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Regional Case Study

Improving Low Carbon Development Performance at the Local Level through Multi Criteria Decision Analysis

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Abstract

Climate change necessitates immediate local interventions to guarantee environmental stability. Notwithstanding emission target agreements, Mojokerto Regency's contribution to regional low-carbon development is less than 1%, indicating minimal influence. This study examines the enabling and constraining factors of low-carbon performance and establishes strategic priorities using the Analytical Hierarchy Process (AHP), corroborated through a Cost-Effectiveness Analysis (CEA). Data were gathered through expert interviews, pairwise questionnaires, and a regional fiscal analysis. The findings demonstrate that structural limitations, such as constrained resources and data deficiencies, impede implementation, whereas multi-stakeholder interaction serves as a key facilitator. AHP designated Community Engagement as the key choice criterion (31.32%). Thus, waste management using TPS3R was prioritized at 26.12%, followed by tree planting at 20.09% and organic fertilizer at 13.88%, together comprising 60.09% of choice preferences. CEA validates these findings, indicating that prioritized community-based methods provide enhanced fiscal efficiency, substantial landfill cost savings, and local job creation. They surpass capital-intensive alternatives, such as Intelligent Transportation Systems (ITS/ATCS), which provide minimal carbon value. This report advocates for the reallocation of municipal finance to prioritize community empowerment and nature-based initiatives, underpinned by institutional legislation that requires data sharing for Measurement, Reporting, and Verification (MRV) systems to facilitate an economically sound and socially equitable shift.

Keywords: Analytical hierarchy process; climate change; low carbon development; Mojokerto Regency

1. Introduction

Climate change is an urgent global issue that can cause environmental instability and an increase in the average temperature (Fahmi, 2025). According to data from the Meteorological, Climatological, and Geophysical Agency (2025), the average temperature of the Earth in 2024 reached its highest point since 1981. The Government of Indonesia has initiated the Enhanced Nationally Determined Contribution

(ENDC), intending to elevate the national emission reduction target to between 31.89% and 43.20% by 2030, contingent on the degree of international assistance. This national commitment is outlined in the Indonesian Medium-Term Development Plan 2025-2029 document through important programs, including the transition to renewable energy, peatland restoration, and waste management (Republik Indonesia, 2025).

Although the Indonesian government has set national targets and programs for reducing emissions, the implementation of low-carbon development at the regional level often faces obstacles. Mojokerto Regency has shown its commitment to reducing emissions by preparing the Regional Medium-Term Development Plan (RPJMD) document for the years 2025-2029, which was established in Regional Regulation Number 6 of 2025. Unlike previous planning documents, the RPJMD 2025-2029 clearly sets cumulative greenhouse gas (GHG) reduction targets, which are then established as Regional Performance Indicators (IKD). In 2025, the cumulative GHG reduction achievement of Mojokerto Regency was 215,448.56 tons CO_2-eq, reaching 99.97% of the target. Compared to the achievements of East Java Province, Mojokerto Regency contributed only 0.92%. From 2021 to 2024, Mojokerto Regency's contribution to reducing GHG emissions in East Java stagnated at 0.71%–1.08%. This condition is influenced by supporting and inhibiting factors in the implementation of low-carbon development. However, these factors have not yet been clearly defined in the literature.

One approach to improve the performance results is to review previous research on similar topics. Research conducted by (Hardyanti et al. (2022), Huboyo et al. (2024), and Samadikun et al. (2022) evaluated GHG emissions at the regional level, showing that the resulting mitigation strategies were solely based on one perspective, namely, the technical perspective. Adopting strategies based on only one criterion is often considered less than optimal because of the increasingly complex challenges faced in implementing low-carbon development (Raman et al., 2025). This is in line with the research conducted by Handayani (2021), Husein et al. (2025), and Kartikasari et al. (2019), which shows that neglecting inhibiting factors such as social, economic, and governance factors can lead to program implementation failures. Therefore, to address the conditions in Mojokerto Regency, a comprehensive analytical framework encompassing environmental, social, economic, and technical aspects is required. Without a comprehensive approach, the implementation of low-carbon development in the region will remain fragmented and unable to increase its contribution to emission reduction, which is still stagnant at around 1%.

From a methodological perspective, several previous studies still show limitations, as most of them conduct policy analyses solely using a qualitative approach without a clear mechanism for determining priorities. Other studies have used a quantitative approach model with a rigid top-down hierarchy that is less capable of depicting the conditions and challenges faced by the regions. To address these weaknesses, a systematic decision-making research method, the Analytical Hierarchy Process (AHP), was chosen. One of the advantages of the AHP method is that it can transform various complex and multidimensional criteria into a systematic hierarchical structure based on expert assessment (Ardhiansyah and Novani, 2022; Nugroho et al., 2023). Through a multi-criteria decision-making approach, AHP is considered capable of evaluating various interrelated aspects in decision-making more objectively, such as environmental, social, economic, and technical aspects of the decision. Thus, subjectivity in the regional policy planning process can be reduced, resulting in accountable and strategic priorities.

