EFE) weights toward the same objective. Therefore, contributions from shared factors cancel each other out, and differentiators only appear in a few distinctive factors. Consequently, the top four strategies (organic waste processing, spending reorientation, Marginal Abatement Cost (MAC) audit, and activity replication) should be treated as one priority level to be implemented in parallel rather than as an absolute ranking; the 0.220 gap is what separates the priority group from the three supporting strategies.

Although ranked highest, large-scale organic waste processing depends on an institutional vehicle that is not yet available within the Dinas Lingkungan Hidup (DLH) framework. Respondents suggested establishing a Badan Layanan Umum Daerah (BLUD) first so that DLH can obtain budget flexibility comparable to its partners. Conversely, the MAC audit and spending reorientation can be implemented earlier because they do not require new institutional arrangements, and both provide a more targeted spending foundation for other strategies. Overall, the findings show a consistent pattern: the effectiveness of waste sector mitigation spending is determined more by the accuracy of allocation than by its nominal magnitude.

These findings are consistent with international green budgeting experiences. The OECD (2020) green budgeting framework emphasizes the alignment of expenditures with climate objectives, rather than aggregate spending levels alone, as the basis for effective climate-responsive budgeting. Comparable subnational experiences with green budget tagging point in the same direction, although systematic comparative evidence at the local government level remains limited. In the Indonesian context, Suharyono (2025) examined green budgeting adoption at the aggregate regional budget level, an approach that does not yet distinguish between core mitigation and supporting expenditures; the present study addresses this gap through functional reclassification. However, unlike studies in OECD countries, where institutional capacity for green budget tagging is well established, the Bogor City case reveals that reorienting spending from downstream operations toward upstream prevention faces implementation barriers related to fiscal rigidity and path-dependent budgeting practices. The negative association between core spending and emissions in this study aligns with findings by Halkos and Paizanos (2017), who found that the composition rather than the magnitude of environmental expenditure shapes emission reduction effectiveness. Cross-country evidence points in the same direction: reallocating public expenditure toward public and environmental goods is associated with lower pollution and emissions, whereas expanding total spending without changing its composition is not (Lopez et al., 2011; Jin et al., 2022).

Program and Activity Implementation Matrix

The seven strategies were organized into programs and subsequently broken down into activities according to short-term, medium-term, and long-term stages, accompanied by outputs and implementing work units (Table 10). This staging positions the MAC audit and spending reorientation as initial activities that do not require new institutional arrangements, while large-scale organic processing begins with a BLUD feasibility study as a prerequisite for partnership development.

Table 10. Program and activity implementation matrix

Stage	Activity (implementation)	Output	Implementer
1. Development of large-scale organic waste processing through partnerships			
Short-term	BLUD feasibility study as initial partnership requirement	BLUD feasibility document	DLH (BLUD), Bapperida, BKAD, and Organizational Bureau
Medium-term	BLUD operationalization and partnership establishment with raw material supply certainty and processed product buyers	BLUD operational; partnership running	
Long-term	Full operation of organic processing facility, integrated with source sorting	Organic processing facility fully operational	
2. Reorientation of DLH spending from downstream to source prevention			
Short-term	Organization of waste spending database according to upstream-downstream classification	Spending database ready for analysis	DLH, BKAD, and Bapperida
Medium-term	Gradual shift of spending share to source prevention positions	Upstream spending share increases	
Long-term	Upstream-oriented spending structure becomes a permanent pattern, not a temporary adjustment	Upstream spending structure established	
3. Marginal Abatement Cost (MAC) audit for mitigation spending prioritization			
Short-term	Organize GHG inventory and PEP as materials; initiate MAC study with partners	Emission data ready; MAC study framework prepared	DLH, Bapperida, and academic/technical partners
Medium-term	MAC audit results become reference for mitigation spending priorities in planning and budget documents	Spending priorities based on cost per unit emission	
Long-term	Periodic MAC audits maintain spending directed at cheapest interventions per unit emission	Mitigation spending maintained efficient	
4. Replication of supporting activities for mitigation achievements through RAD GRK acceleration			
Short-term	Evaluation of ongoing mitigation activities to select those proven to reduce emissions	List of effective activities for replication	DLH and Bapperida
Medium-term	Expansion of selected activities with documentation of emission reduction achievements	Effective activities expanded and documented	
Long-term	Replication becomes a permanent pattern,	Emission reduction	

