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Waste Burned, Energy Produced: Is Waste-to-Energy a Climate Solution or a Transfer of Pollution to Poor Communities?

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Abstract

Waste-to-energy technologies are increasingly promoted as solutions to two interconnected urban challenges: growing waste volumes and the demand for alternative energy sources. In Indonesia, however, the expansion of waste-to-energy facilities has generated debates about emissions, public health, environmental safety, and the location of facilities near residential communities. This article critically examines whether waste-to-energy development should be understood as a climate solution or as a mechanism that redistributes environmental risks toward socially vulnerable populations. The analysis focuses on waste combustion, air emissions, residual waste, health concerns, and the spatial distribution of environmental burdens. Particular attention is given to communities living near proposed or operating facilities, including cases where low-income neighborhoods may experience disproportionate exposure to pollution. Through an environmental-justice framework, the article distinguishes between the potential benefits of reducing landfill dependence and the risks associated with combustion-based waste management. It argues that the climate credentials of waste-to-energy cannot be evaluated solely through energy generation or waste-diversion indicators. Full assessment must include life-cycle emissions, waste composition, air-quality impacts, ash management, public health, and meaningful community participation. The article concludes that waste-to-energy can only contribute to a just transition if it is embedded within a broader waste hierarchy emphasizing prevention, reduction, reuse, recycling, and strict environmental safeguards.

[*Teknologi pengolahan sampah menjadi energi semakin dipromosikan sebagai solusi untuk dua tantangan perkotaan yang saling terkait: peningkatan volume sampah dan permintaan akan sumber energi alternatif. Namun, di Indonesia, perluasan fasilitas pengolahan sampah menjadi energi telah menimbulkan perdebatan tentang emisi, kesehatan masyarakat, keselamatan lingkungan, dan lokasi fasilitas di dekat permukiman penduduk. Artikel ini secara kritis mengkaji apakah pengembangan pengolahan sampah menjadi energi harus dipahami sebagai solusi iklim atau sebagai mekanisme yang* *mendistribusikan kembali risiko lingkungan ke arah populasi yang rentan secara sosial. Analisis ini berfokus pada pembakaran sampah, emisi udara, sisa sampah, masalah kesehatan, dan distribusi spasial beban lingkungan. Perhatian khusus diberikan kepada komunitas yang tinggal di dekat fasilitas yang diusulkan atau beroperasi, termasuk kasus di mana lingkungan berpenghasilan rendah mungkin mengalami paparan polusi yang tidak proporsional. Melalui kerangka kerja keadilan lingkungan, artikel ini membedakan antara potensi manfaat pengurangan ketergantungan pada tempat pembuangan sampah dan risiko yang terkait dengan pengelolaan sampah berbasis pembakaran. Artikel ini berpendapat bahwa kredibilitas iklim dari pengolahan sampah menjadi energi tidak dapat dievaluasi hanya melalui indikator pembangkitan energi atau pengalihan sampah. Penilaian menyeluruh harus mencakup emisi siklus hidup, komposisi limbah, dampak kualitas udara, pengelolaan abu, kesehatan masyarakat, dan partisipasi masyarakat yang bermakna. Artikel ini menyimpulkan bahwa pengolahan limbah menjadi energi hanya dapat berkontribusi pada transisi yang adil jika diintegrasikan dalam hierarki pengelolaan limbah yang lebih luas yang menekankan pencegahan, pengurangan, penggunaan kembali, daur ulang, dan perlindungan lingkungan yang ketat.*]

Keywords: waste-to-energy, PLTSa, environmental justice, air pollution, climate policy

Introduction

Waste-to-energy (WtE) has increasingly been positioned as a technological response to two interconnected urban problems: the growing volume of municipal solid waste and the demand for additional sources of energy. The basic proposition appears attractive. Instead of allowing waste to accumulate in landfills, combustible waste can be processed through thermal treatment and converted into electricity or heat. In Indonesia, this approach has received explicit policy support through the national waste-management framework and the acceleration of waste-to-electricity facilities. Presidential Regulation No. 35 of 2018, for example, established an accelerated framework for the construction of environmentally friendly waste-processing facilities that generate electricity, while the national waste strategy under Presidential Regulation No. 97 of 2017 places waste reduction and handling within a broader national policy framework (Indonesia 2017, 2018).

The attraction of WtE nevertheless depends on an assumption that requires closer examination: that converting waste into energy necessarily produces an environmental benefit. Life-cycle research shows that the environmental performance of waste incineration is considerably more complicated. Incineration can reduce the volume of waste requiring final disposal and can substitute for some forms of fossil-fuel-based energy production, but its overall climate and environmental performance depends on waste composition, energy efficiency, emissions-control technologies, transport, residual ash management, and the emissions displaced elsewhere in the energy system. Han et al. (2023), for example, found substantial variation in the life-cycle greenhouse-gas emissions of municipal solid-waste incineration and identified the fossil-carbon content of waste—particularly plastics—as a major contributor to emissions. Their analysis also showed that increasing plastic recycling and improving electricity-generation efficiency could reduce the climate burden of incineration.

The same complexity appears when WtE is evaluated beyond greenhouse-gas emissions. A life-cycle assessment of municipal waste incineration found that the technology can generate both avoided and additional environmental impacts depending on the system boundary and technological configuration (Ripa et al. 2021). Although modern incinerators can substantially reduce certain pollutant emissions through flue-gas treatment, the treatment systems themselves consume materials and energy and generate additional environmental impacts. Ripa et al. therefore argue for combining life-cycle assessment with health-impact and epidemiological approaches rather than assuming that technological emission controls automatically eliminate health concerns. Similarly, research on flue-gas treatment has demonstrated that technologies designed to reduce particulate matter, acidification, and other pollutants can simultaneously create additional environmental burdens, illustrating the trade-offs embedded within apparently "clean" combustion systems (Mayer et al. 2020).

These findings complicate the climate narrative surrounding WtE. If the objective of waste combustion is presented primarily in terms of electricity generation or landfill diversion, the analysis risks overlooking the carbon embedded in the waste itself and the emissions generated throughout the treatment chain. The importance of waste composition is particularly evident in recent research. A 2024 life-cycle assessment found that waste composition strongly affects WtE's environmental performance and that substantial reductions in climate impacts would require additional technological interventions such as carbon capture and storage (CCS) (2024). Even in scenarios involving CCS, however, improvements in climate performance can be accompanied by increased impacts in other environmental categories. The implication is straightforward: there is no automatic equivalence between producing energy from waste and producing climate benefits.

The Indonesian context makes this question especially important because WtE is developing within a waste-management system that continues to face problems of waste generation, collection, separation, recycling, and final disposal. Law No. 18 of 2008 concerning Waste Management establishes a comprehensive approach to waste management and explicitly recognizes the environmental and public-health consequences of inadequate waste management. It also places waste management within a broader framework involving government responsibility, community participation, and environmentally sound management (Indonesia 2008). Government Regulation No. 81 of 2012 subsequently established the regulatory framework for household waste and waste of a similar nature, reinforcing the need for systematic waste reduction and handling rather than relying exclusively on end-of-pipe disposal (Indonesia 2012).

This legal framework is significant because it suggests that WtE should not be interpreted as an independent waste solution. It is one component within a larger waste-management hierarchy. The policy question is therefore not simply whether Indonesia can transform waste into electricity, but whether investment in thermal treatment strengthens or potentially displaces higher-priority strategies such as waste prevention, reuse, recycling, and source separation. Evidence from Surabaya illustrates the importance of this distinction. A recent life-cycle assessment found that the introduction of WtE could reduce aggregate greenhouse-gas emissions in the city's waste-management system, but the researchers also found that increased recycling and improved waste separation could generate additional reductions (2024). The result does not demonstrate that WtE is ineffective; rather, it demonstrates that WtE performance must be evaluated against alternative waste-management pathways rather than in isolation.

The question becomes even more consequential when the geographical distribution of environmental burdens is considered. Waste is generated throughout an urban economy, but waste-processing infrastructure is spatially concentrated. A WtE facility therefore creates a potentially important separation between the population that generates and consumes products and the population living near the facility that experiences its localized environmental risks. This spatial separation is central to an environmental-justice analysis because the benefits of electricity generation and improved waste disposal may be distributed widely, while exposure to emissions, traffic, noise, ash handling, and other risks may be concentrated geographically.

Recent evidence on WtE-related health burdens reinforces the importance of this distributional question. Cui et al. (2025), examining waste-to-energy plants and air-pollution health burdens, found that nitrogen oxides and sulfur dioxide were major contributors to premature mortality associated with regulated flue-gas pollutants. The study also identified substantial spatial variation in the benefits that could be obtained from stronger emission controls, particularly in densely populated areas. These findings do not establish that all communities near WtE facilities experience unacceptable health impacts, nor do they demonstrate that modern emission controls are ineffective. They do, however, demonstrate that the location of WtE facilities is itself an environmental-governance issue, because the consequences of emissions depend on population density, exposure, baseline vulnerability, and the effectiveness of regulatory enforcement.

This creates the central tension examined in this article. WtE can potentially reduce dependence on landfills, recover energy, and contribute to improved waste management. At the same time, combustion transfers part of the waste problem from solid waste accumulation to a more technologically controlled but still environmentally consequential system involving atmospheric emissions, residual ash, and energy consumption. The relevant question is therefore not whether WtE is categorically “green” or “dirty.” Its environmental and social consequences depend on what waste is burned, where it is burned, how it is burned, who lives nearby, how emissions are controlled, what happens to residual waste, and what alternatives are displaced by the facility.

