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Multi-Actor Governance of Waste-to-Energy: A Case Study of the Putri Cempo Waste-to-Energy Power Plant in Surakarta City

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ABSTRACT: This research examined the dynamics of governance in waste management through a case study of the Putri Cempo waste-to-energy (WTE) power plant. The growing volume of global waste has driven the need for multi-level governance to advance WTE technology. The application of WTE technology became part of the national commitment to climate change mitigation outlined in the Nationally Determined Contribution (NDC) framework. The development of WTE also contributed to the attainment of several Sustainable Development Goals (SDGs), notably SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), by providing renewable energy and reducing greenhouse gas emissions. The main focus was to analyse how multi-actor governance was implemented in WTE management practices at the local level, as well as the challenges that arose in ensuring operational sustainability. Employing a descriptive qualitative approach, this study adopted a multi-actor and institutional governance perspective and applied Biermann's Five A's concept, architecture, agency, adaptiveness, accountability, and allocation, as the analytical framework for mapping the governance situation of the Putri Cempo WTE facility. The findings indicated that despite regulatory support, including Presidential Regulation No. 35 of 2018 and Indonesia's enhanced NDC targets, the implementation of the Putri Cempo WTE still faced technical challenges, particularly high moisture content specifications and inadequate waste sorting, which disrupted the gasification process. In addition, the surrounding community reported environmental problems. Increasing technical capacity, developing an effective waste-sorting system, and ensuring more transparent environmental monitoring by managers and supervisors were needed to support the long-term sustainability of waste-to-energy power plant operations.

KEYWORDS: WtE power plant; Putri Cempo; global governance; NDC; SDGs

1. Introduction

Along with global population growth and rising living standards, the consumption of goods and energy increased sharply, leading to a rise in solid waste that was difficult to control. This was due to changes in consumption patterns, urbanization, and modern production methods, which increased urban waste flows and reduced the proportion that could be recycled. Several

reviews indicated a significant upward trend in global urban solid waste, with projections and observations suggesting that global waste production would continue to increase, requiring more effective and integrated management solutions. In one literature review on WtE, it was emphasized that WtE technology was one option to reduce the burden on landfills while supporting the circular economy through energy recovery from waste [1]. Based on data from the United Nations Environment Programme, the global community produced around 2.1 billion tons of waste in 2023, 45% of which was unmanaged, contributing to air and water pollution and increased greenhouse gas emissions, such as methane from the decomposition of waste in landfills [2]. Another source of human-generated emissions contributing to greenhouse gas effects was carbon dioxide (CO2) emissions from the burning of fossil fuels and the industrial revolution [3].

At the national level in Indonesia, similar challenges also arose. As a country with a population of around 284 million [4], Indonesia faced significant waste management challenges. By 2025, the Indonesian government targeted a 23% share of renewable energy [5], with the following composition: coal 55%, natural gas 22%, liquid fuels 0.4%, and renewable energy 23%. However, as of 2023, the contribution of renewable energy had only reached 14.5% of total primary energy [6]. The national waste volume reached 36.7 million tonnes [7], with 60% of waste coming from urban areas. Most of this waste still ended up in landfills with open disposal systems, which had the potential to produce high methane emissions. Surakarta was one of the cities in Indonesia facing similar waste problems. Based on data from the National Waste Management Information System (SIPSN), waste production in Surakarta reached 420 tons per day in 2024, with most of it coming from household sources. Therefore, one literature review on energy innovation emphasized the need for technological innovation, policy instruments, and funding mechanisms to accelerate the energy transition in line with SDG 7, including the use of alternative energy sources to reduce dependence on fossil fuels while improving energy security [8].

In global governance, attention to emissions from the waste sector increased following the adoption of the Paris Agreement in 2015 at the Conference of the Parties, COP21, which set a global target to keep the average global temperature rise below 2°C and strive to limit it to 1.5°C compared to pre-industrial levels [9]. This international agreement marked an important transition in global environmental governance, emphasizing the responsibility of all countries developed and developing, to take concrete action in addressing climate change. As part of this commitment, the Paris Agreement emphasized the participation of all countries in formulating their national contributions to the NDC, which is at the core of the Agreement [10]. Each country was required to outline its national targets and strategies for reducing greenhouse gas emissions and promoting sustainable development. The obligation to formulate an NDC was carried out every five years. In the context of global governance, the Paris Agreement marked a paradigm shift from a command-and-control-based climate regime to a collaborative and nationally committed approach [11].

