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Refuse-derived fuel policy frameworks and stakeholder engagement: Case study in Padang City, Indonesia

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ABSTRACT

Indonesia faces significant challenges in waste management, with most waste ending up in landfills, contributing to environmental pollution and greenhouse gas emissions. To address landfill overcapacity, Padang City initiated Refuse-Derived Fuel (RDF) processing at Aie Dingin Landfill, supported by the cement industry as an off-taker. However, policy frameworks for Waste to Energy (WtE) remain limited in Indonesia, posing governance challenges. This research investigates governance readiness for sustainable RDF implementation in Padang City, focusing on policy frameworks and stakeholder engagement. Employing a mixed-methods approach involving content analysis of regulations and stakeholder interviews, the study finds that both national and sub-national policy frameworks provide a robust legal foundation for RDF. Padang City demonstrates strong local commitment through its Waste Management Master Plan (2024–2044), which designates RDF development as a priority. Nevertheless, significant governance gaps persist at the national level due to the lack of comprehensive technical standards for WtE technologies. Additionally, waste management is categorized as a “non-basic service compulsory affair” under Law No. 23 of 2014, potentially leading to lower prioritization in local planning. The stakeholder analysis reveals that while formal roles are outlined by law, practical implementation involves expanded responsibilities. Non-regulated actors like academia and informal waste workers are not yet formally integrated into legal instruments, despite vital contributions through research, pre-sorting, and waste segregation. The paper concludes that addressing these governance gaps through adaptive policy instruments and inclusive institutional arrangements is essential for long-term RDF implementation success.

INTRODUCTION

Municipal solid waste management is a significant environmental and social burden, particularly in rapidly urbanizing nations like Indonesia. Urban solid waste management has become a major challenge in cities worldwide, driven by rapid urbanization and economic growth and constrained by limited municipal budgets and high management costs (B. D. Azevedo et al., 2019). There is an urgent need for comprehensive reform of municipal administrative structures in developing countries (B. Azevedo et al., 2020). Inadequate waste management practices, marked by prevalent open dumping and overcapacity of landfills, contribute to environmental pollution,

including soil and water contamination, and are a major source of marine litter originating from land-based waste (Kementerian PPN/Bappenas, 2023; KLHK, 2022; Kumar et al., 2023). Generally, it is estimated that only 60%–70% of the waste produced is transported to final disposal sites, with the remainder being burned or discarded into rivers (Damanhuri et al., 2009; Sari et al., 2022).

Waste management is one of the key environmental issue affects not only regional conditions such as air, soil, and water pollution, but also has global impacts through greenhouse gas (GHG) emissions (Abushammala et al., 2011; Kristanto & Koven, 2019; Lino & Ismail, 2017; Puppim de Oliveira, 2019). Furthermore, the waste

sector in Indonesia contributes substantially to GHG emissions, a factor that highlights the urgency of effective waste management (Climate Transparency, 2022; Nur et al., 2024). The design and selection of municipal waste management strategies play a critical role in shaping environmental quality and advancing the effectiveness of sustainable waste management systems (Stepanov et al., 2018). Recognizing the urgency of the waste issue, Indonesia's legal framework, as underscored by Article 28H paragraph (1) of the 1945 Constitution of the Republic of Indonesia, guarantees every person the right to a good and healthy environment, thereby mandating the government to provide necessary public services (Republic of Indonesia, 1945).

In response to these challenges, Waste-to-Energy (WtE) technologies are emerging as a promising avenue (Fetanat et al., 2019; Kumarasiri & Dissanayake, 2020; Tsui & Wong, 2019). WtE refers to the process of converting or recovering energy from waste materials into usable forms of energy, such as electricity, heat, or fuel (Keunecke, 2016; Kumarasiri & Dissanayake, 2020; Zhang et al., 2021). WtE can create new employment opportunities and foster the development of new businesses (Rehana et al., 2017). Urban waste composition is dominated by organic fractions with high moisture content and low calorific value, averaging approximately 1,000 kcal/kg (4.18 MJ/kg) (PT SMI, 2023). This condition poses a significant challenge to energy recovery from waste in Indonesia (Widowati, 2023). Acknowledging the persistent difficulties in Indonesian waste management, including the slow advancement of recycling and the less-than-optimal functioning of waste bank programs, possibly due to social hurdles, the government is also increasingly exploring WtE technologies, particularly for urban areas (Azis et al., 2021).

