Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 23, No 1, 2026,
Article available at homepage presipitasi

Regional Case Study

Environmental Communication and Community Empowerment in CSR-based Refuse-Derived Fuel (RDF) Production: A Case Study in Cirebon, Indonesia

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Abstract

Inadequate waste management in rural areas contributes significantly to environmental degradation due to limited infrastructure and low public awareness. This study addresses a critical gap in RDF research, which has largely emphasized technical feasibility while overlooking social empowerment and institutional challenges. A qualitative case study was conducted in three villages in Cirebon Regency, Indonesia, supported by descriptive quantitative analysis. Data collection included interviews, focus group discussions, field observations, and document reviews, with NVivo software used for coding and triangulation. The findings demonstrate that participatory training, decentralized waste sorting, and incentive-based schemes enhanced household waste behavior and doubled RDF output in 2023. Yet, persistent gendered inequalities, lack of legal status for waste units, and weak stakeholder coordination undermined long-term sustainability. This study contributes to environmental communication and empowerment scholarship by showing how inclusive governance and institutional reform determine the success of waste-to-energy programs. Practically, the results provide policy guidance for CSR-based initiatives, emphasizing gender equity, participatory monitoring, and transparent financing as prerequisites for sustainable RDF governance.

Keywords: Alternative fuel; community empowerment; community waste management; refuse-derived fuel; social inclusion; waste valorization

1. Introduction

The global waste crisis poses a major challenge to sustainable development, particularly in low- and middle-income countries where limited infrastructure and weak institutional systems exacerbate environmental degradation (Khan et al., 2022; Sarquah et al., 2023). Rapid urbanization and rising consumption have intensified solid waste generation, while reliance on landfilling and open dumping remains environmentally hazardous (Fatimah et al., 2020). These conditions underscore the need for waste-to-energy strategies that integrate technical, social, and governance dimensions. Refuse-derived fuel (RDF) has emerged as a promising solution, converting combustible fractions of municipal solid waste into alternative fuel for energy-intensive industries such as cement manufacturing (Tihin et al., 2023).

In Indonesia, RDF pilot projects demonstrate both technical and economic feasibility, with measurable reductions in methane emissions and greenhouse gas (GHG) outputs (Paramita et al., 2018;

Liem et al., 2024). However, while the engineering and environmental potential of RDF has been documented, the social and institutional foundations of its sustainability remain underexplored. This study contributes to filling that gap by examining how environmental communication and community empowerment are operationalized within a CSR-driven RDF program in Cirebon, West Java. Unlike earlier RDF research that primarily focused on calorific values or emission reduction, this article highlights the role of participatory communication, gender dynamics, and institutional legitimacy in shaping program outcomes. By situating the analysis at the village level, the study offers new insights into how waste-to-energy transitions intersect with local governance, community agency, and inclusive development.

While the importance of community involvement in environmental initiatives is well established, research specifically examining empowerment strategies within RDF programs—especially in rural and peri-urban regions of the Global South—remains limited. Existing studies tend to prioritize urban infrastructure development or top-down policy frameworks, often neglecting local cultural dynamics and grassroots agency (Alao et al., 2022; Agaton and Santos, 2025). This represents a critical research gap, given that RDF implementation frequently intersects with localized social systems, requiring context-sensitive approaches to communication and empowerment to ensure inclusive and sustainable outcomes.

Similar insights are reflected in the literature on collaborative governance, where transnational municipal networks have been shown to foster local regimes for more effective environmental management (Picavet et al., 2023). Recent literature strengthens this argument. Purwono et al. (2025) underscore the importance of environmental literacy among youth—particularly Generation Z—in fostering sustainable waste practices, thus pointing to the relevance of educational and participatory communication. Prayogo (2024) shows how socio-demographic factors such as education, income, and length of residence significantly affect household waste behavior, indicating that RDF strategies must be tailored to community-specific conditions. Additionally, Sari et al. (2021) illustrate how digital environmental communication via social media can effectively mobilize collective action, showing the potential of participatory digital tools in fostering environmental awareness and engagement. This article examines how environmental communication and community empowerment are operationalized in a corporate social responsibility (CSR)-driven RDF initiative in Cirebon Regency, West Java. Focusing on participatory training, decentralized waste sorting at the household level, and community-managed incentive systems in three pilot villages—Palimanan Barat, Cupang, and Kedungbunder—this study aims to explore how locally grounded communication strategies contribute to the environmental sustainability, social inclusion, and operational effectiveness of RDF programs in rural Indonesia.