NDCs served as a global governance instrument linking international commitments with domestic policies. Through this approach, mitigation responsibilities were shared proportionally between developed and developing countries based on the principle of common but differentiated responsibilities. At the national level, the Indonesian government issued several regulations to support the implementation of the Enhanced NDC, including accelerating renewable energy development through Waste-to-Energy (WtE) power plants. This effort

integrated urban waste management with environmentally friendly electricity production. The utilization of waste as an energy source developed into a national strategy for strengthening renewable energy, especially since the issuance of Presidential Regulation No. 35 of 2018 [12], which served as the legal basis for accelerating WtE power plant implementation in various cities.

As a technical response, WtE utilized a thermal process that converted waste into electrical energy. This process reduced the volume of waste ending up in landfills, minimized secondary environmental pollution from methane emissions, and optimized the energy content of non-recyclable waste by converting it into electrical and thermal energy [13]. In line with global development trends, a WtE power plant was not only a solution for national waste management but also had strategic value in achieving the 2030 Agenda for SDGs, a global framework aiming to improve human quality of life and environmental sustainability through 17 goals and 169 targets [14]. From an SDG perspective, WtE development aligned with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). The transition to clean energy sources and energy technology innovation increased energy security while reducing the carbon intensity of the national energy system [8].

SDG 7 aimed to achieve sustainable, affordable, reliable, and modern energy access [15], including promoting renewable energy and energy efficiency. WtE power plants contributed to clean energy targets by using waste as an alternative energy source [16]. SDG 13 emphasized climate change mitigation and the reduction of greenhouse gas emissions, particularly methane from waste decomposition in landfills. The Intergovernmental Panel on Climate Change report highlighted methane as a major contributor to short-term warming, with greenhouse gas concentrations in the atmosphere projected to continue rising, potentially affecting the global climate [17]. Previous research by Qodriyatun (2021) highlighted that although WtE power plants could provide a rapid solution for cities with high waste volumes and limited landfill space, their success depended heavily on policy consistency, the readiness of competent resources, bankable financing models, and coordination among cross-sector actors. These findings indicated that accelerating WtE development required not only strong regulations but also institutional synergy and continuous implementation support [18].

2. Materials and Methods

2.1. Theoretical framework.

In this research, waste management at the Putri Cempo WtE power plant was an important element for understanding cross-level governance in practice. This research adopted a global governance perspective, combining multi-actor and institutional approaches. The Commission on Global Governance (1995) defined governance as “the sum of the many ways individuals and institutions, public and private, manage their common affairs” [19]. Global governance is not equivalent to world government; governance analysis must place states and non-state actors (international organizations, NGOs, the private sector, civil society movements, and other actors) as part of a network of joint action rather than a formal government hierarchy.

Implementing governance for WtE power plants required not only regulations but also institutional synergy, multi-stakeholder coordination, and consistent financial and technical support. The energy governance architecture was multi-stakeholder and fragmented, so achieving SDG 7 and the low-carbon transition required inter-institutional coordination,

technology transfer, and clear international funding mechanisms. At the same time, WtE literature emphasized the need for cohesive national policies and global collaboration to close implementation gaps [20]. To strengthen the environmental and cross-scale dimensions, this framework was reinforced by the concept of Earth System Governance (ESG) proposed by Biermann (2007). Biermann argued that environmental management in the modern era could not be carried out solely by national governments, but also through a system of cross-actor and cross-level governance. The management of contemporary environmental issues, such as waste management and climate change, took place within a dynamic governance network [21].

The ESG concept does not focus solely on policy outcomes but rather on the processes, institutional structures, relationships, and coordination mechanisms that shape the implementation of environmental policies. Within the ESG framework, the Five A's to analyze the complexity of environmental governance was developed: Architecture, Agency (beyond the state), Adaptiveness, Accountability, and Allocation. This framework was used as the main analytical tool because it allowed for systematic examination of regulatory structures, actor roles and interactions, oversight and accountability mechanisms, distribution of benefits and risks, and policy adaptation capacity. Further details are summarized in Table 1.