Municipal solid waste in tropical regions like Indonesia often contains sufficient energy to potentially eliminate the need for supplementary fuel in WtE processes, positioning it as a viable alternative energy resource (Pasek et al., 2013; Peerapong & Limmeechokchaib, 2016). Among WtE technologies, Refuse Derived Fuel (RDF) production, which processes municipal solid waste into a combustible fuel source, presents a dual benefit of reducing landfill burden and offering

alternative fuel (Dace & Blumberga, 2012; Shehata et al., 2022). RDF has demonstrated significant benefits, including waste volume reduction, fossil fuel savings, incorporation of residues into clinker composition, and decreased CO₂ emissions from fossil fuel use (Ouigmane et al., 2022; Reza et al., 2013), and also contributed to reducing up to 50% of urban solid waste sent to landfills over recent decades (Yang et al., 2021). This is seen as a crucial strategy for reducing reliance on conventional fuels and significantly lowering greenhouse gas emissions from both waste management and industrial activities, thereby playing a vital role in the broader transition towards a more sustainable energy future.

Waste management is a complex system with multiple interrelated aspects, including legislative, economic, institutional, and technical dimensions, in which implementation choices shape environmental and sustainability outcomes (Bonnet et al., 2023). Despite the availability of energy recovery technologies, sustainable solid waste management in developing countries remains constrained by political, financial, and regulatory barriers (Rezania et al., 2023). The long-term sustainability of WtE projects, including RDF initiatives, also depends not only on technological readiness but also on robust governance (Vujic et al., 2015). Waste management failures, particularly in developing countries, are frequently attributed to governance-related deficiencies such as weak policies, insufficient financing, or a lack of public participation, rather than technical shortcomings (A. H. Khan et al., 2022; Serge Kubanza & Simatele, 2020; UNEP, 2015). To address these multifaceted governance issues, this study draws on the Integrated and Sustainable Waste Management (ISWM) framework as its analytical lens. Originally developed by Van de Klundert and Anschütz (2001) and later elaborated by Wilson et al. (2012), ISWM reconceptualizes waste management not merely as a technical service, but as a complex and interlinked system that integrates physical components with governance strategies. As incorporated into UNEP's Global Waste Management Outlook, this framework has been widely recognized as a strategic approach for managing municipal solid waste pressures in developing countries (Asefi et al., 2020; Batista et al., 2020), making it

particularly relevant for examining governance readiness for RDF implementation in Padang City.

There is a need to align legislation across different levels of aspects, particularly in areas such as energy efficiency and innovation, supported by coherent organizational, financial, economic, and legal frameworks (Melnik & Lukishina, 2016). Some studies support the argument that the success of WtE projects in developing countries is often constrained by non-technical barriers. For instance, in Sri Lanka, WtE projects is hindered by the absence of a coherent regulatory framework and a lack of national strategy, which have created procedural complexities, deterred private sector participation, and delayed project implementation (Kumarasiri & Dissanayake, 2020). Similarly, in Latvia, due to an unclear policy framework, the absence of sectoral policies and legislative clarity further limits the development and investment appeal of WtE technologies, which undermine investor confidence and disrupt project continuity (Beloborodko et al., 2015). While in Ghana, there are no direct or clear guidelines that focus on the design, operation, and monitoring for WtE implementation (Williams et al., 2023). These regulatory challenges have led to frequent project delays and, in some cases, project abandonment, highlighting the critical role of coherent and supportive institutional settings in enabling WtE deployment.

The presence of unclear or fragmented legal and institutional frameworks also often results in overlapping responsibilities among government entities, complicating the coordination and execution of WtE initiatives. In Iran, the distribution of waste management duties across multiple ministries created significant challenges in ineffective decision-making and policy enforcement at various administrative levels: national, provincial, and local levels (Ahmadia et al., 2013). Similar conditions are observed in Balkan countries such as Serbia and Bosnia-Herzegovina, where, despite the existence of adequate strategies and regulatory frameworks to support the circular economy, implementation remains weak due to insufficient monitoring, limited enforcement mechanisms, and the lack of strict control over waste management and recycling practices (Bjelić et al., 2024). Serbia also experienced institutional

fragmentation during its transition toward WtE adoption, facing difficulties in project planning and execution due to poorly defined departmental roles (Vujic et al., 2015). While in Ghana, there is weak cross-sectoral collaboration that has led to lack of budgetary allocations, low political will, and poor coordination (Williams et al., 2023). This underscores a persistent governance challenge across developing contexts, including Indonesia, where comprehensive WtE policy frameworks and coherent governance structures remain underdeveloped.

Padang City has taken a proactive step in this direction by initiating the application of RDF technology at the Aie Dingin landfill. This initiative is driven by the overcapacity of the existing landfill, which is projected to reach its full capacity by 2026 (Chan, 2022; Kinarina, 2023). The quantity of waste reaching the Aie Dingin Landfill is substantial, with approximately 550 tons per day recorded in 2024 (KLH, 2025). Moreover, a large proportion, 77% of the city's total waste, still ends up in this landfill. This initiative is further supported by the presence of a dedicated off-taker from the cement industry, establishing an economic foundation for the sustainable and proactive management of waste through a circular economy framework. The adoption of RDF technology is seen as a potential alternative to address this issue and enhance the sustainability of waste management in the city.