Based on the literature, most RDF studies in Indonesia emphasize technical feasibility and emission reduction, while few examine how community empowerment and communication strategies influence institutional sustainability. Recent studies further emphasize that empowerment is most effective when rooted in participatory action and inclusive planning processes (Ataöv et al., 2022). This creates a research gap in understanding the socio-institutional factors that determine long-term RDF success. To address this gap, this study develops a research framework that integrates three interrelated dimensions: (1) operational and HSE compliance, (2) participatory communication and CSR-based engagement, and (3) community empowerment and institutional capacity. These dimensions interact to influence both process performance (RDF quality, safety, and production stability) and sustainability outcomes (environmental benefits, social inclusion, and governance legitimacy. By positioning the Cirebon RDF case study within this framework, the article contributes to filling the gap between technical engineering literature and socio-institutional analysis of RDF implementation in the Global South.

2. Methods

2.1 Study Area and Site Selection

This study was conducted in Cirebon Regency, West Java, Indonesia—a peri-urban region facing persistent challenges in managing municipal solid waste (MSW). The research focused on three pilot villages: Palimanan Barat, Kedungbunder, and Cupang, selected in 2022 under a CSR-based RDF program by PT Indocement Tunggal Prakarsa. Selection criteria included socio-economic diversity, infrastructure readiness, and governance capacity (Enwin and Ikiriko, 2023). The geographical distribution of these sites is shown in Figure 1.

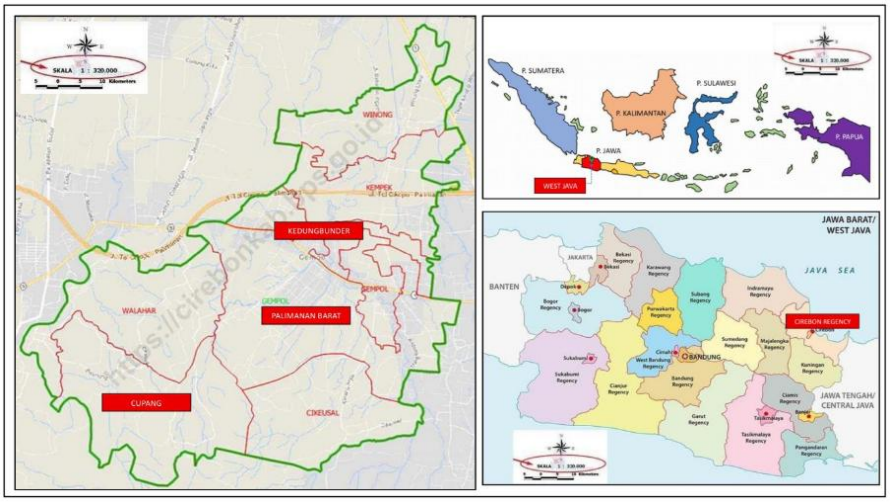

Figure 1. Geographical locations of the study areas in the selected villages in the Cirebon Regency, West Java, Indonesia

This study employed an embedded qualitative case study design. Fifteen key informants were purposively selected based on their involvement in RDF planning, implementation, and evaluation, including RDF unit managers, village leaders, CSR officers, environmental agency staff, and active residents. One focus group discussion (FGD) was conducted with ten participants of varied gender and age. Interviews and FGDs were audio-recorded, transcribed verbatim, and coded using NVivo 12 software through iterative thematic analysis. Triangulation was applied across interviews, field observations, and document reviews to strengthen validity. The qualitative case study approach was selected to provide contextual depth, allowing for an in-depth understanding of empowerment and communication processes within a real-world RDF initiative.

2.2 Research Design and Sampling

An embedded qualitative case study was employed with a mixed-methods approach. Fifteen key informants were purposively selected based on their involvement in RDF planning, implementation, and evaluation—comprising RDF unit managers, village leaders, CSR officers, environmental agency staff, and active community members. Data saturation was reached by the thirteenth interview. One focus group discussion (FGD) was conducted involving participants of varied gender, age, and participation levels.

2.3 Data Collection Techniques

Qualitative data were gathered through semi-structured interviews, FGDs, participatory observations at RDF facilities, and document reviews. All discussions were audio-recorded, transcribed verbatim, and analyzed using NVivo 12 software (QSR International). Document sources included CSR reports, public outreach materials, and corporate social media. Triangulation was applied to ensure data validity (Buabeng and Amo-darko, 2024).