Table 1. Application of the Five A's concept by Biermann in the governance of the Putri Cempo WeE Power Plants.

No	Aspect	Explanations	Application in the Putri Cempo WtE Power Plant	Interpretation
1	Architecture	Institutional structure, norms, and coordination mechanisms across levels (global-national-local)	The multi-layered legal and governance framework relationship connecting the Paris Agreement as a global norm, Indonesia's Enhanced NDC as a national policy, such as Presidential Regulation No.35 of 2018, and its implementation at the local level by the Surakarta City Environmental Agency, PT SCMPP, and local communities.	The architecture demonstrates vertical policy integration; however, its effectiveness is highly contingent upon the capacity of local institutions to translate global norms into concrete operational practices.
2	Agency	Describes the roles of various actors involved, both state and non-state	**State Actors** - Central government: the Ministry of Energy and Mineral Resources (MoEMR), the Ministry of Environment and Forestry (MEF), as the national policy maker. - The regional government: the Environment Agency Surakarta City (EA) is responsible for monitoring, supervision, and local regulatory enforcement. - PLN: acting as a state-owned enterprise and electricity off-taker under a state-regulated tariff scheme. **Non-State Actors** - *PT Citra Metrojaya Putra* and *PT Pembangunan Perumahan* (PP): collaborate to establish a special purpose company (SPC), namely *PT Solo Citra Metro Plasma Power* (SCMPP) - The local community	

No	Aspect	Explanations	Application in the Putri Cempo WtE Power Plant	Interpretation
3	Adaptiveness	How responsive the system is to change, technological innovation, and new challenges	The Putri Cempo WTE power plant demonstrates adaptability through the application of environmentally friendly WTE technology, but still faces several technical challenges. Based on stakeholder interviews, waste moisture levels can reach up to >80% during the rainy season, far exceeding the gasifier's machine specification <20% [22]. The heterogeneous composition of municipal solid waste further constrains operational efficiency.	The system demonstrates technological adaptiveness; however, socio-institutional adaptiveness remains underdeveloped. Limited implementation of upstream household-level waste sorting contributes to a mismatch between high-end gasification technology and the realities of raw material supply.
4	Accountability	Mechanisms of accountability, transparency, and Public acceptance in the governance system	The Surakarta City EA plays a key role in monitoring and supervision to ensure the transparency of the Putri Cempo WtE operations. Environmental oversight is conducted through laboratory-based air quality testing twice a year, and a water quality assessment was carried out once at the initial operational stage.	Accountability mechanisms remain largely formalistic, with oversight practices centered on procedural compliance rather than continuous public disclosure. The absence of real-time and transparent environmental data sharing limits social legitimacy and weakens public trust in the project's long-term sustainability.
5	Allocation	Relates to the fair and proportional distribution of rights, responsibilities, benefits, and burdens.	- The Surakarta City Environmental Agency (EA): acts as the waste supplier and permit facilitator, benefiting from improved urban cleanliness, with no tipping fee utilized. - PT SCMPP: serves as the technical manager and private partner, responsible for project implementation and bearing all operational costs, while revenue is derived solely from electricity sales to PLN via a PPA Agreement. - PLN: purchase of electricity generated by the Putri Cempo WtE power plant with a state-regulated feed-in tariff. - The local community: as end users, beneficiaries, and social stakeholders affected by the project.	Risk allocation is asymmetric, placing the primary financial burden on the private partner [23]. In the absence of robust oversight mechanisms, this structure may incentivize cost-minimization practices, potentially undermining environmental safeguards in pursuit of economic efficiency.

2.2. Study area.

This research was conducted at the Putri Cempo WtE Power Plant, located in Surakarta City, Central Java Province, Indonesia. This location was chosen as a case study because of its strategic role as one of Indonesia's WtE projects, developed to support national renewable energy targets and urban waste management goals. The Putri Cempo plant represents a relevant implementation of local-level WtE governance, involving multiple stakeholders from the government, private sector, and community, making it an appropriate setting for studying the dynamics of multi-stakeholder governance.