However, Padang City currently faces several persistent governance challenges in implementing sustainable waste management, ranging from financial constraints to institutional coordination gaps. These local issues reinforce the broader argument that the sustainability of waste management initiatives depends critically on robust governance, rather than solely on technical readiness. Therefore, understanding the governance readiness of Padang City, particularly its policy frameworks and stakeholder dynamics, becomes essential before advancing RDF implementation.

Despite the growing interest and potential for RDF implementation in Indonesian cities like Padang, best practices and comprehensive policy designs for waste-to-energy governance in the country remain limited. This absence of established frameworks presents unique challenges, particularly concerning the readiness of governance structures. While the success of WtE projects is critically

dependent on both technical feasibility and robust governance, existing literature often highlights the non-technical barriers in developing countries, such as unclear or unstable legal frameworks, the lack of detailed national strategies, limited local institutional expertise, and protracted administrative approval processes. This underscores a significant gap in understanding how effective policy frameworks can be developed and how diverse stakeholders can be adequately engaged and coordinated to ensure the long-term sustainability and operational efficiency of RDF initiatives in the Indonesian context.

Therefore, this research aims to analyze the governance readiness for sustainable RDF implementation in Padang City, specifically focusing on its policy frameworks and the dynamics of stakeholder engagement. By investigating these critical governance aspects, this study seeks to contribute theoretically by complementing and confirming existing theories on waste management governance in developing countries, and practically by providing a valuable reference for other regions in Indonesia considering or developing similar RDF technologies.

MATERIALS AND METHODS

This research employed a mixed-methods approach, with a strong emphasis on qualitative techniques to explore governance readiness for Refuse-Derived Fuel (RDF) implementation in Padang City. The study area focused on the Aie Dingin Landfill, a critical site for RDF development in Padang City. The research design combined a comprehensive content analysis of existing laws and policies to assess the readiness in supporting RDF development in Padang City and stakeholder interviews to ensure a comprehensive assessment.

Data for this study were collected through both secondary and primary sources. Primary data were collected through in-depth, semi-structured interviews with four purposively selected key informants representing the central government (Ministry of Environment/Kementerian Lingkungan Hidup and Ministry of Public Works), local government (Environmental Agency of Padang), and private sector or off-taker (PT Semen Padang). These stakeholders were chosen based on their involvement, authority, and technical relevance to RDF development in Padang. Secondary data

sources included official government regulations, technical guidelines, planning documents, and project reports. These documents provided the legal and institutional context necessary to assess the robustness of policy frameworks.

Data analysis consisted of qualitative content analysis to evaluate the alignment and clarity of national and local policy instruments regarding waste to energy, including RDF, and to overview the stakeholders' roles and authorities within waste and RDF implementation. The analytical process was adapted from Saldaña (2013), involved several key stages: defining research questions, sorting data, developing a coding scheme, coding process (using Nvivo software), analyzing the coded data, interpreting the results, and reporting the findings. For stakeholder analysis, a Power vs. Interest Grid was conducted to identify the relationships, interests, and influence of various stakeholders on the project's decision-making process (Ackermann & Eden, 2011; Brugha & Varvasovszky, 2000). The classification was directly derived from the primary data collected through in-depth, semi-structured interviews with purposively selected key informants. During these interviews, informants were asked to provide an assessment of each key stakeholder's role and authorities in the RDF implementation project.

RESULTS AND DISCUSSION

Policy Framework Analysis

The success of WtE initiatives is highly dependent on the strength and coherence of regulatory frameworks at both national and local levels (Ahmadia et al., 2013; Le et al., 2018). There are several national and local regulations that will be reviewed in this section to find insights of waste management and waste-to-energy planning and readiness.

Overview of Waste and Waste-to-Energy National Regulation in Indonesia

The implementation of a waste management system and the conversion of waste into energy requires a solid legal foundation and an operational framework that aligns with national objectives. National mandates, issued in the form of laws, presidential and ministerial regulations, and strategic planning documents serve as key enablers for prioritizing waste management within government programming and funding mechanisms.

In total, 9 national regulations will be reviewed in this section, each contributing to the regulatory landscape supporting WtE, including RDF development. The following is a summary of national regulations related to waste management and its relevance WtE and RDF.