Indonesia's regulatory framework recognizes some of these concerns. Minister of Environment and Forestry Regulation No. 70 of 2016 establishes emission standards for thermal waste-processing activities and explicitly recognizes that thermal waste treatment has the potential to affect the environment through released emissions (Indonesia 2016). The existence of such standards is important, but regulation alone does not resolve the justice question. An emission limit determines what level of pollution is legally permissible; it does not by itself determine whether the resulting environmental burden is equitably distributed or whether a particular community has had meaningful influence over the facility's location and operation.

This article therefore approaches WtE through an environmental-justice framework. It argues that the climate credentials of waste combustion should be evaluated through three interconnected dimensions: distribution, procedure, and environmental performance. Distribution concerns who receives the benefits of energy recovery and who bears pollution and health risks. Procedure concerns whether communities affected by WtE facilities possess meaningful access to information, participation, and decision-making. Environmental performance concerns whether WtE actually reduces life-cycle emissions and ecological burdens relative to alternative waste-management strategies.

The article advances a central argument: waste-to-energy should not be considered a climate solution merely because waste is converted into electricity. Its legitimacy depends on whether it reduces overall environmental burdens without disproportionately transferring pollution and risk toward communities with limited political and economic power. In this sense, the issue is not simply “waste burned, energy produced,” but whose waste is burned, whose air is affected, and who ultimately pays the environmental cost of producing that energy.

The analysis consequently treats WtE as a question of both technological choice and political economy. If WtE facilities are deployed primarily as a means of accommodating continuously increasing waste generation, they may reinforce a linear consumption model in which waste prevention and material recovery remain secondary. If, by contrast, thermal treatment is applied only to appropriate residual waste after prevention, reuse, recycling, and recovery measures have been maximized—and accompanied by strict emission controls, transparent monitoring, safe ash management, and meaningful community participation—it may have a more defensible role within an integrated waste-management system. The distinction between these two models is fundamental to determining whether WtE represents a component of a just transition or merely a technological transfer of environmental burdens from one place to another.

Previous Studies and Theoretical Framework

1. Waste-to-Energy between Climate Mitigation and Waste Management

The literature on waste-to-energy (WtE) does not support a simple conclusion that converting municipal solid waste into electricity is inherently beneficial for the climate. Rather, the environmental consequences of WtE depend on the composition of the waste stream, the technology employed, the efficiency of energy recovery, the emissions-control system, the treatment of residual ash, and—most importantly—the alternative waste-management pathway against which WtE is evaluated. A comprehensive review of 315 peer-reviewed life-cycle studies concluded that waste avoidance and reuse remain higher in the waste hierarchy than energy recovery, while WtE becomes more defensible when reuse and material recycling are technically or environmentally unsuitable (Laurent et al. 2019).

This finding is analytically important because it challenges the tendency to treat WtE as an independent climate technology. WtE is not environmentally meaningful in isolation; its performance is comparative. Burning waste may appear beneficial when the alternative is uncontrolled disposal or a landfill without effective methane recovery. However, the same incineration pathway may be less attractive when the alternative involves prevention, reuse, recycling, anaerobic digestion, or improved material recovery. A later review of WtE life-cycle studies reached a similar conclusion, finding that the diversion of municipal waste from landfilling to incineration generally reduces global-warming impacts but that human-health consequences remain uncertain and that results vary substantially according to the specific waste-management system (Dastjerdi et al. 2020).

The implication is that the frequently used equation "waste + combustion = renewable energy" is analytically inadequate. Municipal waste is not a homogeneous renewable fuel. A significant proportion may consist of plastics and other fossil-derived materials, while another proportion may contain biogenic carbon. Consequently, the climate effect of combustion depends partly on the carbon composition of the waste and on whether the recovered electricity displaces electricity generated from higher- or lower-carbon sources. This is why life-cycle assessment is particularly important: it moves the analysis beyond the smokestack and asks what happens across the entire waste-management chain.

The methodological literature reinforces this point. Astrup et al. (2015), in a critical review of 136 peer-reviewed articles covering 250 WtE case studies, found considerable variation in assumptions concerning waste composition, energy substitution, emission controls, residue management, system boundaries, and other modelling parameters. These assumptions can substantially affect the conclusions of an LCA. Thus, a claim that WtE "reduces emissions" is meaningful only when the reference scenario, system boundary, waste composition, and substituted energy source are clearly specified.

This is particularly relevant for Indonesia, where waste streams may contain substantial quantities of organic and wet waste. A technology designed for a relatively dry and calorific waste stream may not produce the same environmental or economic performance when applied to a waste stream with high moisture content. Consequently, technological transfer from countries with different waste characteristics cannot be treated as evidence that the same WtE configuration will produce equivalent results in Indonesia.

2. Waste Hierarchy and the Risk of Technological Lock-In

The second debate concerns the position of WtE within the waste hierarchy. International waste-management research generally places prevention, reduction, reuse, and material recovery above energy recovery. Laurent et al. (2019) explicitly identify waste avoidance and reuse as preferable options, followed by recycling and recovery, with disposal occupying the least preferred position. The significance of this hierarchy is not merely normative. It reflects the different environmental value generated by maintaining materials within productive use compared with destroying them to recover energy.

This creates a structural dilemma for large-scale WtE. A facility requires a relatively predictable supply of combustible waste. Once substantial public and private investment has been committed to incineration infrastructure, there may be institutional pressure to maintain sufficient waste throughput to keep the facility economically viable. This creates a potential technological lock-in: infrastructure designed to solve the problem of excess waste can acquire an economic interest in the continued existence of that waste.

The problem becomes particularly important when WtE is presented as an alternative to recycling rather than as a treatment option for residual waste. If recyclable plastics, paper, or other materials are diverted toward combustion, society loses the opportunity to recover their material value. The environmental question therefore becomes not simply whether incineration produces electricity, but whether electricity generation justifies the destruction of materials that could have remained in circulation.

Dastjerdi et al. (2020) demonstrate why this cannot be resolved through a universal ranking of technologies. Their systematic review found that different WtE technologies perform differently depending on the type of waste being treated, and that assumptions concerning the products displaced by recovered energy represent a major source of uncertainty. This suggests that a rational WtE policy should be waste-stream specific, rather than assuming that all municipal waste should be directed toward thermal treatment.

For Indonesia, this argument is particularly significant because the national legal framework does not conceptualize waste management simply as disposal. Law No. 18 of 2008 establishes waste reduction and waste handling as components of national waste management, while Presidential Regulation No. 97 of 2017 establishes national policy and strategy for household and similar waste management. Indonesia's WtE policy should therefore be interpreted within this broader hierarchy rather than as a replacement for upstream waste reduction.

The analytical concern is consequently not that WtE necessarily undermines recycling. Rather, the design of WtE policy determines whether it complements or competes with material recovery. Where WtE is restricted to genuinely residual waste after feasible material recovery, its role is substantially different from a system in which increasing waste generation is treated as the feedstock requirement for expanding incineration capacity.

3. Life-Cycle Assessment and the Problem of Environmental Trade-Offs

Life-cycle assessment provides one of the most useful tools for addressing these competing claims because it evaluates environmental consequences across multiple stages of a system. Yet LCA does not produce a universally predetermined answer. The literature shows that WtE can generate environmental benefits in some impact categories while increasing burdens in others.

A 2020 review of WtE life-cycle studies found that implementation can have “large consequences” for the environmental performance of municipal waste-management systems, but that those consequences can be positive or negative depending on geographic conditions, waste composition, modelling assumptions, and the configuration of the existing waste system (Mayer et al. 2020).) The study also found relatively consistent evidence that replacing landfilling with incineration can reduce global-warming impacts, but it emphasized uncertainty concerning human-health consequences.

This is a crucial distinction. A reduction in one environmental indicator does not establish overall environmental superiority. An incinerator may reduce methane emissions associated with landfilling while simultaneously producing direct fossil-carbon emissions, requiring energy and chemicals for pollution control, and generating bottom ash and fly ash that require further treatment. A narrow climate calculation can therefore produce a more favorable result than a comprehensive environmental assessment. Recent systematic research makes the same point. A 2025 review of incineration technologies argues that environmental evaluation should integrate environmental, economic, and social dimensions rather than relying exclusively on technological or emissions indicators. The authors specifically identify the need to incorporate social and socioeconomic dimensions into WtE assessment.

This development in the literature is significant for the present study because it creates a bridge between LCA and environmental justice. Conventional LCA is particularly useful for determining the total environmental burden of alternative systems, but it does not necessarily reveal how that burden is distributed among social groups. Two waste-management systems may produce similar aggregate environmental impacts while exposing entirely different populations to those impacts. Therefore, LCA answers an important question—how much environmental burden does the system produce?—but environmental justice asks an additional question—who bears that burden?

4. From Emissions to Public Health

The environmental debate surrounding WtE cannot be separated from public-health concerns. Modern incinerators are substantially different from older facilities because emission-control technologies can reduce concentrations of particulate matter, acid gases, heavy metals, and other pollutants. Nevertheless, the existence of technological controls does not eliminate the need for exposure assessment.

A systematic review of health impacts associated with waste incineration concluded that the evidence remains heterogeneous, partly because studies involve different generations of incineration technologies, different exposure pathways, and varying methodological quality. The review found stronger associations between older incineration technologies and adverse health outcomes, while also emphasizing that evidence concerning newer facilities remains comparatively limited and that a precautionary approach remains appropriate (Kim et al. 2019).

