



Strengthening Pro-Environmental Behavior through Methane Gas Utilization and Environmental Education at Talangagung Landfill

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Abstract

Despite increasing attention to pro-environmental behavior, previous studies have largely examined environmental education and renewable energy utilization separately, leaving limited understanding of how their integration relates to sustainable behavioral change in landfill communities. This study addresses this gap by examining how environmental education integrated with methane gas utilization is associated with pro-environmental behavior among communities surrounding TPA Talangagung, Malang Regency, Indonesia. Using a qualitative case study design, the study involved 30 purposively selected participants, comprising community members, landfill managers, waste workers, and local government officials. Data were collected through semi-structured interviews, participant observation, and document analysis and analyzed using thematic analysis through coding, categorization, and theme development. The findings reveal four key dimensions: environmental education was associated with environmental literacy and ecological responsibility; participants reported that methane gas utilization provided household fuel savings of IDR 50,000–100,000 per month while encouraging environmental participation; community participation was reflected in waste segregation, composting, and collective environmental maintenance; and institutional support contributed to program sustainability through infrastructure and local policies. However, unequal environmental literacy, infrastructure limitations, and inconsistent policy implementation remained significant challenges. Theoretically, this study contributes to pro-environmental behavior research by showing how environmental education and methane gas utilization may operate as complementary components in supporting environmental commitment. Practically, the proposed four-pillar model offers an adaptable framework for community-based landfill management. These findings contribute to environmental education and sustainability research by offering an integrated model for community-based environmental transformation.

Keyword: Pro-environmental Behavior; Methane Gas Utilization; Environmental Education; Sustainable Development; Talangagung Landfill

1. INTRODUCTION

Improper waste management remains one of the most persistent sustainability

challenges confronting developing countries in the twenty-first century(Jaya et al., 2024). According to the United Nations Environment Programme (UNEP), global municipal solid waste generation is projected to rise from approximately 2.01 billion tonnes in 2016 to 3.40 billion tonnes by 2050, with the steepest growth trajectories concentrated in low- and middle-income countries across Southeast Asia, Sub-Saharan Africa, and South Asia (UNEP, 2021). In Indonesia, the landfill system (Tempat Pembuangan Akhir/TPA) remains the primary final disposal mechanism, with more than 380 operational sites distributed across the archipelago(Tian & Liu, 2022). However, the majority of these facilities operate under open dumping or semi-controlled conditions that fall substantially short of the sanitary landfill standards required by Law No. 18 of 2008 on Waste Management, generating severe environmental burdens including leachate contamination, uncontrolled greenhouse gas emissions, and chronic community health risks(Lange, 2023).

The environmental significance of poorly managed organic waste decomposition in landfills extends beyond local impacts(Majid et al., 2025). Methane gas produced by anaerobic decomposition carries a global warming potential approximately 28 times greater than carbon dioxide over a 100-year period (IPCC, 2021), making landfill emissions a direct contributor to national greenhouse gas inventories. Indonesia's National Action Plan for Greenhouse Gas Reduction (RAN-GRK) specifically identifies the waste management sector as a priority emission reduction target, reinforcing the national policy relevance of sustainable landfill transformation(Liu & Green, 2024). When recovered through engineered gas capture systems, however, landfill methane can be converted into a locally accessible alternative energy source, simultaneously mitigating environmental damage and generating tangible economic benefits for adjacent communities. This waste-to-energy potential represents a critical operational nexus between environmental protection, community energy access, and sustainable development(Raza et al., 2024).

Achieving sustainable waste management outcomes, however, is not solely a matter of technical infrastructure(Ribeiro et al., 2025). A growing body of evidence in environmental psychology, behavioral economics, and sustainability science demonstrates that durable improvement in waste practices depends fundamentally on pro-environmental behavioral change among community members whose daily habits determine the operational effectiveness of waste management systems(Foster et al., 2022). Pro-environmental behaviordefined as the full range of actions intentionally undertaken to minimize negative human impact on the natural environment (Stern, 2000) encompasses both private-sphere activities such as waste sorting and energy conservation, and public-sphere activities such as environmental program participation and advocacy(Yusliza et al., 2020). The conditions under which such behavior develops, stabilizes, and diffuses within communities remain imperfectly understood, particularly in the specific context of peri-urban landfill communities in developing countries.

Three principal theoretical frameworks guide the analytical approach of this study. The Value-Belief-Norm (VBN) theory (Stern, 2000) proposes that pro-environmental action is activated sequentially through the internalization of environmental values, the recognition of ecological threats, and the formation of personal moral obligation norms. The Theory of Planned Behavior (Ajzen, 1991) identifies attitudes toward behavior, subjective norms from reference groups, and perceived behavioral control as the primary cognitive antecedents of environmental intention and action. The multi-factor behavioral determinant framework (Lisboa et al., 2024) argues that pro-environmental behavior is jointly determined by individual cognition, social context, institutional environment, and structural opportunity. Each framework captures a distinct dimension of behavioral

dynamics relevant to TPA Talangagung, where economic incentives, educational programs, peer norms, and institutional governance interact in producing community environmental outcomes (Appiah-Kubi et al., 2024).