Thus, this study is novel in its integration of qualitative and quantitative approaches. Thematic analysis was used to empirically identify the factors that support and hinder the implementation of low-carbon development. Then, the Analytical Hierarchy Process (AHP) was used to determine the priority of mitigation strategies, and the prioritization results of these strategies were validated using Cost-Effectiveness Analysis (CEA). This comprehensive approach is expected to produce recommendations that are financially viable and can be implemented according to the conditions of the Mojokerto Regency. This study has two main objectives: analytical and policy. The analytical objective of this study was to identify supporting and inhibiting factors, formulate priority strategies using AHP, and evaluate the economic value efficiency of the resulting priority strategies. The policy objective is to formulate evidence-based and gradual recommendations that function to improve decision-making at the local government level.

2. Materials and Methods

2.1. Study Area

This study was conducted in Mojokerto Regency, East Java Province, Indonesia. Figure 1 illustrates the location of the study. Mojokerto Regency has an area of 98,438.09 ha located at 111°20′13″ to 111°40′47″ East Longitude and 7°18′35″ to 7°47′30″ S. The contribution of achievements in reducing greenhouse gas emissions in Mojokerto Regency to East Java Province has stagnated at approximately 1%, necessitating the formulation of strategies to enhance emission reduction achievements. This condition served as the basis for selecting the research location.

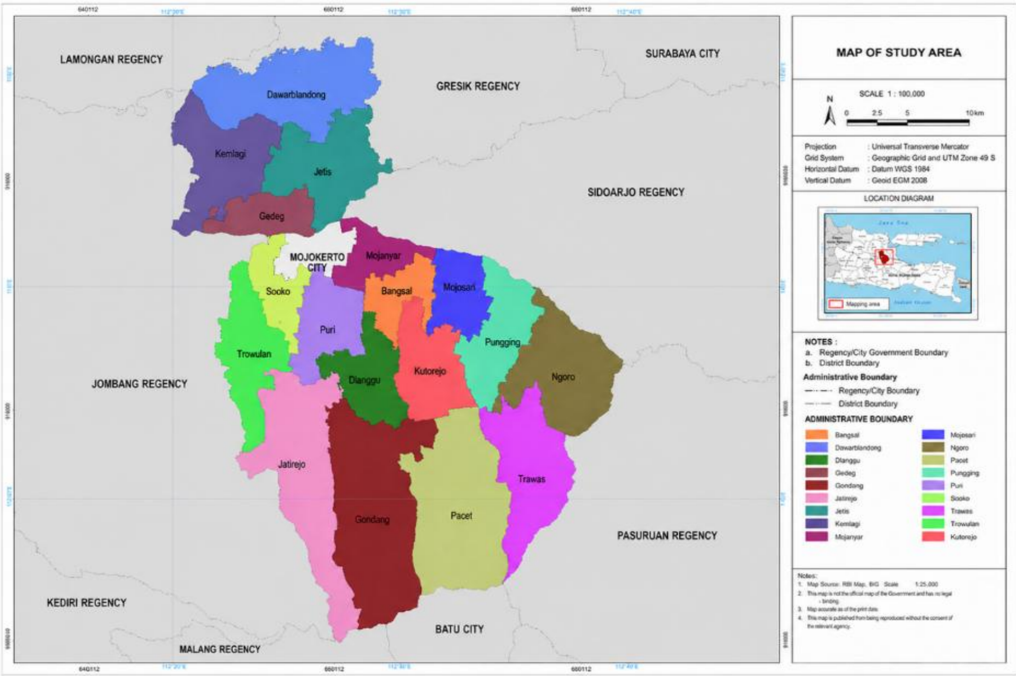

Figure 1. Study area

2.2. Data Collection

This research employed a mixed-methods approach. The primary data collection in this study used two techniques: purposive sampling with respondents who have expertise and a good understanding of climate change policies, as well as in-depth interviews with four key informants. The four key informants were coordinators at each regional apparatus organization (OPD) responsible for mitigation, with a minimum of four years of experience in the field of low-carbon development. This interview aims to explore the implementation of low-carbon development from the planning process to its evaluation, which can then identify the supporting and inhibiting factors.

In the quantitative stage, a comparison questionnaire was distributed to nine respondents. In research using the AHP method, the quality and consistency of expert assessments are emphasized more than the sample size; therefore, the number of nine respondents is considered adequate (Ardhiansyah and Novani, 2022; Nugroho et al., 2023; Nugroho and Iskandar, 2020). The respondents involved in the AHP assessment consisted of structural and functional officials from local governments, coordinators at the provincial government level, and academics with a minimum of three years of experience in the field of low-carbon development. Thus, the respondents' empirical experience and understanding of relevant regulations are important for them in providing their assessments.