This evidence requires a balanced interpretation. It would be analytically incorrect to infer that every contemporary WtE plant produces serious health effects. At the same time, it would be equally problematic to assume that technological modernization makes health risks irrelevant. The correct analytical position is conditional rather than categorical. Risk depends on emissions, technology, maintenance, regulatory enforcement, exposure, population characteristics, and facility location.

The spatial dimension is particularly important. Air pollution does not affect all populations equally because exposure depends on where people live relative to the emission source and on atmospheric conditions. A recent review of environmental justice around waste-management facilities finds that socioeconomic disparities are repeatedly associated with proximity to environmentally burdensome waste facilities and emphasizes the relationship between environmental exposure and social vulnerability. The issue is therefore not simply whether an incinerator complies with an emission standard. Compliance establishes a regulatory threshold; environmental justice asks whether the resulting residual risk is concentrated among communities that already possess fewer resources to manage additional environmental burdens.

5. Waste Infrastructure and the Geography of Environmental Justice

The environmental-justice literature provides a particularly important analytical lens for understanding the spatial politics of WtE. Urban waste systems create a geographical separation between waste generation and waste exposure. Waste is produced throughout an urban economy, but treatment facilities require specific locations. The result is that the environmental burdens associated with waste management can become concentrated in particular neighborhoods even though the waste itself originates from millions of households and businesses.

This spatial concentration creates what can be described as a collective-consumption versus localized-exposure problem. Urban residents collectively benefit from sanitation and waste removal, while communities located near treatment facilities may experience more concentrated exposure to traffic, noise, air emissions, odor, ash transportation, and other risks.

The distributive dimension becomes even more significant when socioeconomic inequality is incorporated into the analysis. Communities with lower incomes may have fewer opportunities to move away from environmentally burdensome infrastructure and may possess less political influence over land-use decisions. Conversely, communities with greater political and economic resources may be better positioned to resist undesirable facilities.

The 2026 environmental-justice review provides contemporary evidence for this pattern, emphasizing the relationship between socioeconomic characteristics, proximity to waste facilities, and health concerns. Although such evidence cannot establish that every WtE facility is deliberately located in disadvantaged communities, it establishes a structural concern that the siting of environmental infrastructure can reproduce existing spatial inequality. This changes the analytical meaning of facility location. Siting is not merely a technical question of proximity to waste sources, transportation infrastructure, grid connections, or land availability. It is also a question of political representation and distributive justice. A technically optimal location may not necessarily be socially equitable if the optimization process ignores differences in community vulnerability and political capacity.

6. The Indonesian Context: PLTSa as a Governance Problem

Indonesia's policy framework demonstrates the tension between technological waste treatment and broader waste governance. Law No. 18 of 2008 establishes environmentally sound waste management, while Presidential Regulation No. 97 of 2017 establishes national policy and strategy for reducing and managing household waste and similar waste. The later Presidential Regulation No. 35 of 2018 specifically accelerated environmentally friendly waste-processing facilities capable of generating electricity.

These regulations demonstrate that Indonesia does not treat WtE simply as an energy policy. It is situated at the intersection of waste management, environmental protection, urban infrastructure, and energy policy. This institutional intersection is precisely why the technology requires critical analysis. The regulatory framework governing thermal waste processing also matters. Minister of Environment and Forestry Regulation No. P.70/MENLHK/SETJEN/KUM.1/8/2016 establishes emission-quality standards for thermal waste-processing activities. Such standards are necessary because combustion transforms a solid-waste problem into a multi-media environmental-management problem involving atmospheric emissions and residual materials.

Yet regulation also creates an analytical limitation. An emission standard is generally designed to establish a permissible concentration or quantity of pollutants; it does not necessarily capture cumulative exposure, socioeconomic vulnerability, or alternative development pathways. Consequently, regulatory compliance and environmental justice should be treated as related but distinct standards of evaluation.

A facility may satisfy technical emission requirements and still generate legitimate justice concerns if communities have had little influence over its location or if the facility contributes to a disproportionate concentration of environmental infrastructure in a disadvantaged area. Conversely, strong participation and equitable siting cannot compensate for poor emission control. Justice therefore requires both environmental performance and fair governance.

7. Rethinking the Meaning of a "Climate Solution"

The preceding literature suggests that the term "climate solution" should be used cautiously. A climate solution should produce a demonstrable reduction in climate-related harm relative to realistic alternatives. It is insufficient for a technology merely to generate electricity or reduce landfill volume. WtE can potentially produce climate benefits where it replaces high-emission disposal practices, captures useful energy, and processes residual waste that has limited material-recovery potential. The literature, however, indicates that these benefits are highly context dependent. The 2020 review by Mayer et al. emphasizes that WtE outcomes differ considerably across waste-management systems and that a context-specific LCA is required before determining the environmentally preferred option. Dastjerdi et al. (2020) similarly identify assumptions concerning energy substitution as a major source of uncertainty in WtE assessments.

The consequence is that "WtE reduces landfill use" and "WtE reduces climate impacts" are not equivalent propositions. The first is a physical statement about waste disposal. The second is a comparative environmental claim that requires evidence. The distinction also matters politically. Describing WtE as a climate solution can create a powerful narrative of technological progress. Once a facility becomes associated with climate policy, criticism of its environmental or social consequences can be portrayed as opposition to climate action itself. This creates a risk of technological depoliticization, whereby questions concerning waste generation, consumption, corporate responsibility, and inequality are reframed as technical problems that can be solved through infrastructure.

An environmental-justice perspective challenges this framing. It asks whether the transition is changing the underlying production of waste or merely changing the technology used to process it. If waste continues to grow while society expands its capacity to burn it, the system may become more efficient at processing waste without becoming less dependent on waste generation.

8. Environmental Justice as the Missing Dimension

The strongest contribution of an environmental-justice framework is therefore its ability to connect environmental performance with political power. Three dimensions are particularly important. First, distributive justice asks whether the benefits and burdens of WtE are fairly allocated. Electricity and improved waste services may benefit an entire metropolitan population, while localized pollution and infrastructure burdens fall on a much smaller community. Second, procedural justice asks whether affected residents have meaningful opportunities to influence decisions about facility location, design, operation, monitoring, and mitigation. Public meetings alone are insufficient if decisions have effectively been predetermined. Third, recognitional justice asks whether communities are treated as legitimate political actors rather than merely as obstacles to infrastructure development. Their concerns about air quality, health, property values, traffic, or environmental change should constitute relevant evidence in decision-making.

These three dimensions reveal why WtE cannot be assessed solely through LCA. LCA can demonstrate whether a system produces more or fewer aggregate emissions, but it cannot determine whether the distribution of those emissions is politically acceptable. Conversely, community opposition cannot by itself establish that a technology has poor environmental performance. The two forms of evidence must be combined. This article therefore conceptualizes environmental justice not as an argument against WtE but as a condition for evaluating its legitimacy.

9. Research Gap and Analytical Framework

Although the international literature on WtE has become increasingly sophisticated, a significant analytical gap remains in discussions of Indonesian PLTSa. Much of the technical literature focuses on waste characteristics, energy recovery, technological efficiency, LCA, and emissions. These are essential dimensions, but they leave a less developed question: how are the environmental benefits and burdens of WtE distributed across Indonesian urban populations?

The present study addresses this gap by connecting four dimensions that are often examined separately:

1) Climate performance — whether WtE actually produces net greenhouse-gas benefits relative to alternative waste-management pathways;
2) Waste hierarchy — whether WtE supports or potentially displaces prevention, reuse, recycling, and material recovery;
3) Environmental and health risk — including air emissions, residual ash, and exposure pathways; and
4) Environmental justice — concerning the distribution of burdens, community participation, and recognition of vulnerable populations.

The resulting analytical framework can be represented as: *Waste generation → waste composition → treatment choice → energy recovery → emissions and residuals → spatial exposure → differentiated social impacts → questions of justice.*

The central proposition derived from this framework is that WtE should be considered a conditional climate strategy rather than an inherently climate-positive technology. Its legitimacy depends on comparative life-cycle performance, appropriate placement within the waste hierarchy, effective pollution control, transparent monitoring, responsible residual-waste management, and meaningful participation of affected communities.

Accordingly, the key question is not whether waste can be converted into energy. It clearly can. The more consequential question is whether the production of that energy reduces total environmental harm without transferring a disproportionate share of the remaining pollution and risk to communities with less economic and political power. That question moves the analysis from technological efficiency toward environmental justice and provides the conceptual foundation for examining PLTSa as a contested form of climate and waste governance in Indonesia.

Methods

This study employs a qualitative descriptive-analytic approach to examine waste-to-energy (WtE) as a climate and environmental-governance intervention in Indonesia. The analysis draws on four categories of secondary sources: peer-reviewed international journal articles on WtE, life-cycle assessment, climate mitigation, pollution, public health, and environmental justice; Indonesian laws and regulations; government and institutional documents; and selected credible news reports for contextual evidence. The literature is assessed comparatively rather than assuming that WtE is inherently beneficial or harmful. This is important because previous research demonstrates that the environmental performance of WtE varies according to waste composition, energy efficiency, emission controls, system boundaries, and the alternative waste-management pathway against which it is compared (Astrup et al. 2015; Laurent et al. 2019; Dastjerdi et al. 2020).