Table 1. Reviewed National Regulations

No.	Regulation	Main Provisions	Relevance to WtE and RDF
1	Law 18/2008	Provides a comprehensive legal framework for waste management in Indonesia, covering definitions, principles, implementation mechanisms, and authorities for central and local governments	Foundational legal basis for waste processing, which defined broadly as changing the characteristics, composition, and quantity of waste, which could implicitly allow for WtE technologies
2	Law 23/2014	Defines the division of authority and responsibilities between central government, provincial governments, and city governments, categorizing waste management as a mandatory affair for local administration	do not contain specific content on WtE or RDF
3	Government Regulation 81/2012	provides specific details on waste management activities, including waste reduction, waste sorting, collection, transportation, processing, and final processing. It also specifies requirements for local governments to develop master plans and feasibility studies for household and similar waste management	Explicitly energy recycling as one of the waste processing methods
4	President Regulation 97/2017	Outlines an integrated and sustainable approach for the period 2017 until 2025, aiming for a 30% reduction and 70% handling of household and similar waste from the pre-policy waste generation figures by 2025	Emphasis on Environmentally Friendly Technology, including the application of environmentally friendly and appropriate technology for handling household waste and similar household waste
5	President Regulation 35/2018	Mandates the acceleration of waste-to-energy power plant (PLTSa) development based on environmentally friendly technology in specific priority locations. It outlines procedures for permitting, financing, and incentives	Detailed and comprehensive legal framework, including financial incentives and institutional coordination, to rapidly establish large-scale WtE facilities (PLTSa) across designated cities in Indonesia.
6	Ministry of Public Works and Housing Regulation 2/2013	Provides technical guidelines and standards for waste management infrastructure and facilities for all levels of government and stakeholders.	This regulation explicitly covers the potential for waste processing into energy through various technologies, including incineration, pyrolysis, gasification, production of RDF, and utilization of biogas from organic waste processing or methane gas from landfills

7	Mistry of Home Affair Regulation 7/2021	Establishes guidelines for local governments to calculate waste retribution fees, ensuring they cover operational, maintenance, and capital costs related to waste handling	includes the calculation method for waste retribution using the RDF mechanism. This signifies central government recognition and accounting for RDF within waste management financing frameworks.
8	Ministry of Energy and Mineral Regulation 53/2018	Aims to accelerate the development of renewable energy sources for national electricity supply.	Specifically mentions the "utilization of heat/thermal energy using thermochemical technology as one method for PLTSa". This broadly implies that technologies using waste-derived fuels like RDF are covered under the scope of PLTSa.
9	Ministry of Finance 26/2021	Regulates central government budget (APBN) funding support for waste management activities in regions	Specifically mentions APBN funding support for the acceleration of PSEL (Waste-to-Energy Power Plant) development. This indicates financial backing from the national budget for WtE projects, which can include RDF.

The national policy framework in Indonesia indeed provides a comprehensive legal foundation for waste management, covering fundamental definitions, principles, and implementation mechanisms, including the authorities of central and local governments. It also establishes clear mandates for regional governments to undertake sustainable and environmentally conscious waste management. This strong framework is built upon foundational legislation such as Law No. 18 Year 2008 on Waste Management, which provides a comprehensive legal basis for waste processing, implicitly allowing WtE technologies by defining waste processing broadly as changing the characteristics, composition, and quantity of waste. Complementing this, Law No. 23 Year 2014 on Regional Development categorizes waste management as a “concurrent affair”, meaning its authority is shared between the central government and regional governments. A significant implication for local governments is this Law classifies waste management as a “non-basic service compulsory affair”. Further solidifying this stance, Government Regulation No. 81 Year 2012 on Management of Household Waste and Similar Waste explicitly recognizes energy recycling as one of the waste processing methods, signaling a clear national intent to recover value from waste. This evolving legal landscape underscores a national strategy shifting from traditional waste disposal towards a circular

economic approach, treating waste as a valuable resource for energy and material recovery.

This national commitment is further reinforced by more specific and comprehensive regulations designed to accelerate and financially support WtE initiatives. Presidential Regulation No. 35 Year 2018 stands out by mandating the acceleration of Waste-to-Energy Power Plant (PLTSa) development, providing a detailed legal framework that includes financial incentives and institutional coordination to rapidly establish large-scale WtE facilities in designated cities. Complementing this, Minister of Public Works and Housing Regulation No. 3 Year 2013 explicitly covers the production of RDF as a potential method for waste processing into energy, offering technical guidelines and standards for waste management infrastructure. Financial backing from the national budget for WtE projects, which can include RDF, is ensured through Minister of Finance Regulation No. 26 Year 2021. Furthermore, the recognition of the RDF mechanism in waste retribution fee calculations by Minister of Home Affairs Regulation No. 7 Year 2021 signifies central government acknowledgement within waste management financing frameworks. This comprehensive suite of national policies demonstrates a clear and actionable intent at the national level to promote and financially support WtE technologies, including RDF, providing a strong legal mandate and strategic

direction for their implementation across the country.