2.3. Research design.

This research aimed to uncover the actual practices occurring in the field. Qualitative researchers focus on socially constructed realities, build close relationships with research

participants, and seek answers that highlight how social experiences are formed and interpreted. Whitney (1960) further explains that descriptive research aims to interpret existing conditions, relationships, ongoing processes, effects, and developing trends. Based on these foundations, this study adopted a qualitative descriptive approach with a case study method at the Putri Cempo WtE Power Plant in Surakarta City. This approach was chosen to gain an in-depth understanding of the regulatory framework, the roles of actors involved in policy implementation at the local level, and the governance and waste management practices applied at the Putri Cempo plant.

2.4. Data collection.

Data collection for this research uses secondary and primary data. Primary data were obtained through interviews with two key informants, namely monitoring representatives from the Surakarta City Environment Agency (EA) and representatives of local communities living in the vicinity of the Putri Cempo PLTSa. Secondary data was obtained through literature studies focused on journals and books, alongside documentation studies of official policy and regulation documents sourced from authorized public information portals. Therefore, this study emphasizes analysis of governance and regulatory aspects, rather than a detailed technical evaluation of the facility's operational performance.

3. Results and Discussion

Indonesia’s Enhanced NDC affirms the country’s increased ambition to reduce greenhouse gas emissions while promoting the implementation of renewable energy projects at the local level, including the construction of the Putri Cempo WtE power plant in Surakarta City. This commitment represents a strategic step for the government in integrating climate change mitigation actions with low-carbon development policies. The enhanced commitment not only demonstrates Indonesia’s seriousness in supporting the global agenda to reduce emissions but also reflects the need to strengthen the management of urban waste, which continues to increase.

Indonesia raised its ambition in its Enhanced NDC, updated in 2022 [24], by highlighting the waste sector as a key focus for greenhouse gas emission reduction. This emphasis is driven by the significant potential for methane emissions from landfills and the opportunities for mitigation through WtE conversion, aligning with the national climate agenda and long-term low-carbon development targets. The Enhanced NDC targets a 31.89% reduction in emissions unconditionally and a 43.2% reduction conditionally by 2030 [25], representing an increase from previous targets. The document identifies five priority sectors: energy, waste, industry, agriculture, and forestry. These targets align with the 2025–2045 National Long-Term Development Plan, which aims for waste reduction and net-zero emissions by 2060 [26]. The Enhanced NDC policy serves as an operational framework connecting global commitments with concrete local-level actions, including renewable energy projects such as WtE power plants.

Currently, Indonesia generates approximately 36.6 million tons of waste annually, with urban growth and population density increasing pressure on landfills [4]. Urban development ideally balances land availability with population density; imbalanced growth can exacerbate environmental problems. To address these challenges, the construction of the Putri Cempo WtE power plant in Surakarta City was planned as a concrete implementation of the Enhanced NDC

at the local level. The project has been in planning since 2016, and construction officially began in 2019 following a feasibility study and the establishment of a cooperation agreement between the local government and the private sector. The plant is located at the Putri Cempo landfill area in Mojosongo, Surakarta, covering 10 hectares, with a management capacity of approximately 545 tons of waste per day and potential electricity production of 5–8 megawatts.

The Putri Cempo WtE power plant is managed through a public-private cooperation scheme between the Surakarta City Government and PT Solo Citra Metro Plasma Power (PT SCMPP). PT SCMPP is a consortium comprising PT Pembangunan Perumahan (PT PP) Persero and PT Citra Metrojaya Putra [28]. The cooperation agreement, signed in December 2016 [27], is valid for 20 years, with operations planned to begin in 2024. The cooperation scheme is summarized in Figure 1.