TPA Talangagung in Kepanjen District, Malang Regency, represents one of the most comprehensively documented examples of successful controlled landfill transformation in Indonesia (Helferich et al., 2023). Since the early 2000s, Talangagung has evolved from a conventionally managed open disposal site into an integrated waste management facility incorporating engineered methane gas recovery, community-based waste segregation programs, composting operations, a formally recognized waste bank (*bank sampah*) system, and a nationally recognized environmental education and eco-tourism center (*pusat edukasi dan wisata lingkungan*) (van de Wetering et al., 2025). The landfill's biogas recovery infrastructure distributes methane gas through underground pipelines to hundreds of surrounding households, providing clean cooking fuel as a substitute for Liquefied Petroleum Gas (LPG) while simultaneously strengthening community acceptance of landfill management ((Zhang et al., 2025).

Beyond its technological achievements, Talangagung constitutes a distinctive educational case because environmental education is institutionalized as a continuous community learning process rather than being implemented as a series of isolated awareness campaigns. Environmental learning is embedded through regular public education programs, school visits, demonstration activities, waste management training, and direct community participation in waste segregation, composting, methane utilization, and waste bank management. This integration enables residents to acquire environmental knowledge, develop pro-environmental values, and translate these into everyday environmental practices that are reported and observed over time. Consequently, Talangagung functions not only as a landfill but also as a living laboratory for environmental education, where technological innovation, economic incentives, and social learning interact to shape sustained environmental practices.

A systematic review of the relevant literature reveals three substantive research gaps. First, previous studies on TPA Talangagung have primarily emphasized landfill operations, methane technology, and environmental tourism, while providing limited theoretical explanation of how environmental education influences the development of pro-environmental behavior. Second, international studies on landfill gas utilization and community-based waste management have focused predominantly on technical performance indicators, such as gas recovery efficiency, renewable energy production, and greenhouse gas mitigation, with comparatively little attention to the educational and behavioral processes that sustain environmental practices within local communities ((Bangwal et al., 2025). Third, no existing study has empirically integrated environmental education, methane utilization, and pro-environmental behavior into a single conceptual framework capable of explaining how educational processes and economic incentives jointly facilitate long-term behavioral transformation in landfill-adjacent communities. (Bilynets & Knezevic Cvelbar, 2022).

Accordingly, the originality of this study lies in proposing an integrated conceptual framework that positions environmental education as the primary mechanism through which methane utilization functions not only as an economic incentive but also as an educational catalyst for strengthening pro-environmental behavior. Rather than examining these components independently, the framework explains their dynamic interaction in producing sustained behavioral change through cognitive development, value internalization, community participation, and institutional support. This integrated perspective extends existing pro-environmental behavior literature by incorporating

educational, economic, social, and governance dimensions within a unified analytical model applicable to community-based landfill management. Based on these gaps, this study addresses the following research questions: (1) How does environmental education implemented at TPA Talangagung contribute to the development of sustained pro-environmental practices among surrounding communities?, (2) How does methane gas utilization interact with environmental education and community participation in shaping behavioral transformation, (3) What integrated strategic model can effectively explain and support sustainable pro-environmental behavior in landfill-based communities

The findings are expected to contribute theoretically by advancing an integrated framework linking environmental education, methane utilization, and pro-environmental behavior within the context of sustainable community-based waste management. Practically, the study provides evidence-based recommendations for policymakers, local governments, environmental educators, and landfill managers in designing educational and waste management strategies that foster enduring behavioral change and support the broader implementation of sustainable landfill governance in Indonesia and other developing countries.

2. METHODS

This study employed a qualitative research approach using a case study design to analyze strategies for strengthening pro-environmental behavior through methane gas utilization and environmental education at TPA Talangagung. A qualitative approach was considered appropriate because this study aims to understand social behavior, community participation, environmental awareness, and the interaction between environmental education and methane gas utilization within the real-life context of landfill-based communities. The case study method allows researchers to explore complex social phenomena comprehensively and contextually, particularly when the boundaries between phenomenon and context are closely interconnected. The research was conducted at TPA Talangagung, located in Kepanjen District, Malang Regency, East Java, Indonesia. This location was selected purposively because Talangagung Landfill is recognized as one of the most successful examples of controlled landfill transformation in Indonesia, integrating methane gas recovery, environmental education, and community-based waste management.(Cassady et al., 2025), the landfill has functioned not only as a final waste disposal site but also as an environmental education center and a source of methane gas distribution for surrounding households. The research was conducted from September to October 2025.

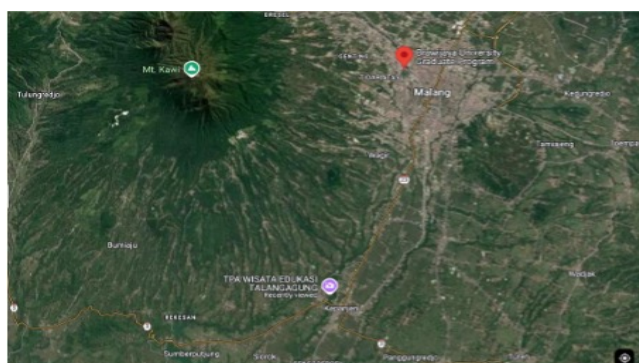




Figure 1. Research Location of Talangagung Landfill

Figure 1 shows the geographical location of Talangagung Landfill in Kepanjen District, Malang Regency. The strategic location supports direct interaction between landfill operations and surrounding communities, making it highly relevant for analyzing pro-environmental behavior and community-based environmental management.