Overview of Waste and Waste-to-Energy Sub-National/Local Regulation in Padang City

Waste management is designated as a mandatory governmental function under Law No. 23 of 2014 on Regional Government. This designation obliges the Padang City Government to undertake various responsibilities, including the overall management of waste; the regulation and licensing of private sector actors involved in recycling, waste processing, transportation, and final disposal; as well as the supervision and capacity-building of privately conducted waste management operations. Additionally, within the domain of public works, regional governments are authorized to develop and manage integrated waste management systems within their administrative areas.

The analysis of local regulations and policies in Padang City is conducted within the legal framework set by national waste management legislation. This analysis seeks to determine whether the Padang City Government is executing its waste management mandate in accordance with prevailing regulatory requirements. It also examines the extent of the city's institutional understanding, commitment, planning, and readiness, particularly in advancing WtE solutions, including the development and implementation of RDF technologies.

This section reviews 6 sub-national/local regulations that shape the governance and strategic direction of waste management and WtE efforts, including RDF in Padang City. The following is a summary of sub-national regulations related to waste management and its relevance WtE and RDF.

Table 2. Reviewed Sub-National Regulations

No	Regulations	Main Provision	Relevance to WtE and RDF
1	Regulation of the City of Padang 21/2012	Mandates waste management in Padang City for environmental preservation and public health, while also aiming to transform waste into a resource.	This regulation describes waste processing types with principles of energy recovery and material recovery, which are fundamental concepts of RDF. This establishes a local policy foundation for waste-to-resource initiatives, including RDF.
2	Mayor Regulation 44/2018	Sets forth policy directions and strategies for integrated and sustainable household waste management in Padang City from 2018 to 2025	explicitly includes a program related to WtE based on RDF, specifically the “utilization of waste into substitute fuel for cement industry or RDF”. It also emphasizes the application of environmentally friendly technologies for sorting, collection, processing, and final disposal to generate renewable energy
3	Mayor Regulation 110/2019	Defines the policy direction for environmental affairs, including waste management, through optimizing waste processing at the source and promoting the 3R (Reduce, Reuse, Recycle) principle.	By emphasizing optimal waste processing at the source and 3R, it indirectly supports RDF by improving the quality of waste as raw material and reducing overall waste volume.
4	Mayor Regulation 3/2021	To provide incentives or awards to individuals who report violations of waste management prohibitions	does not directly address WtE or RDF.

5	Mayor Regulation 39/2021	The objective is to foster a creative economy in Padang by promoting cleanliness through the management and marketing of competitive recycled waste products	does not directly address WtE or RDF.
6	Mayor Regulation 15/2024	Outlines the long-term, medium-term, and annual waste management plans for Padang City. It aims to shift from an "end-of-pipe" approach to one that treats waste as a resource	This master plan designates RDF development as a short-term priority. It also includes the institutional transformation for TPST RDF as a medium-term priority, and the implementation of circular economy-based technologies and household-scale waste processing research as long-term priorities.

The local policy framework in Padang City demonstrates a proactive and comprehensive commitment to integrating Waste-to-Energy (WtE) technologies, particularly Refuse-Derived Fuel (RDF), into its waste management strategy. Despite Law No. 23 of 2014 classifying waste management as a “non-basic service compulsory affair”, this effort is highly commendable and demonstrates significant proactive leadership and a strong sense of local ownership. However, according to the Ministry of Environment, the classification means that waste management often receives lower priority in regional budget (APBD) allocations, compelling it to compete with sectors that are classified as “basic services” like education and health. As documented by the Environmental Agency of Padang City (DLH Kota Padang, 2023), the current waste retribution fees collected from the public remain insufficient to cover total operational costs, deepening the city's dependence on the local government budget (APBD) that is already under pressure due to the “non-basic service” classification discussed above.

For instance, Padang City Local Regulation No. 21 Year 2012 mandates waste management for environmental preservation and public health, specifically aiming to transform waste into a resource by describing processing types that include principles of energy and material recovery, which is the concepts fundamental to RDF. Further solidifying this intent, Padang Mayor Regulation No. 44 Year 2018 explicitly includes a program related to WtE based on RDF, focusing on the “utilization of waste into substitute fuel for the

cement industry or RDF” and emphasizing environmentally friendly technologies.

This local commitment extends to detailed planning and strategic implementation, aiming for long-term sustainability through a circular economy approach. The Padang Mayor Regulation No. 15 Year 2024, which outlines the city's Waste Management Master Plan for 2024-2044, explicitly designates RDF development as a short-term priority, alongside institutional transformation for TPST RDF as a medium-term priority, and the implementation of circular economy-based technologies as long-term goals. This master plan signifies a deliberate shift from an “end-of-pipe” disposal approach to one that treats waste as a valuable resource. The presence of a dedicated off-taker from the cement industry further underpins the economic viability of RDF, establishing a critical foundation for sustainable waste management within a circular economy framework. This supports the argument that the success and sustainability of WtE initiatives are highly dependent on the presence of reliable off-takers to mitigate financial and operational risks associated with high investment and maintenance costs (Koech, 2015; Soltani et al., 2016). Even though local regulations that do not directly address WtE or RDF, such as Mayor Regulations 3/2021 and 39/2021, indirectly support these initiatives by promoting responsible waste handling, valorization, and encouraging the diversion of recyclable materials, thereby improving the quality of residual waste for RDF production.