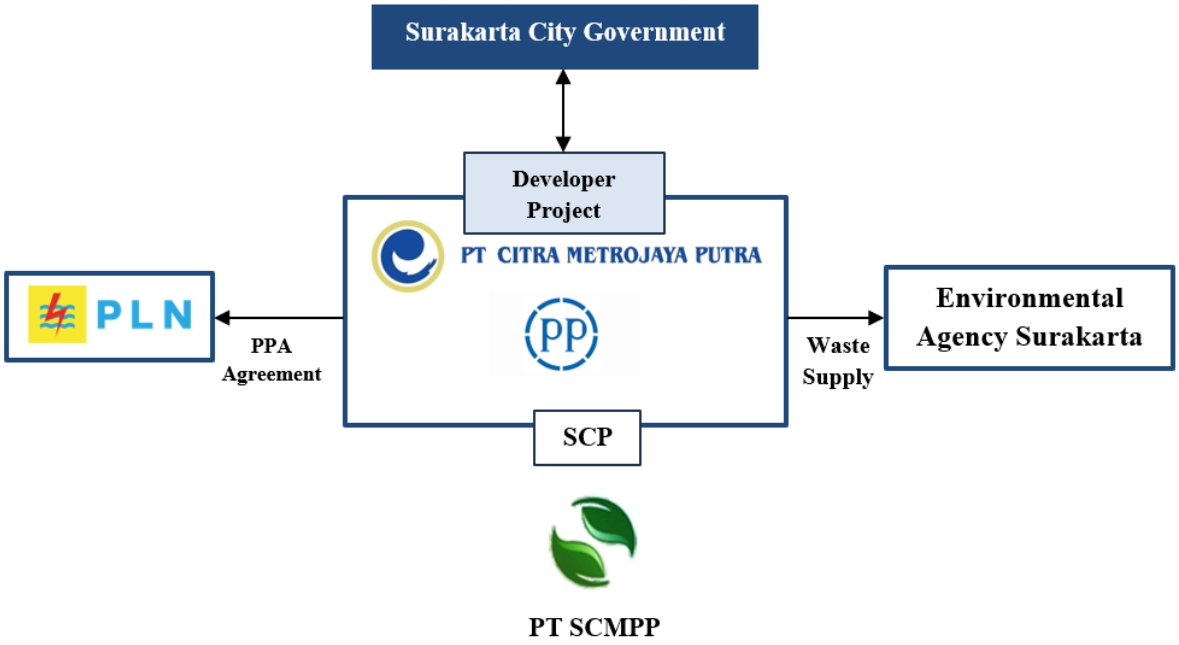

Figure 1. Cooperation scheme of the Putri Cempo waste-to-energy.

3.2. Aspect architecture.

The architecture aspect of the Putri Cempo WtE power plant governance was built within a multi-layered framework that connects global norms, national policies, and technical implementation at the local level. At the global level, the Paris Agreement promoted emission reductions through the energy and WtE sectors as mitigation strategies.

At the national level, the Indonesian government issued several regulations related to the development of WtE power plants (PLTSa) as a form of Enhanced NDC implementation toward low-carbon development. These regulations and legislation cover areas such as waste management, renewable energy development, water quality control, and monitoring of PLTSa management. A summary of relevant regulations applicable to the Putri Cempo case study in Surakarta City is presented in Table 2. Cross-level policy integration was important because climate mitigation efforts could only be effectively internalized if national and local policy directions were aligned. Without such alignment, the implementation of WtE power plants (PLTSa) risked facing uncertainties, such as fluctuations in funding, changes in program priorities, and weak monitoring systems. The success of PLTSa projects was highly influenced

by the central government, regional regulations, and technical practices in the field, which needed to work together within a mutually reinforcing framework.

Table 2. Regulations and legislation related to the development of WTE in Indonesia.

No.	Regulations and Law	References
1	The Law No. 30 of 2007 on Energy.	[29]
2	The National Energy (Government Regulation) No. 79 of 2014.	[30]
3	The power purchase agreement (PPA) from a municipal waste-based power plant (Ministerial MoEMR), Law No. 44 of 2015.	[31]
4	General Waste (local domestic, household waste, specific waste), the management is under the Local Government Act No. 18 of 2008.	[32]
5	Presidential Regulation (The Development of WtE Power Plant Facilities), Law No. 18 of 2018.	[12]
6	Environmental Quality (environmental protection and management), Law No. 32 of 2009.	[33]
7	Environmental Quality (water quality monitoring and pollution control on inland).	[34]

This multi-layered legal framework created the expectation that WtE projects should address mitigation targets and comply with national technical standards. However, in practice, the effectiveness of this architecture was determined by the capacity of local institutions to implement national policies into operational practices, such as land provision, feedstock supply guarantees, and monitoring systems. This ensured that the relationship between policy and implementation was not only normative but also operational. The architecture aspect thus ensured that a legal and policy framework supported waste and energy management, minimized legal risks, and maintained environmental standards.