Participants were selected using purposive sampling based on their direct involvement in landfill management and environmental activities at TPA Talangagung. The study involved 30 participants, comprising 5 officials from the Environmental Agency (DLH) of Malang Regency, 4 landfill management personnel, 15 community members living around the landfill and benefiting from the methane gas program, and 6 informal waste workers (scavengers). Participants included men and women aged 25–65 years, with varying educational levels, occupations, and lengths of involvement in environmental and waste management activities. This stakeholder diversity enabled the study to capture multiple perspectives regarding pro-environmental behavior and sustainable landfill management.

Data were collected through semi-structured interviews, participant observation, and document analysis (Paswan & Saini, 2021). The interview protocol consisted of open-ended questions exploring environmental awareness, behavioral changes, methane gas utilization, participation in environmental education, institutional support, and challenges to sustainable environmental practices. Each interview lasted approximately 45–90 minutes, was audio-recorded with participants' consent, and subsequently transcribed verbatim. Participant observation was conducted through field visits to examine waste segregation practices, methane gas utilization, recycling activities, environmental cleanliness, and community participation in environmental education programs. Field notes and observational records were used to compare participants' narratives with observed practices (Gomez-Escalonilla, 2021). Documents were purposively selected based on their relevance and included government reports, landfill operational records, village regulations, policy documents, photographs, and sustainability program reports.

The qualitative data were analyzed using thematic analysis. Interview transcripts, field notes, and documents were first read repeatedly to achieve data familiarization, followed by open coding to identify meaningful units. Similar codes were then grouped into categories, from which broader themes were generated, reviewed, refined, and interpreted through constant comparison across data sources. Emerging findings were regularly discussed among the research team to critically examine interpretations and reduce potential researcher bias. Data triangulation among interviews, observations, and documents was also used to strengthen the credibility of the findings.

Table 1. Data Collection Techniques

NO	Technique	Source of Data	Purpose
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1	Semi-structured Interview	DLH, landfill management, local community, scavengers	To explore perceptions, behavior, and participation
2	Direct Observation	Field conditions and community activities	To validate actual environmental practices
3	Documentation Review	Reports, policies, records, previous studies	To strengthen evidence and institutional context

The qualitative data were analyzed using thematic analysis as the primary coding and theme-development strategy. Interview transcripts, field notes, and documents were first read repeatedly to achieve data familiarization, followed by open coding to identify meaningful units. Similar codes were then grouped into categories, from which broader themes were generated, reviewed, refined, and interpreted through constant comparison across data sources.

The interactive model proposed by Miles, Huberman, and Saldaña was used as an organizing cycle for managing the analytical process, rather than as a separate analytical method. Data reduction involved selecting, simplifying, and categorizing relevant information from interviews, observations, and documentation. Data display organized the coded information into thematic categories such as environmental awareness, supporting factors, inhibiting factors, methane gas benefits, and strategic development models. Conclusion drawing involved interpreting patterns, relationships, and strategic implications related to pro-environmental behavior. Thus, thematic analysis guided the coding and development of themes, while the interactive model provided the broader cycle for organizing, displaying, comparing, and interpreting the qualitative data.

Table 2. Stages of Data Analysis

No	Analysis Stage	Description
1	Data Reduction	Selecting, simplifying, and categorizing relevant findings from interviews, observations, and documents
2	Data Display	Organizing findings into thematic categories such as environmental awareness, supporting factors, and strategic models
3	Conclusion Drawing	Interpreting patterns, relationships, and strategic implications for sustainable behavior strengthening

To ensure the trustworthiness of the findings, this study adopted the criteria of credibility, transferability, dependability, and confirmability. Credibility was enhanced through source and method triangulation by comparing information obtained from community members, landfill managers, government officials, and waste workers, as well as cross-checking evidence from semi-structured interviews, participant observations, and documentary sources (Moyo & Obadire, 2024). Member checking was conducted by sharing interview summaries and preliminary thematic interpretations with eight purposively selected participants representing the stakeholder groups. Participants were invited to verify the accuracy of the researchers' interpretations and to provide clarification or additional information where necessary. The member-checking process was used to assess whether the preliminary interpretations were consistent with participants' accounts. Transferability was supported by providing a rich description of the research context, participant characteristics, and the implementation of environmental education and methane gas utilization programs to enable readers to assess the applicability of the findings in similar settings. Dependability was ensured through a comprehensive trail

documenting the research design, data collection procedures, coding process, and analytical decisions. Confirmability was maintained by preserving interview transcripts, field notes, observation records, and documentary evidence while continuously comparing interpretations across multiple data sources to ensure that the findings were grounded in empirical evidence rather than researcher assumptions.