2.4 Quantitative Data and Descriptive Analysis

Quantitative data were sourced from operational monitoring reports of CSR Indocement and verified with the Cirebon Environmental Agency and UPS managers. In 2024, the RDF output at UPS Palimanan Barat increased from 5.0 to 10.0 metric tons/day. Descriptive analysis using Microsoft Excel was applied to assess trends in production volume and output consistency. No inferential statistical analysis was conducted, considering the limited case scope.

2.5 Energy Data and Technical Reference

This study did not perform direct calorific measurement. However, secondary data from Indocement's internal technical reports indicated that RDF produced from plastic and dry waste had calorific values ranging from 3,000–4,000 kcal/kg—within the standard range for medium-grade RDF.

2.6 Analytical Framework

The study was guided by the hypothesis that community empowerment through participatory training, inclusive communication, and local incentives improves RDF quality and output. The framework drew on participatory development and environmental governance theory, emphasizing inclusiveness and collaborative management (Haque et al., 2025; Krishnan et al., 2025).

2.7 Validity and Limitations

Potential interviewer bias was mitigated through data triangulation. The study's limited geographical scope restricts generalizability, but provides depth to understand semi-rural RDF systems.

2.8 Main Equipment

The core equipment used in the RDF processing units included a crusher, which played a critical role in breaking down hard plastic and mixed dry waste into finer particles suitable for fuel processing. The crusher was operated manually and integrated into a small-scale, community-run facility. Supporting equipment included a manual sorting conveyor used for segregating combustible waste, a basic waste shredder for initial size reduction, and a solar-based drying unit to reduce moisture content before RDF packaging. These tools were selected for their appropriateness in rural settings and ease of maintenance. A layout of the RDF processing station is presented in Figure 2.

Figure 2. Crusher operated by local community to process dry mixed waste for RDF production

3. Result and Discussion

3.1 Waste Management Challenges in Pilot Villages

Cirebon Regency continues to encounter significant structural and operational barriers in municipal solid waste (MSW) management, especially in the three RDF pilot villages: Palimanan Barat, Kedungbunder, and Cupang. Field observations and in-depth interviews revealed notable disparities in both infrastructure quality and community engagement levels across the sites. These variations reflect

uneven implementation capacity and differing baseline conditions among villages. A summary of the key waste management issues identified in each location is presented in Table 1.

Table 1. Waste management challenges in pilot villages

Village	Main Issues
Palimanan Barat	No structured waste sorting; minimal household-level segregation; UPS not yet optimal
Kedungbunder	No waste transport fleet; no incentives; low participation; conventional disposal
Cupang	Critical waste handling; waste dumped in yards; only one DLH bin; no fee system

The findings indicate that the observed challenges in the three pilot villages are not solely technical, but deeply rooted in institutional inadequacies. From a cybernetic perspective, an effective waste management system should contain feedback loops that allow operational-level inputs—such as low public participation or poor household sorting—to inform responsive policy adaptations. However, in Palimanan Barat, the waste processing unit (UPS) functioned suboptimally despite community efforts in waste separation. As noted by Sudirman (interview, March 28, 2025), source-separated waste was often recontaminated during collection, revealing a breakdown in feedback mechanisms and poor subsystem coordination.

More critical gaps were evident in Kedungbunder and Cupang, where the absence of transport fleets and incentive structures exposed the lack of sustainability mechanisms for community engagement. Using the political systems lens (Menon et al., 2025), the inability to transform grassroots participation into actionable policy outputs reflects a deeper systemic dysfunction. Although the RDF program aims to integrate local aspirations, the failure to establish incentives and reward schemes weakens community ownership. This directly affects RDF quality, diminishes the impact of CSR programs, and erodes public trust in local waste governance. The systemic analogy extends to broader governance failures. Jefferson (2024) highlights how the Advanced Research Projects Agency (ARPA) in the United States implemented feedback-control principles to restructure institutional responsiveness. If national institutions can adapt using feedback logic, the inability to apply such mechanisms at the village level points to limited institutional learning and capacity.

To address this, PT Indocement has introduced a sustainability roadmap to increase alternative fuel use from 18.3% in 2023 to 25% in 2025, and 42% by 2030. However, achieving this target will require more than technological advancement. A robust social infrastructure is needed to support adaptive, feedback-based communication and inclusive engagement cycles. Interviews with Dinas Pemberdayaan Masyarakat Desa (DPMD) officials suggest that government support via alokasi dana desa (ADD) is intended to fund temporary waste storage units (TPSS), sorting infrastructure, and transport. Nevertheless, issues of transparency and participatory planning persist, necessitating institutional reforms to strengthen collaborative decision-making processes.