2.3. Thematic Analysis

The interview recordings were converted into transcripts and analyzed using NVivo software to identify the supporting and inhibiting factors. Each statement was assigned an initial code after data familiarization. The source triangulation process was carried out to ensure validity by only including codes explicitly mentioned by all four informants and grouped into main themes. Meanwhile, codes not mentioned by all four informants were eliminated to reduce subjective bias. The intensity level of each identified factor can then be displayed after calculating the frequency of occurrence of the validated factors.

2.4. Analytical Hierarchy Process (AHP)

The AHP method was used to analyze data to solve multi-criteria decision-making problems. Saaty developed a method that transforms qualitative assessments into numerical values used to measure the relative importance of decision elements by conducting pairwise comparisons using a 1-9 scale (Saaty, 1980). The three main levels of the hierarchical structure in this study are (1) the improvement of low-carbon development effectiveness as the main objective, (2) evaluation criteria covering environmental, social, economic, and technical aspects based on the Triple Bottom Line framework, and (3) alternative mitigation strategies. This combination of criteria encapsulates the intricacies of environmental decision-making (Ardhiansyah and Novani, 2022; Nugroho et al., 2023; Nugroho and Iskandar, 2020).

Tabel 1. Saaty scale

Numerical values	Description	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgement favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very importance of one element over another	An element is very strongly favoured
9	Extreme importance of one element over another	An element is favoured by at least order of magnitude
2, 4, 6, 8	Intermediate values between two adjacent judgements	Used to compromise between two judgements

Nine potential strategies were developed based on national programming activities with GHG reduction effects (identified by Bappenas) and tailored to the jurisdictional authority of Mojokerto Regency. Figure 2 illustrates the hierarchy and objective weights of the criteria.

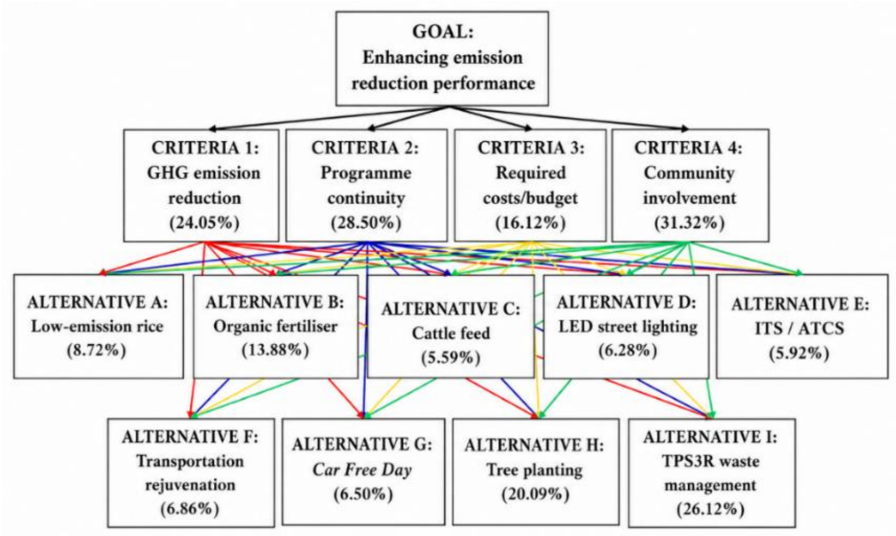

Figure 2. AHP hierarchical structure of the study

The geometric mean is used in the aggregation process, which serves to combine the assessments of experts while maintaining the proportionality of the ratios between elements. To calculate the eigenvector value that represents the final priority weight for each decision element, the matrix from the previous aggregation stage is used. The validity of the weighting was affirmed by the Consistency Ratio (CR), with all matrices attaining a CR value of ≤ 0.1, signifying logically consistent and acceptable expert evaluations.

2.5. Economic and Cost-Effectiveness Evaluation

The study employed a quantitative Cost-Effectiveness Analysis (CEA) and socioeconomic impact evaluation through secondary data triangulation to deliver a strong economic rationale for the prioritized initiatives. Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) were obtained from the 2025 Mojokerto Regency Regional Budget Implementation Documents (DPA SKPD) and City Sanitation Strategy data. Emission reduction forecasts and technical specifications were obtained from the National Low-Carbon Development Application (AKSARA). Additionally, socio-economic multipliers were obtained via expert interviews, and international benchmarks from the World Bank and IPCC were used to compute regional fiscal savings and standard carbon economic values. The cost-effectiveness ratio was determined by dividing the total annualized cost by the anticipated annual decrease in GHG emissions (Tonne CO_2-eq/year).

3. Result and Discussion

3.1. Enabling Factors

In-depth interviews with four low-carbon development coordinators revealed various aspects facilitating low-carbon development (Figure 3). A complete consensus was achieved regarding two principal enablers: multi-stakeholder involvement and alignment of low-carbon activities with other thematic programs. Although ad-hoc Corporate Social Responsibility (CSR) and foreign funding were referenced, they were omitted from the final theme construct because of the absence of systematic unanimity among all agencies. The chosen elements indicate a consensus among stakeholders that sustainable mitigation necessitates structural enablers rather than incidental support.