Table 3. Validity Testing Techniques

No	Validation Method	Purpose
1	Source Triangulation	Comparing information from different informants to improve consistency
2	Method Triangulation	Cross-checking interviews, observation findings, and documentation evidence
3	Member Checking	Confirming preliminary findings with participants to ensure interpretation accuracy

Ethical considerations were maintained throughout the research process. In accordance with the applicable institutional requirements, the study involved adult participants and non-invasive qualitative procedures. All participants were informed about the objectives of the study, the voluntary nature of their participation, their right to withdraw at any stage without consequences, and the measures taken to maintain confidentiality and anonymity. Written informed consent was obtained before interviews and observations were conducted, and personal identifiers were removed from the transcripts. Data were securely stored and accessed only by the research team throughout the study.

3. RESULTS AND DISCUSSION

3.1. Forms of Pro-Environmental Behavior

The findings indicate that pro-environmental behavior among communities surrounding TPA Talangagung is manifested through five interconnected forms of daily environmental practices: household waste sorting, methane gas utilization, waste bank participation, environmental education participation, and collective environmental maintenance. These behaviors were consistently identified across interviews, participant observations, and document analysis, demonstrating that environmental management initiatives have become integrated into both household routines and collective community activities. While each behavioral form serves a distinct function, together they illustrate a comprehensive pattern of community engagement in sustainable waste management, reflecting the active involvement of residents in maintaining environmental quality through individual responsibility and collective action.

The findings reveal that communities surrounding TPA Talangagung have developed significant and diverse forms of pro-environmental behavior as direct outcomes of the integrated implementation of methane gas utilization and environmental education programs (Faletar et al., 2021). Table 4 summarizes the five principal behavioral forms identified, their descriptions, environmental contributions, and motivational drivers.

Table 4. Forms of Pro-Environmental Behavior in

No	Behavioral Form	Empirical Findings
1	Household Waste Sorting	Households routinely separate organic and inorganic waste before disposal. Organic waste is composted, while recyclable materials are deposited in the waste bank (C-01).

2	Methane Gas Utilization	Residents use methane gas distributed from the landfill for daily cooking, replacing LPG in most participating households (C-02).
3	Waste Bank Participation	Community members regularly deposit recyclable materials at the waste bank and receive financial compensation based on material type and weight (C-03).
4	Environmental Education Participation	Residents participate in environmental education activities, including workshops, demonstrations, school visits, and environmental tourism programs organized by landfill management (C-04).
5	Collective Environmental Maintenance	Community members engage in regular clean-up campaigns, tree planting, and monitoring to prevent illegal waste disposal around the village (C-05).

Communities Surrounding TPA Talangagung

The findings indicate that pro-environmental behavior in the Talangagung community extends beyond individual household practices to encompass collective environmental actions and active participation in community-based environmental programs. These behavioral forms were consistently identified across interviews, participant observations, and document analysis, demonstrating that environmental management initiatives have become embedded in everyday community practices. Subsequent sections examine the factors influencing these behaviors and the mechanisms through which they are sustained over time. The findings indicate that pro-environmental behavior in the Talangagung community extends beyond individual household practices to encompass collective environmental actions and active participation in community-based environmental programs. These behavioral forms were consistently identified across interviews, participant observations, and document analysis, demonstrating that environmental management initiatives have become embedded in everyday community practices. Subsequent sections examine the factors influencing these behaviors and the mechanisms through which they are sustained over time.

The most visible and consistently documented behavioral form is household waste sorting the systematic separation of organic and inorganic waste prior to disposal. Community members have progressively internalized this practice, directing organic waste toward composting (both individual and community-managed) and channeling recyclable inorganic materials through the waste bank system (Anggana et al., 2022). The waste bank mechanism functions simultaneously as an economic incentive and a behavioral reinforcement tool: monetary compensation for sorted recyclables strengthens habit formation through direct financial reward, (Essl et al., 2025) finding that environmental knowledge combined with economic motivation produces more durable outcomes than knowledge alone. Observational evidence further confirms that established participants model sorting behavior for newer households, indicating pro-environmental norm diffusion through social learning mechanisms (Faletar¹ et al., 2021).

Methane gas utilization represents the most distinctive and strategically significant behavioral form documented at Talangagung. The biogas distribution network, which has supplied household fuel to residential areas since 2009, reduces monthly cooking fuel expenditure by IDR 50,000–100,000 per household a meaningful reduction for low-income families. Critically, this economic benefit does not function merely as a consumption incentive: it generates a sense of ownership and reciprocal responsibility toward the landfill among beneficiary households. Among the community participants who benefited from methane gas, the reported economic benefits of the program were associated with participation in waste segregation, environmental education, and

environmental maintenance activities (Adamska-Mieruszezewska et al., 2024). This behavioral mechanism aligns with Ajzen's (1991) Theory of Planned Behavior, wherein prior positive experience reinforces perceived behavioral control and subjective norms toward environmental action. The methane gas program thus represents a rare institutional case where environmental technology and community livelihood improvement converge to produce mutually reinforcing pro-environmental outcomes without reliance on coercive regulatory measures.