3.2 RDF Program Implementation and Technical Flow

The RDF program initiated by PT Indocement in Cirebon Regency has restructured rural waste management practices through the establishment of decentralized village-scale waste processing units (UPS). These units, operated jointly by village governments and local communities, represent a transition from fragmented systems toward a structured circular economy model. As illustrated in Figure 3, the RDF processing system integrates several technical stages, starting with the collection and preliminary cleaning of household waste, office refuse, used paper, cement sack paper, and energy crops.

Following initial sorting, waste materials are directed into three distinct output streams:

1. Compost, derived from organic fractions such as food waste and leaves, is processed into fertilizer for soil improvement.
2. Biomass, primarily from agricultural residues and energy crops, is utilized as fuel or for land rehabilitation.
3. RDF, composed of non-organic materials with high calorific value (e.g., plastics, multilayer paper, non-recyclables), is refined into alternative fuel to substitute coal in cement production.

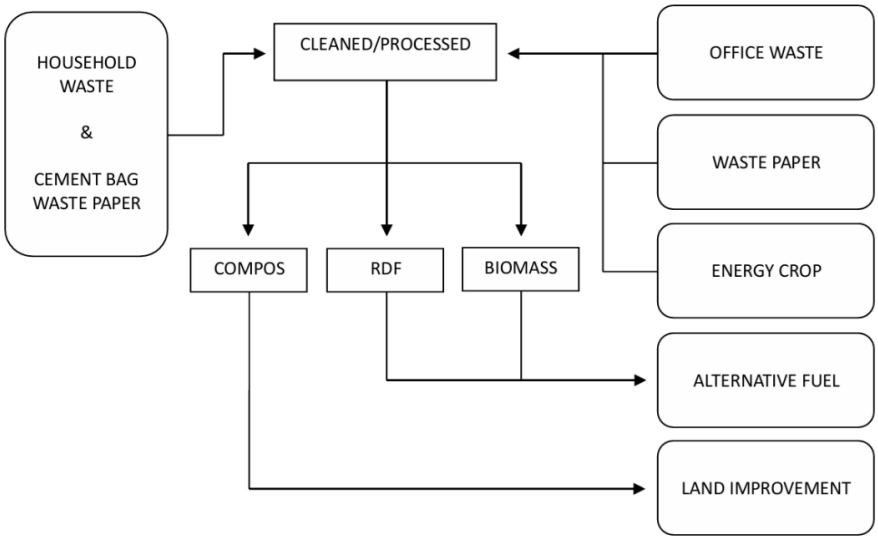

Figure 3. RDF waste production flow at UPS Palimanan Barat

The integration of energy crops and industrial waste—such as cement sack paper—ensures calorific consistency, a key metric for combustion efficiency. Meanwhile, the decentralized UPS structure has strengthened local institutional capacity and community ownership. Nevertheless, challenges persist, including inconsistent RDF quality, low waste sorting at household level, and seasonal production drops during the rainy season due to inefficient drying.

Despite these limitations, the program contributes to landfill reduction, GHG mitigation, and the development of a technically and socially integrated waste system. RDF production in Palimanan Barat increased from 5 metric tons/day in 2022 to an average of 10 metric tons/day in 2023, with a target of 30 metric tons/day by 2030 (Table 2).

Table 2. RDF daily production capacity development at UPS Palimanan Barat

Year	Production Capacity (Ton)	Information
2008	0,5	RDF production capacity at the beginning of establishment
2021	5	Average capacity before revitalization
2022	7	Average capacity after revitalization
2023	10	Daily capacity to date
2030	30	The expected future target has been achieved in 2030

Beyond production capacity, these figures also reflect the environmental contribution of RDF adoption. Using an emission reduction factor of 1.75 metric tons of CO_2 per ton of RDF (Widowati, 2023a), the increase from 5 to 10 tons/day in 2023 equates to an estimated annual mitigation of 6,387 tCO_2. This highlights RDF's dual role as a waste management strategy and a climate mitigation pathway. By linking local production improvements with measurable reductions in greenhouse gases, the program demonstrates its alignment with Indonesia's national decarbonization commitments and global sustainable development goals (Afnan et al., 2025).

While Table 2 is based on in-depth interviews rather than administrative data, it reflects a clear upward trend in production capacity. The RDF adheres to RDF-3 standards, as defined by ASTM E856-83, with each ton potentially reducing CO_2 emissions by approximately 1.75 metric tons (Widowati, 2023b). Cross-national insights offer comparative learning. In Poland, RDF has replaced 20–30% of fossil fuel use in the cement industry (Nowak, 2023), while in Ghana, RDF adoption supports clean energy transitions despite institutional challenges. Although Indonesia's governance differs, both cases underscore the need for improved inter-agency coordination and fiscal support at the local level.