Stakeholders Analysis

A clear institutional framework and well-defined roles among stakeholders are crucial for the successful implementation of resource recovery from waste (Aguilar et al., 2021). The legal framework provided by Law No. 18 of 2008 on Waste Management establishes a solid foundation for defining the roles and responsibilities of key stakeholders involved in municipal solid waste management, including Waste-to-Energy (WtE) initiatives such as Refuse-Derived Fuel (RDF).

However, findings from field research conducted in Padang reveal that the implementation of RDF involves a more complex and dynamic constellation of actors whose practical roles often extend beyond those formally prescribed in the law. Table 3 shows the comparative insights between the roles and authorities as defined in Law No. 18 of 2008 and the actual roles observed in the field based on stakeholder engagement and institutional mapping conducted in Padang.

Table 3 Role and Authority of Stakeholders Involved in RDF Implementation in Padang City

Stakeholder	Role & Authority Based on Law 18/2008	Findings from Field Data
Central Government	<ul style="list-style-type: none"> - Formulate national policies and technical norms - Supervise and coordinate regional waste governance - Fund and facilitate technology & infrastructure - Promote R&D and behavior change 	Ministry of Environment <ul style="list-style-type: none"> - Serves as the main regulator; maps potential RDF off-takers; - aligns project goals with national GHG reduction targets; - conducts advocacy on behavioral change; - supervises environmental compliance. Ministry of Public Works: <ul style="list-style-type: none"> - Provides infrastructure funding; - issues technical guidance (Permen PUPR No. 3/2013); - coordinates feasibility studies and planning documents.
Regional Government	<ul style="list-style-type: none"> - Plan and manage city-level waste services - Operate infrastructure - Apply sanctions, monitor, designate final processing site (TPA), temporary shelter (TPS), and integrated waste management site (TPST) 	<ul style="list-style-type: none"> - Functions as the main operator and coordinator of waste and RDF facilities; - leads inter-stakeholder coordination; - prepares readiness criteria and ensures supply of RDF feedstock; - conducts public outreach in surrounding communities
Private Sector - offtaker	<ul style="list-style-type: none"> - Participate in partnerships - Cooperate in integrated waste management 	<ul style="list-style-type: none"> - Acts as the RDF initiator and primary off-taker; - ensures technical quality standards for RDF (quality control and routine testing); - engages with government on infrastructure planning
Academia	Not explicitly regulated, but implied in R&D and community role	<ul style="list-style-type: none"> - Contributes through research and innovation; - Feasibility Study support (2020)

Community (Households)	<ul style="list-style-type: none"> - Required to reduce and manage waste - Participate in decision-making - Entitled to service, info, and compensation 	<ul style="list-style-type: none"> - Engage in basic waste separation; - Targeted in socialization programs about RDF development
(Households, Informal Sector)	Not explicitly regulated, but implied in community role	<ul style="list-style-type: none"> - Contribute to informal sorting recycling; - Potential RDF workforce through manual sorting and material recovery

The table above highlights how the formal roles prescribed by Law No. 18/2008 are complemented and, in some cases, expanded by the practical responsibilities carried out by stakeholders on the ground. This divergence shows the dynamic nature of RDF implementation, where legal mandates provide a foundation, but operational realities necessitate adaptive and often more integrated roles among key actors. In particular, national government institutions such as the Ministry of Environment (Kementerian Lingkungan Hidup) and the Ministry of Public Works (Kementerian Pekerjaan Umum) emerge as key strategic actors. While the law emphasizes their function in policy formulation, coordination, and infrastructure facilitation, the empirical data demonstrate that the Ministry of Environment also plays a significant role in behavioral advocacy, environmental supervision, and emission-reduction mapping, whereas the Ministry of Public Works is actively involved in technical planning, feasibility studies, and infrastructure financing. These functions reflect the evolving operational needs of waste-to-energy projects, particularly in aligning national waste management and emission targets with local RDF implementation.

At the local level, the Environmental Agency of Padang City (Dinas Lingkungan Hidup Kota Padang) is not only implementing the technical waste management responsibilities outlined in the law but also plays a central coordinating role in RDF planning, readiness criteria development, community engagement, and ensuring feedstock availability, including through landfill mining. This expanded role indicates a shift in local government function from mere service provider to project orchestrator, underscoring the importance of institutional capacity in operationalizing RDF facilities. Additionally, the involvement of the main RDF off-taker illustrates the critical role of the

private sector in driving downstream market demand and ensuring the economic viability of RDF. Although the legal framework only loosely defines private sector engagement through partnership provisions, field evidence suggests that private actors play a highly influential role, particularly in technology validation and quality assurance, which are the two aspects vital for the success of RDF supply chains.