Participation in environmental education programs constitutes a third prominent behavioral form (Jain & Rathi, 2023). TPA Talangagung's multi-layered education system encompassing household-level socialization, practical demonstrations, school and university programs, and structured environmental tourism ensures that environmental knowledge and behavioral norms are distributed across age groups and social strata. The pedagogical approach combines experiential learning (direct engagement with landfill operations) with cognitive learning (seminars and workshops), consistent with constructivist environmental education principles (Lülfes & Hahn, 2013) that behavioral change is most durable when learners construct knowledge through direct experience. The educational tourism component generates an additional feedback loop between environmental engagement and economic benefit, reinforcing participation through income from visitor services (Bugdol et al., 2023). Collective environmental maintenance activities village clean-up programs (*kerja bakti*), tree planting, and community-based illegal dumping monitoring represent a qualitative transition from individual pro-environmental behavior toward collective environmental governance. These activities emerge from community consensus and socially embedded norms rather than formal regulatory mandates, corresponding to Bamberg and (Adamska-Mieruszezewska et al., 2023). social-normative pathway in which community identity and shared responsibility become primary behavioral motivators. The visibility of collective action within residential clusters exerts normative pressure on non-participating households, gradually expanding pro-environmental norms across the broader community population.

A critical theoretical contribution of these findings concerns the sequential behavioral pathway observed at TPA Talangagung: initial participation driven primarily by economic incentives (methane gas savings, waste bank income) appears to create a behavioral gateway that progressively opens toward deeper normative environmental commitment and collective stewardship. This sequence economic rationality → environmental awareness → normative obligation → social environmental governance extends existing VBN theory by demonstrating that economic incentive pathways, not only value-driven pathways, can activate the normative activation process in low-income peri-urban communities (Prati et al., 2017). This finding warrants explicit theoretical recognition and further empirical investigation across comparable landfill community contexts.

3.2. Supporting and Inhibiting Factors

The synthesis of the empirical findings indicates that sustainable pro-environmental behavior in communities surrounding TPA Talangagung cannot be explained by a single determinant. Rather, behavioral transformation emerges through the interaction of educational, economic, social, and institutional dimensions that reinforce one another over time. Based on the thematic analysis, this study proposes an integrated **Four-Pillar Model** that conceptualizes the key mechanisms underlying long-term pro-environmental behavior. The model positions environmental education as the foundational component, supported by methane gas utilization as an economic incentive, community participation as a mechanism for social reinforcement, and institutional strengthening as a governance framework that supports the continuity of pro-environmental practices.

Pro-environmental behavior at TPA Talangagung is shaped by a complex and interdependent set of internal and external factors. Table 5 provides a systematic overview of identified supporting and inhibiting factors alongside their theoretical foundations (Munawar et al., 2024).

Table 5. Supporting and Inhibiting Factors of Pro-Environmental Behavior at TPA Talangagung

No.	Factor Type	Empirical Findings
1	Internal Supporting	Environmental awareness and ecological literacy improved through continuous environmental education, encouraging residents to practice waste sorting and maintain environmental cleanliness.
2	Internal Supporting	Pro-environmental values, combined with economic benefits from methane gas utilization and waste bank participation, motivated residents to sustain environmentally responsible behavior.
3	External Supporting	Environmental education programs, methane gas distribution, waste management facilities, and village environmental regulations collectively strengthened community participation in sustainable waste management.
4	Internal Inhibiting	Differences in environmental literacy and persistent traditional waste disposal habits limited consistent participation among some residents, particularly older and less-educated groups.
5	External Inhibiting	Limited waste-sorting facilities and inconsistent enforcement of village environmental regulations constrained effective implementation of pro-environmental practices.
6	External Inhibiting	Community participation tended to decline when educational programs and institutional facilitation became less intensive, indicating dependence on continuous external support.

The proposed Four-Pillar Model demonstrates that sustainable pro-environmental behavior is generated through the synergistic interaction of its four interconnected pillars rather than through isolated interventions. Environmental education establishes the cognitive and normative foundation for behavioral change, methane gas utilization provides tangible economic incentives that encourage participation, community participation reinforces behavioral norms through collective action and social learning, and institutional strengthening secures the continuity of these practices through governance and policy support. Collectively, the model extends existing pro-environmental behavior frameworks by integrating educational, economic, social, and institutional dimensions into a unified conceptual framework, thereby offering a more comprehensive explanation of long-term behavioral transformation in landfill-based communities.

Among internal supporting factors, environmental awareness cultivated through sustained engagement with landfill education programs and reinforced by the lived experience of observing Talangagung's operational transformation emerged as the most foundational behavioral determinant (Anggraini & Purnomo, 2025). Informants demonstrating higher ecological literacy consistently exhibited stronger commitment to waste sorting, composting, and program participation. Personal values rooted in community welfare and culturally embedded religious environmental stewardship (articulated explicitly by multiple informants) functioned as additional motivational resources, suggesting that culturally sensitive value frameworks can amplify the effectiveness of environmental education interventions (Readi, 2024).