Technically, RDF in this program is derived from non-hazardous domestic waste and processed into fluff or pellet form depending on demand. The RDF undergoes standardized stages, including shredding, drying, and metal separation. Feedstock sources include biomass (e.g., rice husks, sawdust) and industrial waste (e.g., discarded tires, shoes), reinforcing RDF's adaptability and contribution to sustainable energy transitions.

The program adopts ASTM-based quality standards to assess parameters such as ash content, chlorine, and sulfur. As shown in Table 3, ASTM methods such as E829-16 and E776-16 ensure combustion quality and safety. These standards are integral to the implementation of the Alternative Fuel and Alternative Material (AFAM) system by PT Indocement. The AFAM framework aligns RDF use with industrial sustainability goals and Indonesia's national energy transition strategy. Under this framework, the company has replaced approximately 20% of its fuel use with alternatives, aiming for a 40% substitution rate by 2030.

Table 3. Standard RDF sample test method based on ASTM

Test Method	ASTM
Test method for collecting gross samples RDF	ASTM D5115-90 (1996) Std
Standard practice for preparing RDF laboratory samples for analysis	ASTM E829-16
Test method for thermal characteristics of RDF macro samples	ASTM E955-88 (2009) e1 Std
Test method for residual moisture in RDF analysis samples	ASTM E790-15 Standard
Test method determination of form of chlorine in RDF	ASTM E776-16 Standard
Test method for total sulfur in the analysis sample of RDF	ASTM E775-15 Standard

RDF production model represents a strategic shift from fossil fuel dependence toward waste-based energy systems, with Figure 4 illustrating the technical operation and energy input structure of the system.

Figure 4. MSW that has been processed with this husk is ready to be used for combustion or into RDF products

3.3 Institutional Sustainability and System Integration

Despite the technical progress achieved by the RDF program in Cirebon Regency, the institutional sustainability of the village-level waste processing units (UPS) remains precarious. Field data indicate that most UPS entities lack formal legal status, standardized financial systems, and adequate technical or administrative capacity to function autonomously. This situation has created a structural dependency on PT Indocement, which retains operational leadership and decision-making authority. The imbalance of power between the corporation, village governments, and local communities has resulted in limited local ownership and weakened autonomy in waste governance (McCarthy and Krause, 2024). Comparable patterns are observed in other contexts, where collaborative governance between governments and NGOs has proven essential for addressing complex waste challenges (Arantes et al., 2020).

Without legal mandates and formalized benefit-sharing mechanisms, community involvement tends to be ceremonial rather than substantive. This undermines public trust and contradicts the principles of collaborative governance, which emphasize decentralized authority and inclusive engagement for program legitimacy. From an open-systems theory perspective, institutional effectiveness depends on the coordination of internal subsystems—households, sorting personnel, transporters, and UPS managers—and their capacity to adapt based on feedback from the environment (Filatotchev et al., 2022). In the RDF context, dysfunction in any subsystem compromises RDF quality and erodes public support.

Besio and Tacke (2024) further argue that hierarchical models often falter in dynamic social environments, advocating instead for horizontally networked institutional arrangements. In the Cirebon RDF case, the absence of such networks has led to fragmentation, reduced performance, and trust deficits. These conditions pose significant risks to the legitimacy of the program and may jeopardize the long-term viability of a circular economy–oriented energy transition at the village level. For further analyze the sustainability of RDF programs, simulations were conducted using SWOT and fishbone diagrams.

Strengths • Corporate commitment • Community participation • Existing infrastructure	Opportunities • Adoption of ISO 21640, BREF CLM, IFC EHS • Policy momentum for coal substitution • CSR-enabled social acceptance
Weaknesses • Inconsistent RDF quality • Limited HSE documentation • Legal/financial gaps of UPS	Threats • Fire risks in storage • Regulatory uncertainties • Fluctuating waste supply

Figure 5. SWOT analysis of the RDF program's sustainability factors

SWOT analysis highlights that the program's strengths include corporate commitment, community participation, and existing infrastructure, while weaknesses involve inconsistent RDF quality and limited documentation of HSE procedures. Opportunities arise from the adoption of international standards (ISO 21640, BREF CLM, IFC EHS), growing policy momentum for coal substitution, and social acceptance through CSR. Threats involve fire risks in storage, regulatory uncertainties, and fluctuating waste supply.