The analysis is organized around four interconnected dimensions: climate performance, waste hierarchy, environmental and health risks, and environmental justice. First, the study examines whether WtE produces a net reduction in greenhouse-gas emissions after considering combustion, energy recovery, waste composition, transport, and residual waste. Second, it evaluates whether WtE functions as a treatment for genuinely residual waste or potentially competes with prevention, reuse, recycling, and material recovery. Third, it considers air emissions, ash, and potential public-health implications, recognizing that compliance with emission standards does not automatically resolve questions of exposure or cumulative environmental burden. Finally, an environmental-justice lens is applied to examine who receives the benefits of energy generation and improved waste services, who bears localized environmental risks, and whether affected communities have meaningful opportunities to participate in decisions concerning facility location and operation. In this framework, the concept of "pollution transfer" refers not necessarily to the intentional movement of pollution, but to the possibility that reducing one environmental burden—such as landfill dependence—may create or concentrate other burdens in particular geographical and social locations.

The study therefore treats WtE as a conditional rather than inherently climate-positive technology. Its legitimacy depends on whether its environmental benefits are demonstrated relative to realistic alternatives and whether remaining risks are effectively controlled and fairly distributed. Indonesian legislation, particularly Law No. 18 of 2008 on Waste Management, Presidential Regulation No. 97 of 2017, Presidential Regulation No. 35 of 2018, and Minister of Environment and Forestry Regulation No. P.70/MENLHK/SETJEN/KUM.1/8/2016, is analyzed alongside the international literature to assess the relationship between technological development and environmental governance. Because this research relies on secondary sources, it does not claim to provide original epidemiological measurements or a project-specific LCA. Instead, it develops a critical framework for determining when WtE can contribute to a just transition and when it risks reproducing existing inequalities. The central methodological proposition is therefore that the question should not simply be whether waste can be converted into energy, but whether energy recovery reduces overall environmental harm without disproportionately transferring pollution and environmental risk to communities with less economic and political power.

Waste-to-Energy in Indonesia: Between Climate Ambition and Environmental Risk

Indonesia's growing interest in waste-to-energy (WtE) reflects the convergence of two policy pressures: the rapid growth of municipal solid waste and the search for alternative sources of energy. In policy discourse, WtE appears attractive because it promises to transform a persistent urban waste problem into an energy resource. The basic proposition is straightforward: waste that would otherwise be transported to landfills can be thermally treated, its volume reduced, and part of its energy content recovered as electricity. Indonesia's regulatory framework has increasingly institutionalized this approach. Law No. 18 of 2008 on Waste Management established a national framework emphasizing both waste reduction and waste handling, while Presidential Regulation No. 97 of 2017 established the National Policy and Strategy for Household Waste Management. Subsequently, Presidential Regulation No. 35 of 2018 accelerated the development of environmentally friendly waste-processing facilities capable of generating electricity. These instruments demonstrate that PLTSa has become part of Indonesia's broader strategy for addressing urban waste. Yet the existence of a supportive regulatory framework should not be interpreted as evidence that WtE automatically constitutes a climate or environmental solution. It establishes institutional authorization for the technology; it does not resolve the questions of comparative environmental performance, public-health risk, or distributive justice.

The central difficulty is that Indonesia's waste problem is not simply a problem of insufficient disposal capacity. It is also a problem of waste generation, material composition, collection, separation, recycling, and unequal infrastructure. This distinction matters because thermal treatment is highly dependent on the characteristics of the waste that enters the facility. Research on WtE repeatedly demonstrates that moisture content, organic material, plastics, calorific value, energy efficiency, and the composition of the residual waste stream can substantially influence environmental performance (Astrup et al. 2015; Laurent et al. 2019). In a country where organic waste constitutes an important proportion of municipal waste, the technical and environmental performance of combustion cannot simply be assumed from experiences in countries with different waste profiles. High moisture content can reduce the energy value of waste and may increase the energy required for thermal treatment. At the same time, plastics can increase calorific value while introducing greater fossil-carbon emissions when combusted. The result is an important contradiction: the characteristics that make waste attractive as a fuel may also increase its climate burden.

This contradiction challenges the common policy narrative that WtE simultaneously solves waste and climate problems. It may reduce the quantity of material sent to landfills, but landfill diversion is not synonymous with climate mitigation. Life-cycle studies show that the climate performance of incineration depends on what would otherwise happen to the waste, what energy source is displaced by electricity generation, how much fossil-derived material is present, and how residues are managed (Dastjerdi et al. 2020). If the reference scenario is an uncontrolled or poorly managed landfill, WtE may produce significant benefits by reducing landfill-related methane emissions. If, however, the alternative is improved recycling and material recovery, the comparison becomes considerably more complicated. Burning recyclable materials may recover some energy but simultaneously destroy material value that could otherwise remain within the circular economy. Thus, the climate argument for PLTSa must always be framed as a comparative claim rather than an absolute one.

This issue is particularly relevant because WtE facilities require a relatively stable supply of feedstock. Large-scale thermal infrastructure can therefore create a potential tension with the waste hierarchy. Once substantial capital has been invested in an incineration facility, maintaining adequate waste throughput may become an economic and operational consideration. The danger is not necessarily that governments will deliberately discourage recycling, but that infrastructure may create a structural preference for maintaining sufficient quantities of combustible waste. The policy objective can gradually shift from "how can waste generation be reduced?" to "how can sufficient waste be supplied to the facility?" Such a shift would reverse the logic of the waste hierarchy. Instead of WtE functioning as a downstream solution for genuinely residual waste, waste combustion could become an infrastructure-dependent response to a problem that should partly be addressed upstream through prevention, reuse, and recycling.

This potential tension is particularly important in Indonesia because the legal architecture already recognizes waste reduction as an important component of waste management. The significance of this principle should not be underestimated. If WtE is introduced primarily to accommodate increasing volumes of waste, it risks treating waste generation as an inevitable condition rather than as an outcome of production and consumption patterns. In that scenario, WtE may improve the efficiency of waste disposal without fundamentally transforming the material economy that generates waste. The result would be a form of technological containment rather than structural waste reduction.

The climate implications are equally complicated by the carbon content of municipal waste. Plastics and other fossil-derived materials are increasingly important components of urban waste streams. When such materials are burned, their carbon is released through combustion. Consequently, the fact that waste is being used as a fuel does not make the resulting carbon emissions equivalent to emissions from genuinely renewable energy sources. The climate accounting of WtE therefore requires careful differentiation between biogenic and fossil carbon. Recent research confirms that waste composition can substantially alter the greenhouse-gas performance of incineration and that increasing the recycling of plastics can improve the climate profile of the overall waste system (Han et al. 2023). This finding has direct implications for Indonesia: a PLTSa project should not be evaluated simply by calculating how many megawatt-hours of electricity it generates. It should also be assessed according to what materials are being burned and what emissions are avoided or created as a consequence.

The environmental implications extend beyond carbon dioxide. Thermal treatment transforms solid waste into a combination of atmospheric emissions and residual materials. Modern WtE facilities employ sophisticated pollution-control systems to reduce particulate matter, sulfur dioxide, nitrogen oxides, heavy metals, and other pollutants. These technologies are essential and have substantially improved the environmental performance of modern incinerators compared with earlier generations. Nevertheless, emission controls do not eliminate environmental impacts; they manage them. Research on flue-gas treatment demonstrates that pollution-control systems themselves consume energy and materials and generate secondary environmental burdens (Mayer et al. 2020). The environmental question is therefore not whether a facility has an emission-control system, but how effectively the system operates, how consistently it is maintained, how emissions are monitored, and whether monitoring results are transparently available to the public.

This distinction becomes especially important in the Indonesian regulatory context. Minister of Environment and Forestry Regulation No. P.70/MENLHK/SETJEN/KUM.1/8/2016 establishes emission-quality standards for thermal waste-processing activities. Such standards are necessary because combustion facilities have the potential to release pollutants into the atmosphere. However, compliance with a regulatory limit should not be treated as the endpoint of environmental analysis. A legal standard establishes what level of pollution is permitted; environmental justice asks how the remaining risk is distributed. If a facility complies with an emission standard but is located in an area with high population density, poor baseline air quality, or limited community capacity to respond to environmental problems, the social meaning of that residual risk may differ from that of a similar facility in a less densely populated and more economically secure area.

This is where spatial inequality becomes central to the analysis. Waste is produced across an entire urban economy, but waste infrastructure is spatially concentrated. Millions of households and businesses may generate waste, while only a small number of communities host the facilities used to process it. The benefits of waste removal are therefore broadly distributed, while some environmental risks are geographically concentrated. This creates an asymmetry between collective waste generation and localized environmental exposure. A community located near a PLTSa facility may experience increased truck traffic, noise, odor, air emissions, ash transportation, and other infrastructure-related impacts, while the electricity generated from the waste serves a much larger population.

The question is not whether these impacts necessarily make WtE unjust. Rather, they raise the question of whether the distribution of burdens and benefits is justified and democratically determined. Recent research comparing Indonesia's Benowo and Putri Cempo WtE facilities is particularly relevant. Astuti et al. (2026) found that the two facilities differed considerably in their implementation of energy-justice principles and that distributive justice remained a significant weakness. The research demonstrates that the question of justice cannot be reduced to whether a facility produces renewable or alternative energy. It requires consideration of who receives the benefits, who experiences environmental burdens, and how institutional arrangements affect those outcomes.