3.3. Aspect agency.

These agents played a role in decision-making, policy implementation, and innovation in sustainability solutions that were not always under state control [21]. The governance of the Putri Cempo WtE power plant was influenced by the involvement of various actors who had different roles, proportions, and interests but shared the common goal of promoting the WTE development agenda. At the global level, the parties to the Paris Agreement acted as normative drivers that set emission mitigation standards and provided international legitimacy for transforming the energy sector and waste management. The role of global actors was not operational but focused on determining policy directions that shaped global standards, encouraged adjustments of national commitments, and opened opportunities for climate financing that influenced national governments.

At the national level, the central government acted as the national policymaker, setting strategic policy directions in the energy and environment sectors, including those related to WtE development. This authority was then implemented through the relevant technical ministries. In the energy sector, the Ministry of Energy and Mineral Resources (MoEMR) established national energy regulations [35]. Within MoEMR, the Directorate of Bioenergy, under the Directorate General of New, Renewable, and Energy Conservation [36], was responsible for developing and facilitating the use of bioenergy, such as WtE technology. The Bioenergy Directorate acted as a central government agency bridging technical coordination with local governments and promoting the development of renewable energy options [37].

In the environmental and waste management sector, national policymakers were led by the Ministry of Environment and Forestry (MoEF), which developed technical standards for

waste management, set emission limits, regulated residues, oversaw Environmental Impact Assessment procedures, supervised WtE facilities, and ensured safe operational standards for the community and ecosystem [38]. The MoEF thus acted as a regulator and environmental quality supervisor, ensuring that WtE plant development and operation adhered to sustainability principles.

At the local level, the Surakarta City Government and the Surakarta Environment Agency (EA) were the main actors in technical implementation. The EA was responsible for waste supply, monitoring, and supervising the daily operations of the Putri Cempo WtE plant, ensuring environmental standards were met. The Surakarta City Government facilitated community involvement, provided land, and acted as a liaison between the community, the private sector (investors), and the central government, ensuring proper governance implementation [27]. On the private sector side, PT SCMPP served as the partner responsible for the construction, planning, and operation of the Putri Cempo WtE plant. PT SCMPP played a key role in gasification-based waste treatment, turbine installation, internal electricity transmission, residue management, and electricity production. Although crucial to daily operations, PT SCMPP remained under government regulatory oversight.

The agency aspect of governance at the Putri Cempo WtE plant illustrated the connection between global actors encouraging climate commitments, state actors translating these into national regulations and technical standards, and local actors implementing policies on the ground. Relationships between these actors were non-hierarchical, influenced by the alignment of interests and institutional capacity. Due to the dynamic and uncertain nature of the Earth system, management systems needed to adapt to new changes. The Putri Cempo WtE plant demonstrated technical adaptation efforts in response to urban waste management demands and renewable energy targets. However, operational capacity and adaptive capabilities faced limitations affecting facility performance. A primary challenge was the characteristics of waste, which did not always meet the required raw material specifications. Waste needed to satisfy criteria such as a maximum moisture content of 20% and suitable chemical composition to ensure efficient gasification and high-quality syngas production with low tar residue.

3.4. Aspect adaptiveness.

Due to the highly dynamic and uncertain nature of the Earth's system, management systems must be able to adapt to new changes. The management of the Putri Cempo WtE power plant demonstrates real technical adaptation efforts in response to urban waste management demands and renewable energy targets. However, the operational capacity and adaptive capabilities of the system still face several limitations that affect the performance of the facility, as shown in Table 3. Through thermochemical gasification conversion, solid waste is converted into syngas at high temperatures (< 1000 °C) with limited oxygen supply, and the waste combustion process takes place inside the reactor. The type of fuel used can affect the temperature of the gasification process [41]. In addition, the gasification process also produces residues, such as ash, slag, and char. This residual carbon can be reused, so it still requires further treatment. Otherwise, it has the potential to become waste that pollutes the environment and health. The management has planned to develop a prototype for recycling residues into biodiesel as an innovative effort to reduce waste from gasification. However, this innovation is still in the planning stage and has not yet been implemented. From the perspective of adaptiveness, according to Biermann (2007), the Putri Cempo WtE power plants require

improvements in management of the upstream sorting system, strengthening of technical maintenance, and realistic capacity planning so that the facility can operate stably, reduce the burden of residues, and achieve the targeted contribution.