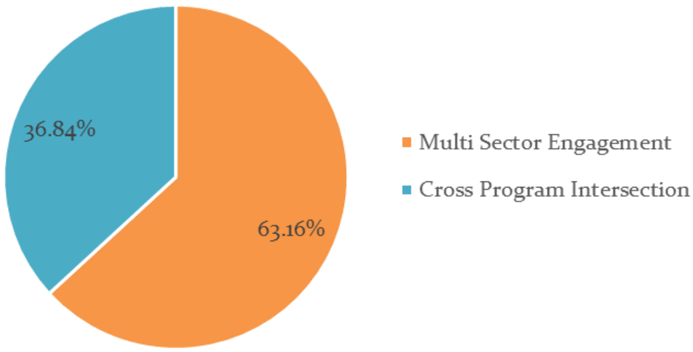

Figure 3. Enabling factors for the implementation of low-carbon development

The primary facilitator, multi-stakeholder participation, functions as both social and institutional capital in navigating intricate climate policies. Mitigation action coordinators emphasize a collaborative governance structure that involves various parties. This is because there is no institution capable of independently managing climate change mitigation efforts in the region itself. Increased policy capacity is achieved through cross-sector collaboration, which includes strengthening interorganizational networks and building consensus. This makes the process of implementing the action plan run smoothly (Mcnaught 2024). Furthermore, the participation of non-governmental organizations (NGOs) can address the resource limitations of local governments, while strengthening cross-regional and sectoral coordination is achieved through inter-agency collaboration. This integrated approach is crucial for enhancing climate resilience and creating effective environmental governance (Husein et al., 2025).

The relationship between low-carbon development actions and other thematic programs is the second supporting factor. This approach can be used as a pragmatic strategy to address budget constraints and program prioritization issues. By integrating low-carbon development actions into other thematic programs, funding opportunities increase, and the acceptance of low-carbon development actions can be enhanced. Various additional benefits can be generated from this programmatic overlap, such as climate change mitigation, which can naturally provide other health benefits (Fernandez-guzman et al., 2023). Another example is the provision of feed supplements to cattle, which not only reduces emissions but also increases milk and meat production, thereby supporting food security (Abd et al., 2024).

Overall, the ability to integrate policies has a greater impact on the effectiveness of mitigation than the technical improvements made separately. Enhanced coordination, implementation effectiveness, and program sustainability can be achieved by strengthening institutional capacity, supported by multi-stakeholder involvement and integrating mitigation actions into other regional development agendas.

3.2. Constraining Factors

All four OPD coordinators agreed that the qualitative investigation revealed six main obstacles to low-carbon implementation in Mojokerto Regency: insufficient funding, a lack of activity data, a lack of commitment from regional leadership, a lack of established institutional arrangements, a lack of human resource capacity, and a lack of supportive regulations. Peripheral elements such as limited community awareness and geographic constraints were excluded from the final theme framework because multi-agency consensus was not reached, as shown in Figure 4. Together, the coordinators concluded that community awareness is a secondary issue that can only be successfully addressed after the establishment of primary institutional and legal frameworks.

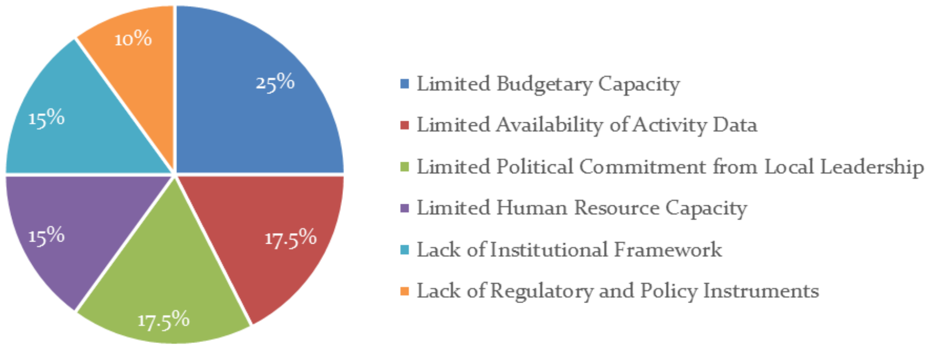

Figure 4. Constraining factors for the implementation of low-carbon development

Significant structural and technical obstacles to policy continuity include budgetary constraints and data deficiencies. Funding shortages, from a conceptual standpoint, show that low-carbon development has not yet been defined as a strategic budgetary priority, making it compete with well-established sectoral programs. According to Lin et al. (2026), financing constraints in regional transitions are closely linked to budget deficits, policy uncertainty, and regulatory fragmentation. This underscores the continuous gap between global climate goals and local financing capabilities. In the absence of strong funding arrangements, implementation is typically project-based and short-term (Bhandary, 2024). Moreover, the Measurement, Reporting, and Verification (MRV) system is compromised by a lack of activity data. In MRV governance, where data availability and cross-institutional integration are crucial, mitigation risks becoming a programmatic claim without quantitative support in the absence of trustworthy data (Perosa et al., 2023; Thornbush and Govind, 2025).