The Benowo experience further demonstrates the complexity of community responses to WtE. Research examining community acceptance found that communication, socioeconomic benefits, infrastructure improvements, and perceived local advantages can contribute to public acceptance, while residents may simultaneously express concerns about odors, leachate, or other environmental impacts (2025). This finding is analytically important because community acceptance should not be confused with environmental justice. A community may accept a project because it provides employment or infrastructure, even though its members remain exposed to environmental risks. Conversely, opposition to a facility does not necessarily demonstrate that the technology is environmentally harmful. Justice therefore requires a more demanding standard: communities should have access to information, meaningful participation, effective grievance mechanisms, and a genuine capacity to influence decisions.

The issue of participation is particularly important because large infrastructure projects often involve substantial asymmetries of technical knowledge and political power. Developers and government agencies may possess technical expertise, financial resources, and access to environmental assessments, while affected residents may encounter difficulties interpreting emission data, risk assessments, or complex regulatory documents. A formally open consultation process can therefore remain substantively unequal if communities lack the resources necessary to participate effectively. Procedural justice requires more than the opportunity to attend a public meeting; it requires the capacity to understand, contest, and influence the decision-making process.

This concern is reinforced by research on WtE acceptance in Indonesia. A recent study from Batam found that public acceptance varies according to socioeconomic characteristics and perceptions of the environmental, strategic, and operational consequences of WtE development (2026). Such findings indicate that public attitudes toward WtE are not simply expressions of environmental preference. They are shaped by expectations about employment, local development, perceived risks, trust in government, and confidence in project management. A community's support or opposition should therefore be interpreted as a form of political and social knowledge rather than treated merely as an obstacle to infrastructure development.

The same argument applies to the distribution of economic benefits. PLTSa can generate electricity, employment, infrastructure, and potentially local fiscal or economic benefits. These benefits can be particularly important for communities surrounding facilities that previously experienced the negative externalities of landfill operations without receiving corresponding economic advantages. Yet benefit-sharing must be evaluated carefully. If the economic benefits are temporary or concentrated among contractors and investors while environmental risks remain long-term and geographically localized, the distributional imbalance may persist. Environmental justice therefore requires not merely benefit generation, but proportional and durable benefit distribution.

The question of residual waste represents another underappreciated dimension of the Indonesian WtE debate. Incineration does not eliminate waste completely. It converts part of the original waste stream into bottom ash and fly ash, while pollution-control systems generate additional residues. These materials can contain heavy metals and other contaminants and therefore require appropriate handling, stabilization, transport, and final disposal. A WtE policy that focuses heavily on electricity production while treating ash management as a secondary issue risks reproducing the same linear logic that characterized conventional landfill-based waste management: the problem is transformed rather than eliminated.

This is particularly important from an environmental-justice perspective because residual waste can generate secondary sites of exposure. Even if the WtE plant itself operates within emission standards, ash must still be transported and managed somewhere. The environmental burden can therefore move through the system—from the original landfill, to the combustion facility, and ultimately to an ash-management or disposal site. This illustrates why the phrase “waste burned, energy produced” captures only part of the process. A more complete description would be “waste transferred, transformed, emissions generated, energy recovered, and residues relocated.”

Such a perspective also helps explain why life-cycle assessment and environmental justice should be combined. LCA can identify the aggregate environmental consequences of these transformations, while environmental justice asks how those consequences are distributed. The two approaches answer different questions but are mutually reinforcing. A WtE system with favorable aggregate emissions may still produce significant localized burdens. Conversely, a system with relatively low localized emissions may have poor aggregate climate performance if it burns large amounts of fossil-derived materials that could otherwise have been recycled.

The Indonesian case consequently reveals a broader tension within contemporary climate governance: the pursuit of low-carbon infrastructure can reproduce conventional patterns of environmental inequality if technological solutions are separated from questions of power and distribution. WtE is attractive within a green-growth framework because it promises simultaneous waste management, electricity generation, technological modernization, and climate action. Yet the environmental-justice question is whether these benefits are achieved by transforming the underlying waste system or simply by making the existing system more technologically sophisticated.

This distinction is particularly important for urban communities with limited political influence. If the largest benefits of PLTSa accrue to metropolitan consumers while the most immediate environmental risks are concentrated among communities surrounding the facility, then the technology may effectively function as a form of urban environmental subsidy: host communities provide land, infrastructure, and environmental capacity for the consumption patterns of a much larger urban population. This does not mean that host communities necessarily receive no benefits. Rather, it means that the value of those benefits must be assessed against the duration, magnitude, and reversibility of the environmental burdens they experience.

The concept of energy justice therefore provides an important complement to environmental justice. Energy justice traditionally emphasizes distribution, recognition, and participation in energy systems. Applied to PLTSa, it asks whether the electricity produced is accompanied by equitable access to its benefits, whether communities hosting the infrastructure are recognized as rights-bearing participants, and whether decisions concerning energy infrastructure are made through fair processes. Astuti et al. (2026) demonstrate the value of this approach in the Indonesian context by showing that WtE governance cannot be understood solely through technical energy indicators.

At the same time, energy justice should not obscure the distinctive character of waste as a policy issue. Electricity generation is only one function of PLTSa. The facility is also part of a waste-management system, which means its climate and justice implications depend on what happens before and after combustion. A genuinely just PLTSa policy must therefore integrate energy justice with waste justice. This requires attention to waste reduction, producer responsibility, recycling, informal waste workers, community health, and residual-waste management.

This broader perspective also challenges the assumption that technological innovation automatically constitutes a “green transition.” A transition is not necessarily just because the technology is newer, more efficient, or associated with renewable or alternative energy. A transition is just when it reduces environmental harm while simultaneously addressing unequal exposure, protecting rights, expanding participation, and ensuring that vulnerable communities are not required to absorb disproportionate costs. WtE can potentially satisfy these conditions, but only if it is embedded within a broader policy hierarchy that gives priority to waste prevention and material recovery.

The evidence from Indonesia ultimately suggests that the most defensible position is neither unconditional support nor categorical rejection of PLTSa. WtE can offer legitimate environmental benefits where it is used for residual waste, where realistic alternatives are comparatively worse, where the facility achieves high energy and environmental performance, and where emissions and residual waste are strictly controlled. But those benefits become substantially less convincing when WtE is used to accommodate continuously increasing waste generation, competes with recycling, relies on weak environmental monitoring, or concentrates environmental burdens in communities with limited political power.

The central issue is therefore conditional legitimacy. A PLTSa project should be judged not by the amount of waste it burns or electricity it produces, but by the total environmental and social consequences of the system it creates. This requires a comprehensive assessment of life-cycle emissions, waste hierarchy, air quality, health risks, ash management, facility location, community participation, and benefit distribution. Only when these dimensions are considered together can WtE legitimately be described as part of a climate solution.

In this sense, the Indonesian WtE debate represents a broader question about the meaning of a just climate transition. Climate policy that focuses exclusively on technological substitution risks overlooking the political economy through which environmental burdens are allocated. A low-carbon technology can still produce high social inequality. Conversely, a technology that carries environmental risks can become more defensible when those risks are minimized, transparently governed, equitably distributed, and subjected to meaningful democratic oversight.

The critical question is therefore not simply whether Indonesia should burn waste to produce energy, but what kind of waste system Indonesia wants to build. If PLTSa becomes a downstream component of a hierarchy centered on prevention, reuse, recycling, and responsible residual-waste treatment, it may contribute to a more integrated waste and energy system. If it instead becomes the principal response to rising waste generation, it risks institutionalizing combustion as a substitute for structural waste reduction. The difference between these two trajectories is ultimately not technological. It is a question of governance, political economy, environmental responsibility, and justice.

PLTSa, Environmental Burden, and the Politics of Pollution Distribution

The Indonesian WtE debate becomes more complicated when the technology is examined not only as an energy-producing facility but as part of a broader political economy of urban waste. Indonesia's waste-management framework explicitly recognizes that increasing population and changing consumption patterns generate growing volumes and increasingly diverse forms of waste. Law No. 18 of 2008 therefore adopts a comprehensive approach that combines waste reduction, handling, public participation, government responsibility, and environmental protection. The important implication is that WtE should be positioned within the broader waste-management system rather than treated as a substitute for upstream waste reduction. This is consistent with international research showing that the environmental performance of incineration depends heavily on the waste stream, the alternative treatment pathway, energy substitution, and the efficiency of the technology (Astrup et al. 2015; Laurent et al. 2019; Dastjerdi et al. 2020). Thus, the expansion of PLTSa does not resolve the political question of why so much waste is being generated and who should bear the responsibility for managing it.

This question becomes particularly important in Indonesia because the physical characteristics of municipal waste create significant technological constraints. Research on major Indonesian cities found that food waste constituted approximately 43.78 percent of municipal waste, while paper and plastics accounted for approximately 16.05 and 14.08 percent, respectively. The same study found an average moisture content of nearly 50 percent and an average heating value of approximately 9.5 MJ/kg, below the cited threshold for refuse-derived fuel, suggesting that sorting and pretreatment may be necessary before thermal conversion (Wahyono et al. 2021). Earlier research likewise demonstrated that differences in waste composition and moisture content substantially affect the calorific value and technological feasibility of WtE systems in Indonesian cities (Novita and Damanhuri 2009). These findings complicate the idea that Indonesia simply possesses a large quantity of "energy-rich waste." A large quantity of waste does not automatically translate into a technically or environmentally optimal fuel stream. The quantity of waste and the quality of waste as a fuel are different policy variables.