Moreover, the academic sector and informal waste actors, while not explicitly covered in Law No. 18/2008, are shown in the field to have substantive influence on RDF development. Universities have contributed through scientific research and technical studies, including feasibility assessments for RDF planning. This highlights the growing need to institutionalize research collaboration within national and regional waste policy frameworks. Similarly, informal waste workers such as waste pickers and small-scale recyclers provide vital labor in pre-sorting waste, thus improving the quality of RDF feedstock. Empowering formal waste workers remains a key success factor, largely depending on how government policies and strategies recognize their contributions and include them as essential stakeholders within the waste management system (Aparcana, 2017). Their role, while acknowledged implicitly in community provisions, is yet to be formally integrated into legal instruments, despite their strategic importance in circular economy and waste valorization pathways.

The central role of actors such as the Local Government (Environmental Agency of Padang City), Ministries, and the off-taker are deeply involved in strategic decision-making, funding, regulation, infrastructure development, and RDF utilization. Their continuous engagement is critical to the success of the project. Notably, Ministries while functioning as policy setters at the national

level, are also technically active due to their high operational involvement and strategic interest in RDF as a climate mitigation tool and infrastructure priority for waste management.

Meanwhile, actors such as academia, informal workers, and households are crucial contributors through their involvement in research, waste segregation at the source, and efforts to build public acceptance. While they do not hold formal authority, their participation is vital to ensuring the sustainability of the RDF project. These contributions directly impact the quality of RDF feedstock and help secure the social license to operate. The law recognizes the role of the community in waste management, but field data

reveal the need for greater institutional support to empower these actors, particularly the informal sector.

Insights from Policy Framework and Stakeholders Analysis

The ISWM framework provides a useful lens for synthesizing and interpreting the findings from both the policy framework and stakeholder analyses presented in this study. ISWM reconceptualizes waste management not merely as a technical service delivery function, but as a complex and interlinked system comprising two primary dimensions: physical components and governance strategies (UNEP, 2015).

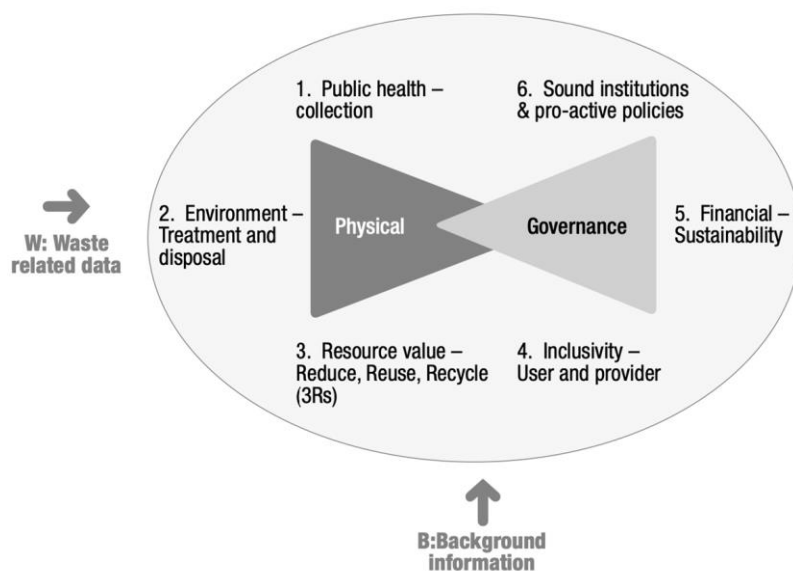


Figure 1. Integrated and Sustainable Solid Management (ISWM) Framework
Source: Global Waste Management Outlook, 2015

The physical components dimension encompasses the core operational elements of waste management, including waste collection, treatment, and final disposal, as well as the promotion of 3R (Reduce, Reuse, Recycle) activities such as composting, anaerobic digestion, and WtE applications like RDF. When viewed through this dimension, Padang City's initiative at the Aie Dingin Landfill represents a meaningful step forward. The RDF facility operationalizes the WtE component of ISWM, reducing landfill dependency while simultaneously generating an alternative fuel product for the cement industry. However, the limited functionality of TPS 3R sites and low waste segregation at the source, as reported by the Environmental Agency of Padang City, indicate that

upstream physical components remain underdeveloped, undermining the consistency and quality of RDF feedstock.