Institutional governance suffers from fragmented organizational arrangements and inadequate political leadership, in addition to technical problems. All stakeholders concurred that institutionalizing climate frameworks and mobilizing resources depend heavily on local political leadership. Inadequate leadership commitment prevents the agenda from being legally enforceable by creating a gap between local authorities' political concerns and global climate ambitions (Jannah et al., 2025). This lack of dedication directly results in poorly defined institutional roles and limited cross-sectoral coordination, which reduces climate action to discrete, isolated activities rather than coherent, multilevel governance (Hapsari et al., 2025). Additionally, this vulnerability is exacerbated by a lack of human resources because technical expertise is not institutionalized as an organizational asset but rather stays embedded within particular persons, endangering system stability during staff reassignments.

Ultimately, low-carbon projects lack legal credibility because of the lack of supporting rules, which makes regional authorities behave extremely cautiously and hesitantly. Regulations are crucial tools for resource allocation and stabilizing governance. Long-term budget allocations cannot be maintained in the absence of a formal regulatory framework, institutional coordination mechanisms remain unenforceable, and sectoral agencies are not legally required to report activity data (Lin et al., 2026). In summary, Mojokerto Regency's low-carbon development is not an institutionalized system but rather a discrete programming change. Aligning climate goals with other thematic initiatives may provide short-term political legitimacy (Fernandez-guzman et al., 2023), but it does not ensure integrated structural indicators, human capacity, or sustainable fiscal support; instead, it places mitigation as secondary to other agendas.

3.3. Model Consistency Validation

The logical validity of the respondents' assessments was evaluated using CR. The CR values for all inter-criteria and alternative comparison matrices in this study varied from 0.002 to 0.06. Given that all values are well below the acceptable criterion of 0.1 (Saaty, 1980), the expert assessments are logically coherent and valid for decision making.

3.4. Multi-Criteria Priority Analysis and Strategic Synthesis

The geometric mean aggregation of expert assessments delineates a distinct hierarchy of criteria, with community involvement receiving the highest weight of 31.32%, followed by program continuity at 28.50%, GHG emission reduction at 24.05%, and required cost or budget at 16.12%, as illustrated in Table 3. The prevalence of community engagement indicates a transition to participatory governance, as the efficacy of emission reductions is significantly contingent upon public endorsement, whereas sophisticated technical mitigations implemented without social legitimacy frequently induce operational instability (Cheng et al., 2019; Lennon et al., 2019; Menegatto et al., 2025; Nielsen et al., 2022). The emphasis on program sustainability demonstrates a priority for the program to continue operating and providing value, even if government funding ceases. Thus, the impact generated, particularly in terms of reducing emissions, can be sustained in the long term through community participation and institutional strengthening (Dushkova et al., 2025; Dushkova and Ivlieva, 2024). Emission reduction targets can be continuously achieved in the long term by creating collaborative and consistent action mechanisms, thereby ensuring the sustainability of mitigation actions (Novaes, 2025; Sebunya & Gichuki, 2024). In contrast, the cost or budget criteria required are given a low value. This indicates that when determining low-carbon development programs, the local government should choose programs that have significant environmental, social, and economic benefits, and not just focus on efforts to minimize costs (Prastika and Candradewi, 2019; Supriono and Efendi, 2024). Thus, in evaluating various existing action alternatives, decision-makers can see the long-term benefit-cost ratio and cost-effectiveness of an action (Yasmi et al., 2023).

The global weight calculations in Table 3 show that the highest priority was obtained by the alternative strategy for waste management through TPS3R (26.12%), tree planting (20.09%), and the use of organic fertilizer (13.88%). Cumulatively, solutions based on the circular economy and ecosystems contributed 60.09% of the overall decision preferences. The high weight assigned to community involvement criteria contributes to this dominance. This finding indicates that community participation is a key factor in the success of mitigation efforts that cannot be achieved solely through technical interventions (Muhtadi et al., 2025). In addition, the three alternatives received high scores in terms of program sustainability because all three alternatives have sustainable benefits and impacts (Fidyariska et al., 2025; Sarahswati and Wedagama, 2025). Waste processing at TPS3R can directly reduce the methane emissions produced at landfills (Pataki et al., 2021). The results of the respondents' assessment of the cost aspect indicate that nature-based approaches, which offer greater benefits relative to the costs required, are far better than infrastructure and technology-based investments that require substantial costs (Akaravarothai et al., 2025; Jara-Samaniego et al., 2017).