Fishbone analysis identifies root causes of sustainability challenges, grouped into six categories: (1) People – uneven HSE training, cultural reluctance to report near-miss incidents; (2) Process – lack of standardized acceptance protocols and sampling; (3) Materials – high moisture levels and contamination; (4) Equipment – insufficient ventilation and monitoring tools; (5) Environment – seasonal effects increasing waste moisture and dust dispersion; and (6) Management – absence of an integrated HSE dashboard and limited community feedback loops.

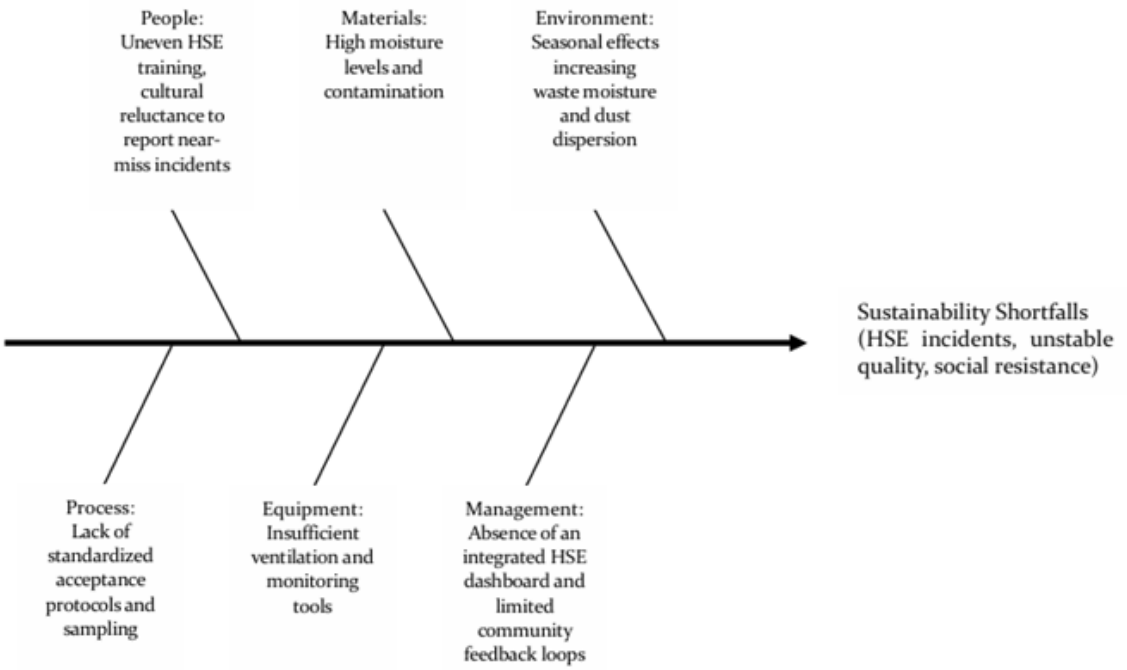

Figure 6. Fishbone diagram mapping the root causes of RDF sustainability challenges

Figures 5 and 6 present the SWOT and fishbone diagrams. Together, these simulations provide a structured visualization of the key drivers and obstacles influencing RDF sustainability. The SWOT analysis emphasizes the interplay between internal capacities and external pressures, while the fishbone diagram traces the root causes of recurrent challenges across technical, organizational, and environmental domains. Taken jointly, the findings indicate that achieving long-term sustainability requires a dual approach: on the one hand, strengthening technical measures such as process standardization, fire safety, and emissions monitoring; and on the other hand, reinforcing institutional mechanisms including continuous training, systematic feedback loops, and participatory governance structures.

3.4 Strategic Implications and Policy Relevance

The RDF program in Cirebon not only introduces alternative waste processing technology but also serves as a platform for operationalizing circular economy principles at the village level. However, the long-term success of this program hinges on participatory governance and the institutional strengthening of local actors. In Cirebon, technical gains have not been matched by equally strong institutional scaffolding. Accordingly, this study recommends the following three strategic interventions:

3.4.1. Village Fund Allocation for Local Waste Infrastructure

Village funds (Alokasi Dana Desa/ADD) are essential for improving waste infrastructure at the local level. They should support TPSS construction, motorized cart procurement, and decentralized RDF storage. Yet, field data show problems such as budget opacity, inconsistent use across villages, and low community involvement. This has led to unequal access, with remote villages often left behind compared to those near industrial zones. Budget control by village elites also weakens community participation. Evidence shows that transparent, community-driven funding models are more effective for sustainable environmental programs (Ezeudu and Bristow, 2024). To make ADD more impactful, clear district regulations and inclusive, gender-aware village forums are needed.