Table 3. Technical criteria and actual operational conditions affecting the adaptiveness of the Putri Cempo WtE power plant.

Element	Ideal (technical criteria)	Actual Field Condition	Challennges
Moisture content of waste	≤ 20% to ensure efficient gasification and low tar production [39]	Can reach >80%, especially during the rainy season	Low combustion efficiency, increased energy required for drying.
Waste composition	Dry and combustible materials (paper, dry leaves, wood, dry organic waste, etc.)	Mixed waste dominates (wet textiles, soil, metal, glass, etc.)	Waste has not been properly sorted. Heterogeneous waste with high water content can reduce reactor efficiency and increase mechanical wear.
Daily waste supply	545 tonnes/day (design capacity) [40]	Approximately 260 tonnes per day (interview data)	Underutilization of plant capacity and reduced electricity generation.
Residu management	Residues are minimized or recycled through secondary treatment	Residual carbon still requires further treatment; innovations in prototypes for recycling into biodiesel are still in the planning stages and are not yet operational.	Potential environmental burden if residues are not properly managed.

This should be a mutual concern for the government, the community, and the management. In terms of regulations, the mechanisms outlined for waste management are quite good, but to implement them in practice, the central government needs to take more strategic measures. Improving the system from the source, starting with waste sorting in households, is a shared task that requires consistent and significant participation from the community. but how to achieve this consistency must be reinforced through upstream policies from the central government, such as mandatory sorting, incentives, and disincentives based on compliance, as well as a measurable monitoring system, to make the waste supply chain entering the WtE power plant more stable, of higher quality, and in line with technological needs, or also to other WTE disposal sites. The implementation of flexible mechanisms capable of responding to changing challenges is the key to success in managing the long-term Earth System.

3.5. Aspect accountability.

In terms of accountability, EA serves as the main institution responsible for monitoring, supervising, evaluating, and ensuring transparency in the daily operations of the Putri Cempo WtE power plants. PT SCMPP, as the manager, has the obligation to report on operational conditions, manage residues safely, and provide technical information to the government and the community. In an interview conducted directly with a representative from the EA Surakarta City, the agency conducts monitoring in several aspects, such as air monitoring through laboratory tests conducted twice a year, water quality checks only at the beginning, and socialization to the community. To improve the accountability of the Putri Cempo WtE power plants, the EA needs to implement a sustainable and participatory data-based environmental monitoring system. Monitoring should be conducted periodically with measurable indicators, and environmental test results should be published openly through a public information portal to ensure transparency.

Based on available information, since June 2025, the Putri Cempo WtE power plants facility has been temporarily shut down to increase capacity and make technical adjustments. This shutdown is justified by the need to balance waste input with machine capacity and improve the feedstock processing system. However, the operational shutdown and previous technical problems have had a real socio-environmental impact. Complaints from local residents regarding the spread of ash from processing around the WtE power plants and concerns about water quality became central issues.

Public concern about the quality of the environment in which they live every day is evident in the statement of a resident who said, "*We have been experiencing shortness of breath, coughing, colds, and itching since the garbage arrived. Residents are very disturbed by this garbage*." [42] The proximity of the garbage dump to residential areas is considered by residents to be a factor that increases potential environmental exposure, thus raising concerns about the quality of the surrounding environment.

One resident who was asked for information conducted an independent water test, and the results showed E. coli content of 9 CFU/100 ml in the resident's water sample. This level exceeds the safe limit. Normally, the presence of E. coli at a level >0 CFU/100 ml [43] indicates fecal contamination, making the water unfit for consumption without treatment. Regular exposure to contaminated water carries the risk of gastrointestinal diseases such as diarrhea, urinary tract infections, and others.

In response to these findings, it is important to immediately take concrete steps and establish coordination between PT SCMPP as the manager, the EA as the monitoring and supervisory body, and the community. The successful implementation of WtE power plants depends not only on the availability of technology or regulatory policies but also on the ability of all actors involved to collaborate in a sustainable manner. The community, as an involved actor, also has an important role in the waste management system, especially in the stage of sorting waste at the household level, which is the starting point for the WTE process to run smoothly.