This distinction has important implications for the climate narrative surrounding PLTSa. Where municipal waste contains substantial organic and wet fractions, thermal treatment may require additional energy or pretreatment, while the combustion of plastics can generate fossil-carbon emissions. Consequently, the electricity output of a facility cannot by itself demonstrate a climate benefit. Life-cycle research consistently emphasizes that WtE must be compared against realistic alternatives, including landfill with gas recovery, recycling, composting, anaerobic digestion, and waste prevention (Astrup et al. 2015; Laurent et al. 2019). The relevant question is therefore not "Does the plant generate electricity?", but "Does the complete waste-management system produce lower environmental impacts than the alternatives that are realistically available?" This distinction is especially important when WtE is promoted under the language of clean energy. Electricity generated from mixed municipal waste may be useful energy, but the environmental classification of that electricity depends on the carbon content of the feedstock and the emissions avoided elsewhere in the energy system.

The Indonesian policy framework itself illustrates this tension. Presidential Regulation No. 35 of 2018 was designed to accelerate waste-processing installations that convert waste into electricity through environmentally friendly technology and explicitly linked WtE with improvements in public health, environmental quality, and reductions in waste volume. The regulation consequently embodies a dual policy ambition: waste is simultaneously framed as an environmental problem and as a potential resource. This framing is politically attractive because it promises that an undesirable material can be transformed into something economically valuable. Yet the "waste as resource" narrative can also obscure an important distinction between recovering value from residual waste and creating an economic dependence on continued waste generation. If a facility requires a continuous and substantial feedstock, the infrastructure may have an institutional incentive to maintain waste flows rather than maximize upstream prevention.

This is why the concept of technological lock-in is particularly relevant. Once governments invest in large-scale WtE infrastructure, establish long-term contracts, and organize electricity generation around waste supply, the facility becomes part of the institutional architecture of urban metabolism. The infrastructure then does not merely respond to waste generation; it can influence how waste-management policy is subsequently organized. Research on WtE has warned that reliance on incineration can create tensions with waste prevention and recycling because combustion facilities require predictable waste flows to remain economically viable. The problem is not that every WtE facility necessarily discourages recycling, but that the political economy of large infrastructure can make waste reduction more difficult if it threatens the facility's operational assumptions. The more capital-intensive the infrastructure, the greater the possibility that policy will become organized around maintaining the infrastructure rather than questioning the volume of material entering it.

From this perspective, the most environmentally defensible role for PLTSa is relatively narrow: it should primarily deal with waste that remains after feasible prevention, reuse, recycling, and other higher-order recovery options have been exhausted. This approach is consistent with the waste hierarchy and with the findings of life-cycle research that generally places prevention and reuse above energy recovery (Laurent et al. 2019). The distinction is consequential. Burning a residual fraction that cannot reasonably be recycled is substantially different from burning materials that could have remained within productive material cycles. The former may represent recovery of otherwise lost value; the latter can represent the destruction of material value in exchange for relatively short-lived energy recovery.

The question of material recovery is especially significant for plastics. Plastics contain considerable embodied energy and material value, but their combustion releases fossil carbon. Where recycling is technically and economically feasible, diverting plastic materials toward combustion can therefore produce a trade-off between energy recovery and material recovery. The policy challenge is not to eliminate all thermal treatment, but to determine which fraction of the waste stream should be burned and which fraction should be kept within material cycles. A climate-oriented waste policy that ignores this distinction risks conflating energy recovery with resource efficiency.

1. Air Pollution and the Limits of Technological Optimism

The environmental risks of WtE become particularly visible in relation to air pollution. Modern incinerators are technologically different from older generations, and sophisticated air-pollution-control systems can significantly reduce emissions. This technological development should be acknowledged rather than ignored. However, it does not justify the assumption that combustion is environmentally risk-free. A systematic review of the health literature found evidence of associations between incineration and several adverse health outcomes, while also emphasizing substantial uncertainty resulting from differences in technology, exposure pathways, study design, and the age of facilities (Tait et al. 2020). The authors concluded that older technologies and poor maintenance were more strongly associated with adverse outcomes, while evidence concerning newer facilities remained less conclusive. The appropriate implication is therefore not categorical rejection of incineration but a precautionary and evidence-based regulatory approach.

This distinction matters for Indonesia because technological standards are meaningful only when supported by reliable monitoring and enforcement. A modern incinerator equipped with effective pollution-control technology can have a substantially different environmental profile from an inadequately maintained facility. Yet the presence of technology does not guarantee its effective operation. Pollution-control systems require continuous maintenance, skilled operators, monitoring equipment, reliable electricity and chemical inputs, and institutional capacity to respond when standards are exceeded. Consequently, the environmental performance of a PLTSa facility depends not only on the technology purchased but also on the governance capacity surrounding that technology.

This is why the legal requirement for environmental standards must be complemented by transparency and independent oversight. Communities living near a facility should not be expected to trust emission claims without access to understandable and verifiable monitoring data. Lahl and Zeschmar-Lahl (2018), examining public acceptance in Germany and Indonesia, identify modern air-pollution controls, safe residue disposal, trustworthy government institutions, and independent scientific measurement as important prerequisites for public acceptance. Their argument is significant because it demonstrates that public trust is not merely a communication problem. Trust is produced through institutional performance. Where communities can independently verify environmental claims, the legitimacy of a facility is more likely to increase; where information is opaque, even technically defensible projects may encounter persistent suspicion.

The same principle applies to environmental impact assessment. Environmental assessment should not be understood as a one-time procedural requirement completed before construction. WtE facilities operate for decades, and their environmental performance may change over time because of changes in waste composition, equipment condition, maintenance quality, and surrounding land use. Continuous monitoring is therefore essential. The environmental question is not merely whether a facility was safe when its permit was issued, but whether it remains environmentally safe throughout its operational life.

2. Residual Waste and the Problem of "Zero Waste" Narratives

Another important analytical issue concerns the residual waste produced by thermal treatment. Incineration substantially reduces the volume of municipal waste, but it does not eliminate material residues. Bottom ash and fly ash require further treatment and disposal, while air-pollution-control systems can produce residues containing concentrated contaminants. This means that WtE changes the physical form and location of waste rather than eliminating the need for final management.

This point is frequently overlooked in policy narratives emphasizing waste reduction. A substantial reduction in volume can be environmentally valuable, particularly where landfills are approaching capacity. However, volume reduction and hazard elimination are not equivalent. The smaller quantity of residual material can potentially contain higher concentrations of particular contaminants, requiring specialized management. The environmental assessment of WtE must therefore extend beyond the incinerator itself to the complete chain of transportation, treatment, storage, and final disposal.

This creates the possibility of a second form of pollution distribution. A community may host the combustion facility while another community hosts the final disposal site for ash. In this situation, environmental burdens are distributed across multiple locations rather than concentrated at one facility. Without careful monitoring, the apparent environmental improvement at the original landfill may therefore obscure the creation of new exposure pathways elsewhere.

The issue also reveals a fundamental limitation of the phrase "waste-to-energy." The phrase emphasizes the conversion of waste into a valuable commodity—electricity—while making the remaining material flows less visible. A more complete environmental accounting would consider the entire sequence: *waste generation → collection → transportation → sorting → pretreatment → combustion → electricity generation → air emissions → ash generation → residue treatment → final disposal.*

Each stage has environmental and social consequences. The climate and justice performance of the system therefore depends on the entire chain rather than on the electricity-generation stage alone.

3. Community Acceptance Is Not the Same as Environmental Justice

The question of public acceptance provides another important dimension of the Indonesian experience. Research in Jakarta found that socioeconomic considerations, environmental impacts, and development-related factors significantly shape residents' acceptance of WtE, with socioeconomic factors emerging as particularly influential (Suryawan et al. 2023). This finding suggests that communities do not evaluate WtE exclusively through environmental risk. Employment opportunities, potential income, infrastructure, education, and expectations of local development also influence public attitudes.

A separate choice-experiment study in Jakarta similarly found substantial willingness among residents to support WtE development, particularly when proposals included public awareness, environmental monitoring, and energy generation (Tehupeiory, Septiariva, and Suryawan 2023). This is important because it indicates that community concerns are not necessarily synonymous with opposition to technological development. Communities may support WtE when they perceive credible safeguards and tangible benefits.

However, public acceptance should not be used as a substitute for justice. A community can accept a project under conditions of constrained choice. If residents face inadequate waste infrastructure, pollution from an existing landfill, limited employment opportunities, or weak alternatives for local development, the benefits offered by a WtE project may significantly influence their willingness to accept environmental risks. Acceptance in such circumstances can reflect rational adaptation to existing socioeconomic conditions rather than an absence of environmental concern.

This distinction is particularly relevant when compensation is used as part of project development. Compensation may be appropriate where communities bear measurable costs, but it should not become a mechanism through which environmental risks are effectively purchased from vulnerable populations. The question should therefore be whether compensation accompanies risk prevention and participation, rather than whether compensation substitutes for them.

In this sense, procedural justice is central. Communities need meaningful access to environmental information, opportunities to scrutinize technical claims, participation in facility siting and monitoring, and effective mechanisms for complaints and remediation. The participation provisions contained within Indonesia's waste-management framework provide a legal basis for this approach. Law No. 18 of 2008 explicitly recognizes public participation within waste management, alongside government and business responsibilities. The practical challenge is converting formal participation into substantive influence.

4. PLTSa and the Spatialization of Environmental Inequality

The spatial dimension of WtE reveals the strongest connection between waste management and environmental justice. Urban waste is generated diffusely across households, commercial activities, institutions, and industries, but treatment infrastructure must be located somewhere. Consequently, the environmental costs of urban consumption become spatially concentrated.