3.4.2. Training for UPS Staff on Machine Operation and Community Engagement

UPS operators are key to RDF operations but are mostly trained in technical skills like shredding and sorting. Their lack of training in public communication, environmental ethics, and conflict handling often causes friction with residents. Female informants also reported exclusion from RDF forums, despite their waste

management role at home. These findings support Arzo and Hong (2024), who call for broader capacity-building that includes facilitation, gender awareness, and power dynamics.

3.4.3 Creation of Multi-Stakeholder Monitoring Units to Evaluate RDF Impact

Without joint evaluation mechanisms, RDF programs risk low accountability and community distrust. This study proposes a monitoring team involving village leaders, local communities (including women and marginalized groups), NGOs, and PT Indocement. The team would review RDF's social and environmental impact, track policy effects, and offer practical recommendations. Schuster and Mossig (2025) highlight that participatory governance boosts program legitimacy. Likewise, Jiang et al. (2025) stress dialogic CSR to build shared ownership and trust. Recent findings also suggest that eco-efficiency can act as a catalyst for citizen co-production in urban governance, reinforcing the relevance of participatory approaches in environmental programs (Zhang et al., 2025). A case in point is Houjie's "Internet + Chuangan National" initiative, which promoted collaboration through open structures and citizen co-creation (Deng, 2019).

Taken together, these three interventions show that RDF programs should be seen as drivers of institutional change, not just technical solutions. A sustainable RDF system needs a clear roadmap—covering financing rules, comprehensive training, and inclusive monitoring. Scaling this model elsewhere requires attention to local politics, institutional readiness, and cultural values.

3.5 Social Dimension: Gender Roles, Distributive Justice, and Community Perception

Field observations revealed persistent gender disparities in the implementation of the RDF program in the pilot villages. At the household level, women—especially housewives—assume the primary responsibility for waste sorting, which directly affects RDF quality. As expressed by Uun, a resident of Kepuh Village (interview, April 2, 2025), sorting is performed every morning while male family members are away for work. However, these ecological contributions are not institutionally recognized nor linked to strategic roles in decision-making. This reflects a gendered division of labor in which women's roles are limited to operational tasks, while planning and facilitation roles are dominated by men or village elites.

The unequal distribution of responsibility and benefit is exacerbated by non-inclusive mechanisms of participation. Suhaimi, a resident of Cupang (interview, March 30, 2025), reported that only those with close ties to the village leadership are regularly invited to training, while others rely on secondhand information. From a theoretical perspective, these findings resonate with Fraser's (2000) framework of social justice, which emphasizes the interconnected dimensions of distribution, representation, and recognition. Although women play a central role in improving RDF quality through daily waste sorting, their contributions remain structurally undervalued. Exclusion from training and decision-making spaces not only reproduces gender inequality but also undermines collective ownership of the program. Such dynamics illustrate how ecological labor performed by women is systematically overlooked, thereby constraining the inclusiveness and long-term sustainability of RDF governance.

This pattern aligns with the concept of triple injustice (Hölscher and Bozalek, 2020), which consists of:

1. Distribution – Women and marginalized residents have limited access to economic benefits and capacity-building programs.
2. Representation – They are excluded from decision-making forums and deliberative spaces.
3. Recognition – Their environmental contributions are institutionally invisible.

These dynamics echo broader evidence from rural contexts, where women's empowerment has been shown to directly influence both efficiency and community-level sustainability outcomes (Tesafa et al., 2025). Similar dynamics have been reported globally. Ismail et al. (2025) observed that refugee women in Afghanistan are active in informal economies but remain excluded from formal policy spaces. Velasco-Herrejón and Bauwens (2024) found that in Mexican communities with high inequality, dissent often manifests through environmental narratives rather than direct critique, due to cultural restraint. In the Cirebon context, the local value of *ewuh pakewuh* discourages especially women from voicing

dissatisfaction with unequal program outcomes, reinforcing the disconnect between contribution and institutional access.

From the perspective of the capability approach, justice requires more than formal equality; it requires the real freedom to pursue and achieve valued goals. Lambe et al. (2022) showed that clean energy programs in Kenya and Uganda succeeded when aligned with local needs and capacities. Similarly, although RDF training and incentives are technically available, women in the pilot villages face social barriers such as household workload, lack of childcare, and rigid training schedules.

Therefore, advancing equitable RDF governance requires structural transformation—moving from formal equality to substantive justice. This involves:

1. Active inclusion of women in program planning and policymaking.
2. Formal recognition of women's ecological labor.
3. Program adjustments responsive to the lived realities of marginalized groups.