Economic motivation constitutes a particularly powerful internal factor: Community participants receiving methane gas benefits described the economic benefits of the program as an important motivation for participating in environmental activities and maintaining environmentally responsible practices, confirming Yuriev et al.'s (2020) meta-analytical finding that perceived proximate personal benefit is among the strongest determinants of pro-environmental behavioral strength. Among external supporting factors, structured environmental education programs delivered by DLH Malang Regency, landfill management, and community facilitators provided consistent reinforcement of behavioral norms across the residential catchment. Infrastructure availability—communal waste bins, composting equipment, and accessible waste bank facilities—significantly reduced the practical barriers to behavioral adoption, consistent with Barr's (2007) finding that infrastructure availability is a necessary precondition for behavioral maintenance. Institutional legitimacy through village-level environmental regulations (*peraturan desa*) provided a governance framework that reinforced community environmental expectations and elevated compliance norms.

Several inhibiting factors continue to constrain the full potential of behavioral adoption. Unequal distribution of environmental literacy most pronounced among older residents and households with limited formal education creates heterogeneous behavioral compliance across the community. Persistent habitual waste disposal practices, including indiscriminate dumping in drainage channels, reflect the inertial resistance to behavioral change identified (Emilda Kholifah Arifah & Triana Rosalina Noor, 2025). Limited availability of household sorting containers in lower-income segments imposes structural barriers that educational intervention alone cannot overcome. Most critically, inconsistent village-level enforcement of environmental regulations and irregular scheduling of community programs undermine institutional credibility aform of governance inconsistency that erodes the normative foundations necessary for long-term behavioral sustainability(Sugiarto et al., 2024). The documented behavioral dependency on external facilitation where participation declines when external support is withdrawn reveals that self-regulated environmental governance has not yet fully consolidated, a vulnerability that warrants targeted policy intervention(Sugiarto et al., 2024).

3.3. Integrated Strategic Model For Sustainable Pro-Environmental Behavior

The integration of the empirical findings reveals that sustainable pro-environmental behavior at TPA Talangagung is supported by a set of interconnected mechanisms rather than by a single intervention. Across the identified behavioral forms and influencing factors, four recurring components consistently emerged: environmental education, methane gas utilization, community participation, and institutional support. These components collectively form the basis of an integrated strategic model that describes the behavioral change process observed in the study.

Based on the synthesis of empirical findings and theoretical analysis, this study proposes an integrated four-pillar strategic model for strengthening pro-environmental behavior at TPA Talangagung and comparable landfill-based communities. The model is grounded in VBN theory (Stern, 2000), the Theory of Planned Behavior (Ajzen, 1991), and the multi-factor behavioral determinant framework (Mulyadin et al., 2024)and operationalizes the behavioral pathway identified in the findings section. Figure 1 illustrates the model's dynamic architecture; Table 6 details its implementation components and expected outcomes(Ahmad, 2019).

BEHAVIORAL CHANGE PATHWAY AT TPA TALANGAGUNG (Integrated Socio-Technical Behavioral Framework)