Stage	Activity (implementation)	Output	Implementer
	periodically reviewed to align with the 2029 regional performance indicator (IKD) targets	achievements traceable to performance indicators	
5. Strengthening access to non-regional-budget climate funding sources			
Short-term	Identification of potential funding sources outside regional budget (national budget, DAK, provincial budget, climate funding)	Map of potential funding sources	DLH, BKAD, and Bapperida
Medium-term	Submission of priority activities resulting from MAC audit to non-regional-budget funding sources	Funding proposals submitted	
Long-term	Funding diversification stabilizes mitigation spending proportions across years	Mitigation spending proportion more stable	
6. Waste-to-energy initiation through landfill partnership			
Short-term	Documentation and preparation of an energy measurement protocol for micro-scale waste-to-energy	Measurement protocol prepared	DLH and business partners
Medium-term	Institutional and technical preparation for development toward city scale	Institutional and technical readiness	
Long-term	Integration with the city-scale waste-to-energy (PSEL) plan accompanied by recording of emission	WtE emission reduction contribution recorded	
7. Strengthening community behavioral education and safe sanitation services			
Short-term	Preparation of source sorting and waste reduction behavioral education program	Education program prepared	DLH, sub-districts/villages, and Diskominfo
Medium-term	Expansion of education and sorting coverage to support raw material supply for organic processing	Sorting coverage increases	
Long-term	Behavioral change becomes a habit that sustainably reduces waste generation	Waste generation sustainably reduced	

Source: analysis results, 2026

Study Limitations

This study has several limitations that should be considered when interpreting its findings. First, the exploratory regression analysis relies on only six observations (n = 6), which limits statistical power and makes the coefficient estimates sensitive to individual data points. Although the analysis is explicitly positioned as exploratory and triangulated with qualitative classification, the results should not be interpreted as causal evidence. Future research should extend the observation period or include comparative data from multiple municipalities to improve statistical robustness. Second, the strategic analysis relies on expert judgment from nine purposively selected respondents, which, while adequate for the Quantitative Strategic

Planning Matrix (QSPM) framework, may introduce subjectivity in factor weighting and attractiveness scoring. Averaging attractiveness scores across the nine respondents mitigates but does not eliminate this limitation. Third, the study focuses exclusively on the authority of the *Dinas Lingkungan Hidup* (DLH) regarding solid waste management within the waste sector; wastewater management, which also contributes to total waste sector emissions, falls under a different institutional authority and is therefore not included in this study. Fourth, the functional reclassification of expenditures, although informed by the *Rencana Aksi Daerah Penurunan Emisi Gas Rumah Kaca* (RAD-GRK) and green budgeting frameworks, involves researcher judgment in categorizing activities as core or supporting expenditures. Different classification criteria may therefore produce different patterns of expenditure composition.

CONCLUSION

This study demonstrates that the effectiveness of DLH Bogor City's budget allocation for waste sector greenhouse gas (GHG) mitigation is determined more by the quality and strategic direction of expenditures than by the overall budget magnitude. The findings indicate that core mitigation activities, which are directly associated with lower GHG emissions, account for only a small proportion of total mitigation expenditures and have tended to shrink since 2018, whereas downstream operational activities continue to dominate the budget structure. The strategic analysis positions DLH within Cell V of the Internal–External (IE) matrix (hold and maintain), indicating that strengthening existing mitigation efforts through budget reorientation is more appropriate than pursuing large-scale expansion initiatives. Among the seven alternative strategies, the development of large-scale organic waste processing through partnerships emerged as the highest-priority strategy, followed by expenditure reorientation toward waste source prevention, Marginal Abatement Cost (MAC) auditing, and the replication of effective mitigation activities, with these four strategies forming a single priority tier that can be implemented in parallel. Collectively, these strategies provide an evidence-based framework for improving the effectiveness of green budgeting practices in the waste sector.

Despite these contributions, this study has several limitations. The exploratory regression analysis is based on a limited number of observations, and the strategic assessment relies on expert judgment within a single local government context, which may restrict the generalizability of the findings. Future studies should incorporate longer observation periods and comparative analyses across multiple local governments to strengthen empirical evidence regarding the relationship between budget allocation and emission reduction outcomes. Furthermore, the development of a standardized functional expenditure reclassification framework would support broader implementation of green budgeting and enhance the consistency of environmental public expenditure analysis across local governments in Indonesia.

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AUTHOR CONTRIBUTION STATEMENT

Ridwan Adithiansyah conceptualized the study, collected and analyzed the data, conducted the empirical and strategic analyses, and drafted the manuscript. A. Faroby Falatehan supervised the research design, contributed to the interpretation of the findings, and critically reviewed and revised the manuscript. Sri Mulatsih contributed to the research methodology, validated the analytical framework and results, and critically reviewed the manuscript. All authors read, approved, and agreed to the published version of the manuscript.

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