This produces an asymmetrical relationship between waste producers and waste hosts. Residents throughout the metropolitan region benefit from the removal of waste from their immediate surroundings. Yet the communities surrounding waste infrastructure may experience more concentrated risks associated with transportation, odors, noise, emissions, and residual waste. The broader metropolitan population therefore benefits from a service whose environmental burdens may be disproportionately localized. The problem becomes more serious when facility locations intersect with socioeconomic inequality. Communities with lower incomes may have fewer opportunities to influence land-use decisions or relocate away from environmentally burdensome infrastructure. They may also depend more heavily on local employment associated with waste facilities, creating a difficult relationship between environmental protection and economic security. This is precisely why environmental justice requires attention to both distribution and recognition.

The Indonesian case illustrates this tension particularly clearly. Benowo, for example, is not simply an energy facility; it emerged within an existing waste-management landscape. Research on the facility indicates that local residents have experienced both perceived environmental improvements and continuing concerns regarding occasional odors and leachate incidents, while also receiving infrastructure and economic benefits (Astuti et al. 2025). The case therefore cannot be classified straightforwardly as either "successful" or "harmful." Its significance lies precisely in the coexistence of environmental improvement, economic benefit, residual risk, and community negotiation.

This complexity is theoretically important. Environmental justice does not require an absence of all environmental infrastructure. Cities need systems for managing waste, wastewater, energy, and transportation. The question is whether these systems are designed and governed so that the communities hosting them are not treated as expendable spaces. A just waste system therefore requires not only technically efficient infrastructure but also fair siting, transparent monitoring, community participation, and meaningful benefit-sharing.

5. The Political Economy of "Green" Waste Infrastructure

The expansion of PLTSa should also be understood within the broader political economy of green development. WtE can attract investment because it creates a hybrid infrastructure linking waste management, electricity production, technology procurement, construction, and long-term operation. This creates economic opportunities for municipalities and private actors while allowing governments to frame waste management as technological modernization.

Yet the language of green infrastructure can make political-economic relationships less visible. The term "green" can suggest that environmental benefits and economic benefits naturally converge. In practice, they may diverge. An investor may benefit from long-term waste supply and electricity contracts, while the municipality benefits from reduced landfill pressure. The community may receive employment and infrastructure, but also bear localized environmental risks. The electricity consumer benefits from energy generation without necessarily experiencing the environmental costs associated with the facility.

The critical question therefore becomes: who captures the economic value created by waste? If waste becomes an energy commodity, households and communities that generate or host the waste infrastructure are not necessarily the principal beneficiaries of the resulting economic value. This raises questions about ownership, electricity pricing, compensation, local employment, taxation, and the distribution of project revenues. Such questions are rarely captured in conventional technical assessments. A life-cycle assessment can calculate greenhouse-gas emissions, energy use, and other environmental indicators, but it cannot by itself determine whether the economic value generated by a project is fairly distributed. Environmental justice consequently requires an additional political-economic analysis.

6. Toward a More Just WtE Policy

The evidence reviewed above suggests that Indonesia does not necessarily face a binary choice between landfills and incinerators. A more appropriate policy approach is hierarchical and differentiated. Organic waste should be directed toward appropriate biological treatment where feasible; recyclable materials should remain within material-recovery systems; hazardous materials require specialized treatment; and only genuinely residual fractions should be considered for thermal energy recovery. Such differentiation is more consistent with the logic of the waste hierarchy than treating mixed municipal waste as a uniform fuel.

This approach also reduces the risk of technological lock-in. If PLTSa is designed specifically around residual waste, the success of upstream recycling and waste reduction does not become a threat to the facility. Instead, decreasing residual waste becomes an indicator of policy success. This reverses the incentive structure: the objective becomes to burn less waste over time, not to maintain a sufficient volume of waste for combustion.

Such a model requires stronger source separation and material recovery. The Indonesian evidence on waste composition indicates why this is technically important. With a large organic fraction and substantial moisture content, mixed municipal waste is not necessarily an ideal combustion feedstock (Wahyono et al. 2021). Sorting can therefore improve both the quality of recoverable materials and the characteristics of residual waste sent to thermal treatment.

The same logic applies to climate accounting. Every PLTSa project should be assessed against a clearly defined counterfactual. At minimum, the assessment should compare the proposed system with realistic alternatives involving landfill management, recycling, composting or biological treatment, and waste prevention. The assessment should account for fossil and biogenic carbon, avoided emissions, transportation, energy substitution, pretreatment, and ash management. Without such comparison, the claim that PLTSa is a climate solution remains incomplete.

Finally, environmental justice requires that the communities closest to WtE facilities become participants rather than passive recipients of environmental risk. Monitoring results should be publicly accessible; independent scientific institutions should be involved where appropriate; complaints should have enforceable follow-up mechanisms; and affected communities should have meaningful opportunities to influence operational and environmental decisions. The evidence from Indonesia indicates that social acceptance is closely connected with communication, perceived benefits, trust, and confidence in environmental safeguards (Lahl and Zeschmar-Lahl 2018; Suryawan et al. 2023).

The broader lesson is that WtE should be judged by the quality of the system surrounding the technology, not by the technology alone. A sophisticated incinerator operating within a weak waste hierarchy can reproduce structural problems. Conversely, a carefully regulated facility treating genuinely residual waste within a system that prioritizes prevention, recycling, transparency, and community participation may have a legitimate role.

Thus, the central policy challenge for Indonesia is not whether PLTSa should exist, but what institutional conditions must govern its existence. These conditions include a clear waste hierarchy, transparent life-cycle assessment, strict emission standards, independent monitoring, safe residue management, meaningful public participation, equitable benefit-sharing, and safeguards against the displacement of environmental burdens onto economically or politically vulnerable communities. Under these conditions, WtE can be treated as one component of an integrated waste-management system. Without them, the language of clean energy risks concealing an older pattern in which the environmental costs of urban consumption are transferred to places and populations with less capacity to resist them.

Toward a Just Waste-to-Energy Transition in Indonesia

The preceding analysis suggests that the central challenge of Indonesia's waste-to-energy (WtE) policy is not the choice between technological optimism and technological rejection, but the construction of an institutional framework capable of ensuring that WtE does not undermine the broader objectives of sustainable waste management. The evidence indicates that WtE can contribute to reducing dependence on landfills and recovering energy from residual waste, but its environmental value depends strongly on the waste stream, technology, energy substitution, and alternative treatment pathway (Astrup et al. 2015; Laurent et al. 2019; Dastjerdi et al. 2020). In the Indonesian context, this condition is particularly important because municipal waste contains substantial organic and moisture fractions, while plastics and other combustible materials also constitute significant components of the waste stream. Research on Indonesian waste characteristics therefore indicates that technological selection cannot be separated from source separation, pretreatment, and the development of an effective material-recovery system (Wahyono et al. 2021). A just WtE transition should consequently begin not with the question of how much waste can be burned, but with the question of how much waste can reasonably be prevented from being generated or recovered through higher levels of the waste hierarchy.

This principle has important implications for how PLTSa should be positioned within Indonesian environmental policy. Waste-to-energy should be treated as a downstream component of waste management rather than as the primary strategy for dealing with increasing waste generation. The distinction is fundamental. If prevention, reuse, recycling, composting, and other recovery strategies are strengthened, the quantity of residual waste available for combustion should decrease. Such a decline should be understood as evidence of policy success rather than as a threat to the economic viability of WtE facilities. By contrast, if a facility requires a continuous and substantial waste supply, there is a possibility that infrastructure investment will create pressure to preserve waste flows. This is the classic problem of technological lock-in: infrastructure established to address a particular environmental problem can subsequently shape the policy environment in ways that make alternative solutions more difficult. The literature on public acceptance also reinforces the importance of maintaining higher-order waste practices. Caferra, D'Adamo, and Morone (2023), for example, found that although WtE can receive public support as an alternative to landfill disposal, such support should not come at the expense of separate collection and more sustainable waste-management practices.

A just transition therefore requires differentiation of waste streams. Organic waste should be considered for biological treatment where technically appropriate; recyclable materials should be directed toward material recovery; hazardous materials require specialized treatment; and only genuinely residual fractions should be considered for thermal treatment. This approach is more consistent with the waste hierarchy than treating mixed municipal solid waste as a homogeneous fuel. It also responds to the technical realities of Indonesian waste. Where high moisture and organic content reduce the calorific value of mixed waste, indiscriminate combustion may require additional energy or pretreatment, potentially reducing the environmental advantage of the technology. A more selective system, by contrast, could improve the quality of both recyclable materials and the residual fuel fraction. The environmental objective would therefore shift from maximizing waste throughput to minimizing residual waste while recovering value from materials that remain.

The second condition concerns life-cycle climate assessment. The environmental legitimacy of PLTSa should not be established by measuring electricity production alone. A comprehensive assessment must include emissions from collection and transportation, sorting and pretreatment, combustion, auxiliary energy use, the fossil-carbon component of waste, avoided landfill emissions, displaced electricity generation, and the treatment and disposal of combustion residues. This is consistent with the broader life-cycle literature, which shows that WtE performance varies substantially depending on system boundaries and assumptions concerning energy substitution and alternative waste-management pathways (Astrup et al. 2015; Laurent et al. 2019). The Indonesian evidence strengthens this argument. A 2024 life-cycle and techno-economic assessment modeled WtE incineration for Java and evaluated environmental impacts across multiple waste categories, demonstrating the importance of considering the full waste-management chain rather than treating combustion as an isolated process. The policy implication is straightforward: no PLTSa facility should be labeled a climate solution without demonstrating a net environmental advantage over realistic alternatives.