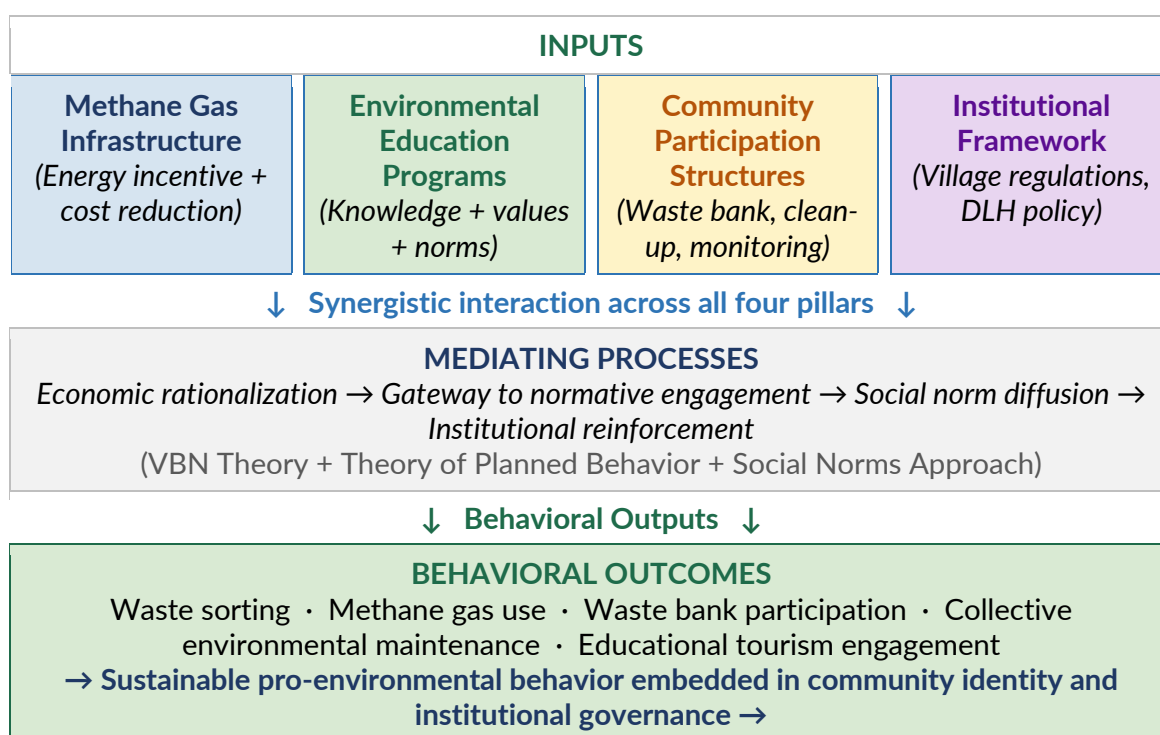


Figure 2. Integrated Behavioral Change Model: Pathway from Program Inputs to Sustainable Pro-Environmental Behavior

The proposed model demonstrates that the four pillars operate as complementary and mutually reinforcing components of community-based environmental management. The empirical findings indicate that environmental education provides the foundation for developing environmental awareness and values, methane gas utilization offers tangible household benefits that encourage participation, community participation reinforces behavioral practices through collective action, and institutional support sustains these practices through coordinated governance. Together, these interconnected processes culminate in observable pro-environmental behaviors, including waste sorting, methane gas utilization, waste bank participation, environmental education engagement, and collective environmental maintenance, which were consistently identified across interviews, participant observations, and document analysis.

The synthesis of the empirical findings identified four interrelated pillars that consistently shaped the development of pro-environmental behavior among communities surrounding TPA Talangagung. These pillars emerged from the thematic analysis of interviews, participant observations, and document analysis, reflecting the educational, economic, social, and institutional dimensions of community-based environmental management. Collectively, they form an integrated strategic model that illustrates the key components, functions, implementation strategies, and expected behavioral outcomes required to sustain pro-environmental behavior.

Table 6. Empirical Traceability of the Four-Pillar Model

Four-Pillar	Underlying Themes	Participant Groups	Observational Evidence	Documentary Evidence
Environmental Education	Environmental awareness; ecological literacy; environmental values; environmental	DLH officials; landfill management; community members; waste workers	Environmental education activities; demonstrations; community participation	Government reports; sustainability program reports; policy documents

	education participation			
Methane Gas Economic Incentives	Household fuel benefits; methane gas utilization; economic motivation; participation	DLH officials; landfill management; community members	Methane gas utilization for household cooking; community participation	Landfill operational records; program reports
Community Participation	Waste sorting; waste bank participation; composting; collective environmental maintenance; social norms	Community members; waste workers; landfill management	Waste segregation; recycling; composting; clean-up; environmental monitoring	Village regulations; program reports; photographs
Institutional Strengthening	Village environmental regulation; institutional support; infrastructure; stakeholder coordination	DLH officials; landfill management; community members	Environmental program implementation and community activities	Government reports; village regulations; policy documents; landfill operational records

The four-pillar model emerged from the convergence of recurring themes across interviews, participant observations, and documentary evidence. Environmental education was associated with environmental awareness, ecological literacy, values, and participation in educational activities. Methane gas utilization was linked to reported household fuel benefits and economic motivation. Community participation was reflected in waste sorting, waste bank activities, composting, and collective environmental maintenance. Institutional strengthening was represented by environmental regulations, infrastructure, stakeholder coordination, and program support. The convergence of these themes across stakeholder accounts and observational and documentary evidence provided the empirical basis for organizing the findings into four interconnected pillars.

The findings demonstrate that sustainable pro-environmental behavior at TPA Talangagung is shaped through the interaction of four complementary pillars: environmental education, methane gas economic incentives, community participation, and institutional strengthening. Environmental education provides the cognitive foundation for developing ecological awareness and values, while methane gas utilization offers tangible economic benefits that encourage community engagement. These efforts are reinforced through collective participation in environmental activities and supported by institutional policies and stakeholder coordination. Together, the four pillars constitute an integrated strategic model that reflects the empirical patterns of long-term behavioral transformation observed in the surrounding community.

The model's central theoretical contribution is its conception of the four pillars not as sequential stages but as simultaneously operating, mutually reinforcing components of a comprehensive behavioral change system. Environmental education builds the cognitive

and normative foundations without which methane gas incentives generate only transactional participation. Methane gas incentives lower the behavioral adoption threshold, making pro-environmental action economically rational for households who may lack sufficient normative motivation alone (Supartin, 2023). Community participation structures distribute ownership and responsibility across social networks, embedding behavioral norms in collective identity rather than individual calculation. Institutional strengthening provides the governance architecture that sustains the system across political transitions, program cycles, and external facilitation withdrawal (Hakim et al., 2024). The interdependence and mutual reinforcement of these pillars represents the primary advancement over single-factor models in the existing literature. Each pillar compensates for specific motivational deficits that others cannot address: where education alone fails to overcome economic barriers, incentives can bridge the gap; where incentives alone generate conditional compliance, education and community participation sustain behavior normatively; where community norms alone are insufficient to overcome structural barriers, institutional governance provides the necessary enforcement and infrastructure framework (Heath et al., 2024).