Table 3. Local priorities of alternatives across evaluation criteria

Priority	Code	Low-carbon development strategy alternative	GHG emission reduction (24.05%)	Programme continuity (28.5%)	Required cost/budget (16.12%)	Community involvement (31.32%)	Global weight
1	I	TPS3R waste management	32.3%	29.3%	21%	21.1%	26.12%
2	H	Tree planting	22.7%	23.8%	14.1%	17.8%	20.09%
3	B	Organic fertilizer	10.9%	12.4%	15.8%	16.5%	13.88%
4	A	Low emission rice	5.3%	6%	10.9%	12.7%	8.72%
5	F	Transportation rejuvenation	8.2%	8.2%	7.5%	4.3%	6.86%
6	G	Car Free Day (CFD)	2.9%	2.8%	7.7%	12.1%	6.50%

Priority	Code	Low-carbon development strategy alternative	GHG emission reduction (24.05%)	Programme continuity (28.5%)	Required cost/budget (16.12%)	Community involvement (31.32%)	Global weight
7	D	LED street lighting	8.4%	6.4%	9%	3.1%	6.28%
8	E	ITS/ATCS	5.8%	7.9%	6.5%	3.9%	5.92%
9	C	Cattle feed	3.4%	3.2%	7.5%	8.5%	5.59%

In the medium-priority class, the alternative strategies consisted of using low-emission rice varieties (8.72%), rejuvenating transportation (6.86%), and Car Free Day (CFD) (6.50%). Research conducted by Xuan et al. (2025) showed that the use of the alternate wetting and drying (AWD) irrigation method in rice cultivation reduces methane emissions in the agricultural sector, which can also increase crop yield productivity. Nonetheless, the renewal of the public transport fleet is hindered by fundamental execution issues (Khatri-Chhetri et al., 2021). The Car Free Day campaign is an effective instrument for public health and awareness; however, its impact on regional pollution is limited, leading to a mediocre ranking (Glazener et al., 2022). The low-priority cluster comprised LED street lighting (6.28%), Intelligent Transportation Systems or ITS/ATCS (5.92%), and cow feed supplements (5.59%), indicating regional financial limitations and negligible immediate societal repercussions. Experts deem high-technology investments inefficient at this stage, as smart city technologies represent long-term objectives that necessitate adequate foundational infrastructure and enhanced civic behavioral maturity prior to being prioritized for mitigation (Niamir et al., 2024; Zhou et al., 2024).

3.5. Economic and Cost-Effectiveness Analysis

A quantitative cost-effectiveness and socioeconomic analysis was performed to create a financial baseline for the proposed mitigation options, independent of the qualitative AHP weighting. The assessment concentrated on the cost-effectiveness ratio, calculated from the total annualized Capital and Operational Expenditures (CAPEX + OPEX) in relation to the anticipated annual emission reduction outcomes. This analysis included the Carbon Economic (CE) Value and direct socio-economic multipliers, such as regional fiscal savings and local employment, to present a more comprehensive fiscal picture. The findings, as outlined in Table 4, demonstrate a distinct hierarchy of methods when analyzed from a quantitative economic perspective.

Table 4. Economic and cost-effectiveness profile of strategy alternatives

Priority	Low-carbon strategy alternative	CAPEX + OPEX (IDR)	Emission reduction (Ton CO_2-eq/yr)	Cost-effectiveness (IDR / Ton CO_2)	Carbon economic value (IDR)	Socio-economic and fiscal impact
1	TPS3R waste management	720,000,000	586.74	1,227,119	~498.73 Million	Employs 145 local workers and Saves IDR 1.25–2.50 billion/year in landfill tipping fees.
2	Tree planting	15,600,000	24.19	644,894	~20.56 Million	High community participation prevents long-term environmental degradation costs.

Priority	Low-carbon strategy alternative	CAPEX + OPEX (IDR)	Emission reduction (Ton CO_2-eq/yr)	Cost-effectiveness (IDR / Ton CO_2)	Carbon economic value (IDR)	Socio-economic and fiscal impact
3	Organic fertilizer	0 (Central subsidy)	1,226.69	0 (Most efficient)	~1.04 Billion	Reduces dependency on costly chemicals; direct economic benefits for farmers.
4	Low emission rice	0 (Central subsidy)	32.56	0 (Most efficient)	~27.68 Million	It maintains agricultural yield with zero local capital expenditure.
5	Transportation rejuvenation	42,603,250	57.46	741,441	~48.84 Million	It improves public transport efficiency but offers marginal direct fiscal savings.
6	Car Free Day (CFD)	0 (Minimal/event)	6.08	0	~5.17 Million	Boosts informal local economy and indirect public health savings.
7	LED street lighting	1,322,100,000	168.19	7,860,752	~142.96 Million	Long-term electricity savings are highly capital-intensive and create minimal jobs (four internal workers).
8	ITS/ATCS	1,399,337,715	36.1	38,762,817	~30.68 Million	No direct fiscal savings; highly capital-intensive; relies on outsourced labor (three external technicians).
9	Cattle feed	163,170,000	7.3	22,352,054	~6.20 Million	It increases livestock yield but provides low emission reduction relative to costs.