Governance system management must be carried out transparently and be accountable to all actors involved. Trust and legitimacy are key to ensuring that all parties feel that the decision-making process is fair and legitimate, thereby supporting sustainability and compliance with existing regulations. Synergistic collaboration between the government, the private sector, and the community is the main foundation for realizing inclusive, transparent, and sustainable waste management governance. With the strengthening of cross-actor coordination, it is hoped that the Putri WtE power plants can resume operations at optimal capacity and make a real contribution to achieving national mitigation targets.

3.6. Aspect allocation.

Aspect allocation determines the fair and effective distribution of responsibilities, rights, and proportional burdens among the various actors involved. In summary, allocation refers to how authority, resources, benefits, and burdens are distributed among actors. Who benefits economically or energetically from a development, and who bears the environmental or social risks of its operation [21]. In the governance of the Putri Cempo WtE power plants, the accountability mechanism is divided into two main levels, namely operational and regulatory responsibility. At the regulatory level, the Surakarta City Government, through the Surakarta Environment Agency (AEA), is responsible for daily operational supervision, environmental

data verification, compliance assessment, and licensing. In the event of abuse of authority, such as falsification of emission data, procedural deviations, or disregard for safety standards, the EA Surakarta is also responsible for weaknesses in its supervisory and control functions. The EA also plays a role in providing 10 hectares of land and supplying the waste needed during the operation of the WtE power plants.

At the operational level, PT SCMPP, as the manager, is the first party responsible in the event of obstacles such as work accidents, environmental pollution, technical failures, or other forms of operational malpractice. This is in line with the operator's obligations under the energy facility processing cooperation scheme, whereby the Company is required to ensure compliance with safety standards, emission quality control, and waste processing procedures in accordance with national regulations.

Based on a mutual agreement, the Surakarta City Government does not implement a tipping-free system in the management of the Putri Cempo WtE power plants. All operational and maintenance costs for the WtE power plants facilities are borne by PT SCMPP as the managing party. All profits from the sale and purchase of electricity are received by the managing party. The electricity generated will be traded through a Power Purchase Agreement (PPA) scheme, which is an electricity sale and purchase agreement between PT SCMPP and PT PLN, in accordance with the provisions stipulated in Ministerial Regulation No. 44 of 2015. This cooperation scheme illustrates the synergy between actors within the framework of multi-actor governance, which is a key feature of environmental governance.

In studies on WtE power plants in Southeast Asia, technological development and governance vary greatly between countries. Most countries, including Indonesia, Thailand, and Malaysia, still face structural challenges in the form of waste heterogeneity, weak upstream selection, and institutional fragmentation in waste management [44]. Meanwhile, Singapore is positioned as a regional leader in WtE power plants development, supported by mature technology and governance. Singapore excels due to its structured institutional system, strict emission regulations, and advanced, measurable technological standards, resulting in relatively higher adaptive capacity of WtE power plants compared to other Southeast Asian countries that remain in a transitional stage of technological development.

4. Conclusions

This research concludes that the implementation of the Putri Cempo WtE plant represents a concrete example of Indonesia’s efforts to translate its Enhanced NDC commitment into mitigation actions at the local level, particularly in the waste sector, which is a priority for reducing greenhouse gas emissions. The facility demonstrates the integration of national policy with urban waste management through the conversion of waste into electrical energy. This effort aligns with the Sustainable Development Agenda, particularly SDG 7, which aims to expand access to clean energy, and SDG 13, which supports climate change mitigation by reducing methane emissions from landfills. However, the achievement of these goals continues to face structural and operational challenges. These include feedstock that often does not meet quality and quantity requirements for the plant, low levels of waste sorting at the source, and operational disruptions that have social and environmental impacts, potentially reducing public acceptance. This study concludes that the effectiveness of the Putri Cempo WtE plant depends not only on WtE technology but also on the quality of cross-scale governance, transparency, institutional capacity, and fairness in the distribution of benefits and risks. By strengthening

policy integration in practice for example, improving waste sorting at the source to facilitate downstream processes and reorganizing the division of responsibilities among actors, the Putri Cempo WtE plant has the potential to become a model of more adaptive and inclusive WtE governance practices.

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Author Contribution

Syavina Damar Rosi: Conceptualization, framework, research data collection, writing, supervision, and funding. Andriko Sandria: Conceptualization, methodology, research data collection, writing, and funding.

Competing Interest

The author declares that no competing interests or other factors have affected the conduct of this research.

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