3.4. Comparative Perspectives from International Cases

To contextualize the empirical findings, this study compared the Talangagung case with selected landfill-based environmental management initiatives reported in other developing countries. The comparison focused on key dimensions identified in the present study, including environmental education, economic incentives, community participation, institutional support, and pro-environmental behavioral outcomes. Although each case reflects different socio-economic and governance contexts, several common patterns and distinctive characteristics were identified. The comparative findings demonstrate that Talangagung shares a number of successful community-based waste management practices with international cases while exhibiting unique integration across educational, economic, social, and institutional dimensions.

Evidence from landfill management experiences in other developing countries both corroborates and contextualizes the strategic model proposed in this study. Table 7 presents a structured comparison of Talangagung with three international cases(Riski Wahyudi & Budiana, 2021).

Table 7. Comparative Analysis: TPA Talangagung and International Landfill Management Cases

Case	Key Program Design	Documented Outcomes	Observed Limitations
TPA Talangagung, Indonesia	Methane gas distribution + env. education + waste bank + institutional policy	Strong participation; IDR 50k–100k monthly savings; self-sustaining community norms	Behavioral dependency on facilitation; uneven literacy; inconsistent village policy
Pune / Bangalore, India	Community biogas + source segregation + education	High household participation when incentives maintained; reduced open dumping	Participation drops when gas supply disrupted without educational foundation

Hanoi / Ho Chi Minh City, Vietnam	Community composting + waste banks + participatory programs	Effective behavioral engagement; reduced organic waste to landfill	Program deterioration without consistent institutional enforcement
Gramacho, Brazil (closed)	Community waste collection + livelihood programs + some education	Short-term community integration; scavenger livelihoods supported	Catastrophic behavioral collapse after abrupt closure without empowerment transition

The comparative findings reveal that all four cases employed community-based approaches to improve waste management outcomes, although the combination of intervention components differed across contexts. Environmental education, community participation, and institutional support were present to varying degrees in each case, while economic incentives were primarily associated with biogas utilization and livelihood programs. Among the cases examined, TPA Talangagung demonstrated the most integrated implementation of educational, economic, social, and institutional interventions, whereas the international cases generally emphasized only selected components. Despite these differences, all cases reported challenges related to sustaining community participation when educational support, institutional commitment, or economic incentives became less effective, highlighting common patterns observed across landfill-based environmental management initiatives.

Across these cases, two cross-cutting insights emerge. First, economic incentives combined with educational reinforcement generate more durable behavioral outcomes than either mechanism in isolation a pattern consistently observed in India, Vietnam, and at Talangagung, and its negative corollary confirmed by the Brazilian case. Second, institutional governance consistency is the most fragile and most critical determinant of long-term program sustainability: even strong community behavioral foundations erode when institutional support is inconsistent or withdrawn (Aguilera & Jackson, 2010). These comparative findings reinforce the four-pillar model's emphasis on institutional strengthening as an indispensable and non-substitutable component. The Talangagung model is distinguished from comparable international cases by three qualities: its exceptional operational longevity (15+ years of integrated program implementation), the depth of its community embeddedness (behavioral norms now partially self-sustaining through social mechanisms), and the multifunctionality of its program design (simultaneous address of economic, educational, social, and institutional dimensions) (Fregidou-Malama & Hyder, 2021). These qualities collectively provide a particularly robust evidence base for policy adaptation and replication across the Global South. The model's principles are potentially transferable to comparable peri-urban landfill contexts in Southeast Asia, South Asia, and Sub-Saharan Africa, where rapid urbanization and growing waste volumes create conditions structurally similar to those that shaped the Talangagung transformation (Habashy et al., 2024).

4. CONCLUSION

This study demonstrates that strengthening pro-environmental behavior in landfill-adjacent communities requires an integrated approach that combines environmental education, economic incentives, community participation, and institutional governance. The proposed four-pillar strategic model contributes theoretically by advancing environmental education research beyond knowledge-oriented approaches, showing that environmental learning becomes more effective when reinforced by economic incentives and community-based participation. The study also extends pro-environmental behavior theory by illustrating how environmental education and methane gas utilization operate as complementary mechanisms for fostering long-term environmental commitment in low-income communities. Practically, the model offers an **adaptable framework** for policymakers, local governments, environmental educators, and landfill managers seeking to promote sustainable waste management and community empowerment. The findings highlight the importance of integrating environmental education into renewable energy initiatives, supported by participatory governance and consistent institutional policies, to strengthen sustainable community development and environmental resilience.

This study has several limitations. As a qualitative single-case study, the findings are context-specific and cannot be generalized to all landfill communities. In addition, the relatively short period of data collection limits the ability to examine long-term behavioral change. Future studies should employ longitudinal and comparative designs across multiple landfill sites and incorporate quantitative approaches to validate and refine the proposed model. Despite these limitations, this study provides a meaningful contribution to environmental education and sustainability research by offering an integrated framework that connects environmental learning, renewable energy utilization, and community participation to support lasting pro-environmental behavior.

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