The strategy with the highest position from the perspective of economic efficiency is the one with a cost-effectiveness ratio of IDR 0 per ton of CO_2. The most economically efficient alternatives identified were the use of organic fertilizers, low-emission rice varieties, and CFD. This is because the local government only incurs relatively small costs to implement these three alternatives. Two of them even receive subsidies from the Central Government. The use of organic fertilizers showed the highest economic performance among the three alternatives, successfully reducing emissions by 1,226.69 tons of CO_2-eq per year and having a Carbon Economic Value of IDR 1.04 billion. Although these alternative strategies offer a high level of efficiency, most of their funding sources still rely on external parties rather than on investments made by regional governments. Therefore, their economic benefits depend on external parties (Liu et al., 2024; Zhou et al., 2019).

Alternative strategies that fall into the second-tier group include waste management at TPS3R and tree-planting. This group has significant socio-economic benefits and high carbon economic value but requires moderate investment from the Regional Government. The cost-effectiveness ratio generated from waste management at TPS3R is IDR 1,227,119 per ton CO_2-eq, indicating that this alternative approach is of high value. Meanwhile, the Economic Value of Carbon from waste management at TPS3R is IDR 498.73 million. In addition, this alternative also provides the largest direct fiscal savings for Mojokerto Regency, estimated to save waste tipping fees at the landfill by IDR 1.25–2.50 billion per year. In addition, this alternative is capable of creating 145 jobs in the local community. The cost-effectiveness ratio for the tree planting alternative is IDR 644,894 per ton CO_2-eq, which contributes to minimizing the costs of environmental damage in the long-term. Thus, a strategy that focuses on community empowerment and nature-based solutions is considered a fiscally viable option, despite requiring a relatively large initial investment (Budhijanto et al., 2024).

In contrast to alternative groups with relatively large initial capital, such as ITS/ATCS, the use of cattle feed supplements and LED lights on street lighting, which have the lowest economic efficiency, requires relatively large capital investment and operational costs, but the reduction in emissions achieved is not proportional to the budget. For example, the ITS/ATCS procurement project has a cost-effectiveness ratio of IDR 38.76 million per ton of CO_2-eq with an initial investment of approximately IDR 1.4 billion, resulting in a relatively small Carbon Economic Value of approximately IDR 30.68 million. Similarly, the program for using LED lights in street lighting is considered capable of generating long-term electricity savings but requires a significant initial investment of approximately IDR 1.32 billion. This program is also considered to create only a few jobs. This result demonstrates a significant fiscal gap between the two. Strategies based on high-tech infrastructure are often deemed unable to provide an equivalent cost-benefit ratio compared to strategies that use social approaches or nature-based solutions (Zhao et al., 2025).

An overview of the overall economic conditions of various low-carbon development alternatives in Mojokerto Regency shows a significant difference between the costs incurred and the efficiency produced. However, there are strategies that require relatively low initial capital and have high community participation, such as waste management at TPS3R and the use of organic fertilizers, which can provide greater socioeconomic impacts and create better cost-effectiveness by generating new jobs and fiscal savings. Capital-intensive initiatives such as ITS/ATCS and LED street lighting facilitate modernization; however, their limited impact on the regency's overall emission reduction, in relation to their substantial financial requirements, indicates that they are less advantageous from a purely economic perspective. These findings establish a quantitative basis for the ensuing discussion on management impact, wherein these economic indicators will be amalgamated with the multi-criteria AHP priorities to ascertain the ultimate strategic roadmap.

3.6. Managerial Implication and Implementation Plan

The integration of AHP goals and economic cost-effectiveness analysis establishes a solid foundation for policy reorientation in the Mojokerto Regency. The findings indicate a substantial congruence between stakeholder-driven goals and financial prudence, with community-based measures, including TPS3R waste management, tree planting, and organic fertilizer, collectively accounting for 60.09% of the total priority weight. This requires a major transition from a hard-infrastructure approach to a socially embedded mitigation strategy. The significant emphasis on community involvement (31.32%) in the AHP, along with the enhanced cost-effectiveness of these strategies, indicates that the efficacy of low-carbon development should be assessed not by technological complexity but by the degree of effective integration of community participation in each mitigation initiative (Gunawan, 2025; Øjvind Nielsen et al., 2024). The top-ranked status of TPS3R waste management (26.12%) was robustly substantiated by its efficacy as a socioeconomic multiplier. The initiative necessitates a moderate capital investment; nonetheless, the economic assessment confirms its role as a financial catalyst, potentially conserving the regional budget between IDR 1.25 and 2.50 billion per year in garbage tipping fees while providing employment to 145 local individuals. Local managers must reallocate budgets from solely physical construction to operational subsidies and management training for village-level, non-governmental groups. The government should enact regulations that require the utilization of recycled products, including compost and maggot-based feed, and provide financial incentives for villages that minimize landfill waste, thus aiding in the reduction of methane emissions and alleviating landfill capacity issues (Astiti et al., 2025; Irawansyah et al., 2025).