The governance strategies dimension of ISWM is where the most significant gaps emerge in the Padang City context. This dimension encompasses three interrelated elements: inclusive stakeholder engagement, financial sustainability, and strong institutional and policy frameworks. Regarding institutional and policy frameworks, the analysis in this study confirms that both national and sub-national regulations provide a formally robust legal foundation for WtE and RDF development. However, the absence of comprehensive technical standards at the national level, combined with the "non-basic service" budget classification under Law

No. 23/2014, reveals a critical disconnect between policy intent and implementation capacity, a gap that ISWM specifically highlights as a governance failure rather than a technical one.

On the dimension of stakeholder engagement, the findings demonstrate that while Law No. 18/2008 prescribes formal roles for central and local governments and the private sector, actual RDF implementation in Padang involves a broader and more dynamic constellation of actors. The expanded roles of the Ministry of Environment, the Environmental Agency of Padang City, and the cement industry off-taker illustrate the kind of adaptive, multi-actor collaboration that ISWM envisions. Nevertheless, the exclusion of academia and informal waste workers from formal legal and institutional arrangements represents a clear gap in inclusive governance. The ISWM framework emphasizes that equitable and participatory governance, including the recognition of informal sector actors is an essential condition for long-term WtE sustainability (Nandy et al., 2015; Tong et al., 2021; Xiao et al., 2020), a principle that remains aspirational rather than operational in the Padang case.

Finally, on financial sustainability, the ISWM framework stresses that WtE projects must be embedded within a supportive financial ecosystem, including diversified funding mechanisms and cost-recovery systems. The current reliance on APBD itself constrained by competing budget priorities without a clear alternative financing strategy, places the long-term viability of Padang's RDF initiative at risk. ISWM-aligned governance would require the city to develop adaptive financial instruments, such as public-private partnerships, green financing, or national grant mechanisms, to complement local budget allocations.

Taken together, the application of the ISWM framework to the Padang case confirms that the primary barriers to sustainable RDF implementation are governance-related rather than technological. This finding aligns with the broader literature on WtE in developing countries (I. Khan et al., 2022; Serge Kubanza & Simatele, 2020; UNEP, 2015) and reinforces the argument that strengthening governance strategies, across institutional, financial, and participatory dimensions is an essential precondition for effective and lasting WtE deployment.

CONCLUSION

The paper concludes that while Padang City has made significant effort in establishing a foundation for Refuse-Derived Fuel (RDF) implementation, further governance enhancements are crucial for long-term sustainability. Regarding the regulation framework, both national and local regulations provide a robust and increasingly explicit legal foundation for WtE technologies, including RDF. National laws like Law No. 18 Year 2008 and Government Regulation No. 81 Year 2012 establish the foundational legal basis and explicitly recognize energy recycling. Critically, Presidential Regulation No. 35 Year 2018 offers a detailed framework for accelerating large-scale WtE facilities, including financial incentives and institutional coordination, while Minister of Public Works and Housing Regulation No. 3 Year 2013 explicitly covers RDF production. At the local level, Padang City demonstrates strong commitment, with Padang Mayor Regulation No. 44 Year 2018 explicitly including utilization of waste into substitute fuel for cement industry or RDF. Most significantly, the recent Padang Mayor Regulation No. 15 Year 2024 (Padang City Waste Management Master Plan 2024-2044) designates RDF development as a short-term priority and institutional transformation for RDF facilities as a medium-term priority, indicating a clear strategic commitment. This comprehensive policy landscape implies a strong legal mandate and strategic direction for RDF, fostering a shift towards a circular economy by treating waste as a resource.

However, the analysis of stakeholder dynamics reveals a more complex operational reality than what is formally prescribed by law. While Law No. 18 of 2008 outlines general roles, field findings show national government institutions like the Ministry of Environment and Ministry of Public Works are more involved due to their high operational involvement and strategic interest in RDF for waste management, climate mitigation, and infrastructure development. The Local Government, Padang City Environmental Agency has also expanded its role from a service provider to a project key player, coordinating RDF planning and feedstock provision. The private sector, particularly the off-taker, plays a critical role in economic viability, quality control, and technology validation, beyond loosely defined partnership provisions.

However, a significant governance gap lies in non-regulated actors like academia and informal waste workers. Despite their vital contributions through research, feasibility studies, pre-sorting, and waste segregation, their roles are not yet formally integrated into legal instruments, highlighting a clear need for greater institutional support and empowerment.

In conclusion, long-term success hinges on addressing these identified governance gaps. The paper underscores the necessity for more specific and comprehensive national technical regulations for WtE technology, along with strategic prioritization. Adaptive policy instruments are crucial to reflect operational realities and complex stakeholder dynamics, complementing existing legal foundations. This calls for institutional innovation, inclusive governance, and legal updates to formally recognize and empower all actors. Ultimately, institutional innovation, inclusive governance, and legal updates are essential to formally recognize and empower all actors, strengthening multi-actor collaborations for effective and sustainable RDF implementation in Indonesian cities.

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