Only by integrating recognition, redistribution, and representation into RDF institutional design can the program evolve into a system that is not only technically sound but also socially inclusive and ecologically just.

4. Conclusions

This study demonstrates that Refuse-Derived Fuel (RDF) programs can simultaneously advance environmental sustainability and community development objectives. In rural and peri-urban settings, success depends not only on technological innovation but also on community empowerment and institutional integration. Measurable improvements in RDF output, material quality, and social ownership were observed when local actors engaged through participatory training, incentivized waste sorting, and village-led initiatives, yet these gains remain constrained by weak legal frameworks and limited stakeholder coordination. However, technical progress alone is insufficient. Long-term sustainability requires transparent financing, supportive regulations, and inclusive governance structures. RDF programs must move beyond top-down models and embed community-driven approaches that institutionalize local agency. Empowered communities are better positioned to manage and scale waste-to-energy systems while fostering trust and accountability.

From a theoretical perspective, this study extends RDF discourse beyond engineering and environmental sciences by emphasizing social, institutional, and governance dimensions. It reinforces open-systems theory, which views organizations as dynamic entities shaped by internal coordination and responsiveness to external feedback. In the RDF context, sustainability is determined not solely by calorific efficiency but by participatory design, feedback loops, and institutional trust. Practically, governments must integrate RDF strategies into village development plans, allocate sufficient budgets for infrastructure, and establish formalized partnerships with private actors such as cement industries. Clear agreements on shared responsibilities, transparent financing, and measurable performance indicators are essential. Community-based monitoring mechanisms can further enhance accountability, ensuring that CSR-driven initiatives align with broader sustainability goals.

In summary, this study advances theoretical discourse by situating RDF within the fields of environmental communication and community empowerment, highlighting participatory governance, gender-sensitive inclusion, and institutional legitimacy as critical determinants of sustainability. At the practical level, it provides policy guidance for CSR-based waste-to-energy programs, emphasizing the need for transparent financing, multi-stakeholder monitoring, and the integration of gender equity into program design. Together, these contributions underscore RDF's role not merely as a technical innovation but as a socio-technical platform for inclusive and climate-resilient development in the Global South.

Acknowledgement

The authors would like to express their sincere gratitude to PT Indocement Tunggal Prakarsa, Tbk. for its collaboration and for granting access to field data throughout the course of this research. Appreciation is also extended to Universitas Muhammadiyah Cirebon, the Government of Cirebon Regency, and the residents of Palimanan Barat, Cupang, and Kedungbunder Villages for their valuable participation and support.

Ethics Statement

This study did not involve clinical procedures or experiments requiring formal ethical approval under national research guidelines. However, all participants were informed about the purpose of the study and provided verbal or written consent prior to participation. Privacy and confidentiality were maintained throughout the research process, and all data were handled in accordance with established ethical standards for social research.

CRedit Author Statement

Author 1: Dikhorir Afnan*

☑ *Conceived and designed the analysis*

Formulated the research design, selected case study sites, and structured the article framework.

☑ *Collected the data*

Conducted fieldwork, in-depth interviews, and focus group discussions.

☑ *Contributed data or analysis tools*

Managed data using NVivo and Excel for coding and categorization.

☑ *Performed the analysis*

Led thematic analysis and interpretation of qualitative findings.

☑ *Wrote the paper*

Drafted the entire manuscript, integrated co-author inputs, and finalized for submission.

*Corresponding author

Author 2: Evan Hakeem Perwira

☐ *Conceived and designed the analysis*

☐ *Collected the data*

☐ *Contributed data or analysis tools*

☐ *Performed the analysis*

☐ *Wrote the paper*

☑ *Other contribution*

Provided high-level technical consultation related to RDF engineering standards and reviewed the conceptual alignment of waste-to-energy processes with environmental engineering frameworks.

Author 3: Agus Irfan

☐ *Conceived and designed the analysis*

☐ *Collected the data*

☐ *Contributed data or analysis tools*

☐ *Performed the analysis*

☐ *Wrote the paper*

☑ *Other contribution*

Provided conceptual and advisory input on community empowerment approaches, particularly in relation to participatory engagement and community-based waste management initiatives.

Author 4: Muhammad Kamaluddin

☐ *Conceived and designed the analysis*

☐ *Collected the data*

☐ *Contributed data or analysis tools*

☐ *Performed the analysis*

☐ *Wrote the paper*

☑ *Other contribution*

Contributed sociological perspectives to support the conceptual framing of the study, particularly regarding social dynamics, community participation, and institutional context.

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