Strategies with a nature-based solutions approach, such as the use of organic fertilizers and tree planting, are increasingly being reinforced as superior strategies in terms of their efficiency. This is demonstrated by a cost-effectiveness ratio of IDR 0 and a high Carbon Economic Value of approximately IDR 1.04 billion. The low risk of this strategy enables immediate implementation. Tree planting programs, which are also budgeted for monitoring growth, can increase plant survival rates and enhance community participation in environmental management (Barrios et al., 2025; Seddon et al., 2021). Local productivity can increase within a closed economic system if agricultural subsidies are reallocated for the use of organic fertilizers (McPhearson et al., 2025; Nassary et al., 2022). The importance of considering the local context and inclusivity principles in the implementation of strategies with nature-based solutions to maximize the long-term benefits obtained (Albert et al. 2021; Kabisch et al. 2022). Therefore, a governance framework is needed to encourage stakeholder involvement in every program implementation (Dushkova and Haase, 2020; Seddon et al., 2021). In contrast to high-tech-based strategies such as ITS/ATCS and the use of LED streetlights, which have low priority and cost-effectiveness, a delay in implementation is needed from a managerial perspective. The results of the economic analysis reinforce this, as indicated by the high cost-effectiveness ratio, relatively small carbon economic value, and lack of fiscal savings. From a managerial perspective, the infrastructure modernization strategy is more appropriate as a long-term strategy, where its implementation will later depend on the regional fiscal conditions and the maturity of the community's behavior in traffic (Alvarez et al., 2022; Gagliardi et al., 2020). Thus, the budget originally projected for the development of advanced transportation technology infrastructure can be redirected to programs that empower the community, which can have a more tangible and quicker impact on reducing emissions and improving social welfare (Bachanek et al., 2021; Elassy et al., 2024).

Based on the results of both analyses, the roadmap for implementing low-carbon development in Mojokerto Regency should be formulated in stages and consist of three phases. Strategies that have a high level of efficiency and a significant multiplier effect should be implemented in the short term, around 1-2 years, particularly in strengthening the operational management of waste at TPS3R and expanding the use of organic fertilizers. The aim of taking this step is to establish good social legitimacy and achieve budget savings in a relatively short time. For the medium term (3-5 years), the strategy focuses on strengthening nature-based solutions and initiating a refresh of public transportation. This goal can be achieved if a good circular economy is established. The long-term strategy (more than 5 years) is the implementation of smart city technologies, such as LED lights on streetlights and ITS/ATCS, which can be carried out gradually in accordance with regional fiscal conditions. This staged plan guarantees that low-carbon growth is environmentally sustainable, commercially viable, and socially inclusive.

4. Conclusions

The main objective of this research was successfully achieved, which was to identify the supporting and inhibiting factors for the implementation of low-carbon development in Mojokerto Regency and to formulate priority strategies. Various structural obstacles were successfully identified, such as budget limitations and data availability, which can be overcome by strengthening multi-stakeholder engagement and synergy between development programs, as a result of the thematic analysis. The results of the AHP, reinforced by the economic analysis, indicate that community-based interventions should be prioritized, with waste management at TPS3R at 26.12%, tree planting at 20.09%, and the use of organic fertilizers at 13.88%. The three are considered the most feasible alternatives for implementation in Mojokerto Regency because they combine social legitimacy with good cost-effectiveness. In addition, all three can generate fiscal savings for the region and create job opportunities. In contrast to alternatives that rely on capital-intensive technology, such as LED lights for street lighting and ITS/ATCS, these options are considered less efficient, given the current fiscal conditions of the region. Therefore, the recommendation from this research is to reallocate the regional budget to strengthen community empowerment programs and develop a regulatory framework that supports the comprehensive development of the MRV data system. These findings indicate that meeting long-term emission objectives necessitates a dual alignment of economic rationale and social agreement, ensuring that climate mitigation is financially sustainable and community-oriented. This integrated approach emphasizes that prioritizing efficiency and socioeconomic multipliers is the most effective strategy for achieving scalable regional climate resilience.

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Ethics Statement

This study involved expert interviews and questionnaire-based data collection. All participants were informed about the purpose of the study, and their voluntary consent was obtained prior to participation. Participant confidentiality and anonymity were maintained throughout the research.

CRediT Author Statement

Fariz Basyiruddin: Idea Development, Research Design, Formal Analysis, Investigation, Resources, Data Curation, Manuscript Draft Preparation, Manuscript Review and Revision, Visualization. **Arief Rachmansyah:** Idea Development, Research Design, Result Verification, Manuscript Review and Revision, Supervision. **Bunga Hidayati:** Idea Development, Research Design, Result Verification, Manuscript Review and Revision, Supervision. **Reny Tiarantika:** Result Verification, Manuscript Review and Revision, Visualization, Supervision. **Naziatul Aziah Mohd Radzi:** Result Verification, Manuscript Review and Revision, Visualization, Supervision.

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