The third condition is strict and continuous pollution control. Modern incineration technology can substantially reduce emissions compared with older generations of waste incinerators, but technological sophistication does not eliminate the need for monitoring, maintenance, enforcement, and transparency. A systematic review by Tait et al. (2020) found evidence of adverse health outcomes associated with waste incineration, while also emphasizing that newer technologies may reduce exposure and that differences in facility age, operating conditions, and methodological quality complicate definitive conclusions. The appropriate policy response is therefore neither to claim that modern WtE is inherently dangerous nor to assume that technological modernization makes health concerns irrelevant. Instead, regulation should follow a precautionary and continuously monitored approach. Emission standards must be accompanied by real-time or frequent monitoring, independent verification, transparent publication of data, and enforceable consequences for non-compliance.

This is particularly important because public confidence is inseparable from environmental governance. Lahl and Zeschmar-Lahl (2018), examining experiences in Germany and Indonesia, argue that public acceptance depends partly on modern air-pollution-control technology, safe residue management, credible government institutions, and independent scientific measurement. This finding has a broader significance for Indonesia. Public resistance should not automatically be interpreted as a knowledge deficit that can be solved through government communication. In many circumstances, distrust may be a rational response to uncertainty, incomplete information, or weak institutional accountability. Consequently, transparency should be treated as an environmental safeguard rather than simply a public-relations strategy.

The fourth condition concerns meaningful community participation. Indonesian research demonstrates that public acceptance of WtE is influenced by socioeconomic expectations, perceptions of environmental impacts, and anticipated development benefits. Suryawan et al. (2023), studying Jakarta residents, found that socioeconomic considerations were particularly important in shaping acceptance, while education and potential project income influenced preferences toward WtE. Tehupeiory, Septiariva, and Suryawan (2023) similarly found that respondents showed willingness to support WtE development when accompanied by greater awareness, environmental monitoring, and tangible improvements in waste processing and energy production. These findings suggest that communities are not necessarily opposed to WtE. Rather, their support depends on whether they perceive the technology as credible, beneficial, and adequately regulated.

Nevertheless, acceptance cannot be equated with justice. A community may support a facility because it offers employment, infrastructure, compensation, or relief from an existing landfill problem. Such support may be entirely rational, but it does not eliminate the need to examine whether the community has meaningful influence over the project. Participation becomes substantive only when residents have access to relevant information, sufficient time and technical capacity to evaluate proposals, opportunities to contest environmental assessments, and mechanisms through which their concerns can alter project design or operation. The distinction between consultation and participation is therefore critical. A process in which government or investors have already made the essential decisions before residents are consulted is procedurally weaker than a process in which affected communities can influence the substance of the decision.

The fifth condition concerns equitable distribution of benefits and burdens. This is arguably the most difficult issue because WtE produces benefits that are geographically broad while environmental risks may be geographically concentrated. Electricity generated by a PLTSa facility can serve a large metropolitan population, while the facility itself may be located within or adjacent to a relatively small community. Residents near the facility may experience traffic, noise, odors, infrastructure pressure, or concerns about air emissions and residual waste. The broader population benefits from waste removal without necessarily experiencing these localized burdens. This creates a distributive problem that cannot be resolved simply by demonstrating that the facility provides electricity.

The Indonesian case of Benowo is instructive because it demonstrates that environmental, social, and economic outcomes can coexist. Research on community perceptions indicates that initial concerns were mitigated through communication, compensation, and infrastructure improvements, contributing to greater local acceptance. The significance of this experience lies not in proving that compensation solves environmental-justice problems, but in demonstrating that local socioeconomic conditions shape how communities evaluate environmental infrastructure. Compensation and development benefits can improve acceptance, but they should supplement rather than replace pollution prevention, participation, and long-term environmental monitoring.

The distributional question should therefore be broadened beyond compensation. A more just WtE system should ask whether host communities receive durable and proportional benefits. These could include local employment, investment in public infrastructure, health and environmental monitoring, community development funds, preferential access to relevant economic opportunities, and transparent reporting of project revenues and environmental performance. At the same time, communities should not be expected to accept environmental risks simply because financial compensation is offered. The principle should be benefit-sharing plus risk minimization, rather than compensation as a substitute for environmental protection.

The sixth condition is recognition justice. Waste infrastructure is often discussed through technical categories—tonnes per day, calorific value, megawatts, emissions, and operating efficiency. Yet communities experience the infrastructure through everyday life: traffic, odors, changes in land use, employment opportunities, health concerns, and perceptions of dignity and territorial identity. A community should therefore not be treated merely as a "stakeholder" whose opinion must be collected before a project proceeds. It should be recognized as a rights-bearing political community with legitimate knowledge concerning the social and environmental consequences of development.

This perspective is especially important for waste workers and other groups whose livelihoods are connected to existing waste systems. A transition from landfill-based disposal toward formalized WtE can change the economic structure of waste management. If informal waste pickers depend on recyclable materials extracted from municipal waste, increased source separation or direct combustion can affect their livelihoods. Consequently, a just transition must consider not only residents living near facilities but also workers whose economic activities are transformed by changes in waste infrastructure. Otherwise, the formalization of waste management may produce environmental improvements while simultaneously displacing economically vulnerable workers.

The seventh condition is safe and accountable residue management. WtE should never be evaluated solely at the point where electricity leaves the facility. Bottom ash, fly ash, and other residues remain part of the waste-management chain. Their treatment and final disposal must therefore be subject to strict environmental standards and monitoring. This is also important for public acceptance. Lahl and Zeschmar-Lahl (2018) identify safe residue disposal as one of the prerequisites for public confidence in WtE facilities. If communities are asked to accept combustion on the grounds that waste is being "eliminated," but residues subsequently require disposal in other communities, the policy merely shifts the geographical location of waste burdens.

A genuinely integrated policy should therefore establish a traceable residue-management chain. Authorities should know how much ash is generated, what its composition is, how it is treated, where it is transported, and where it is ultimately disposed of or reused. These data should be publicly available. Such transparency is particularly important because environmental burdens may otherwise become invisible once waste leaves the WtE facility. Environmental justice requires visibility across the entire waste chain, not simply at the point of combustion.

The final condition is institutional accountability. The effectiveness of WtE depends not only on the engineering design of facilities but also on the capacity of government institutions to enforce standards. Regulations concerning waste, environmental quality, electricity generation, and spatial planning involve multiple administrative actors. Fragmentation among these institutions can create gaps in responsibility. A facility may comply with one regulatory requirement while generating concerns under another institutional framework. For this reason, WtE governance should integrate waste management, environmental protection, public health, energy policy, and spatial planning rather than treating them as separate administrative domains.

Spatial planning is particularly important because the location of a PLTSa facility can determine the distribution of environmental exposure for decades. Decisions about siting should therefore incorporate population density, existing pollution sources, transportation patterns, ecological sensitivity, socioeconomic vulnerability, and cumulative environmental burdens. This is not merely a technical exercise. It is a question of spatial justice because the location decision determines which community will host the infrastructure and therefore experience its localized consequences.

Taken together, these conditions suggest that Indonesia requires a justice-oriented WtE governance model rather than a simple technology-deployment model. Such a model would have at least six interconnected components: waste hierarchy, life-cycle climate assessment, strict pollution control, transparent monitoring, meaningful participation, and equitable benefit-sharing. These components should operate throughout the project life cycle—from planning and environmental assessment to construction, operation, monitoring, and eventual closure or technological replacement.

The significance of this framework extends beyond PLTSa itself. It challenges a broader tendency within climate policy to define successful transitions primarily through infrastructure deployment and technological indicators. A facility can generate electricity and reduce landfill use while still reproducing inequalities if the costs are concentrated among communities with limited political influence. Conversely, a technology can become more socially legitimate when its environmental risks are minimized, its benefits are fairly distributed, and affected communities participate meaningfully in governance.

The central policy principle should therefore be “residual waste first, justice always.” WtE should receive waste only after feasible higher-order recovery options have been considered, while every stage of the technology should remain subject to environmental and social accountability. Such an approach avoids the false choice between technological development and environmental protection. It recognizes that technology can be useful, but only when embedded within institutions capable of controlling its risks and distributing its benefits fairly.

Ultimately, the Indonesian WtE transition should be evaluated not by how rapidly the country can construct incineration facilities, but by whether those facilities contribute to a fundamentally better waste system. A successful transition would mean less waste generation, stronger material recovery, safer treatment of residual waste, lower environmental exposure, transparent governance, and greater protection for communities and workers. Under these conditions, WtE can occupy a limited but legitimate role within Indonesia's environmental and climate strategy. Without them, the technology risks becoming another mechanism through which the environmental costs of urban consumption are displaced onto communities with less power to resist them.

Is Waste-to-Energy Really a Just Climate Solution?

The preceding analysis demonstrates that the environmental value of waste-to-energy (WtE) cannot be determined by technology alone. The central issue is the configuration of the waste-management system in which the technology operates. International life-cycle research has long shown that the environmental performance of incineration varies according to waste composition, energy efficiency, the treatment of residues, electricity displacement, and the alternative scenario against which incineration is evaluated (Astrup et al. 2015; Laurent et al. 2019). This is particularly relevant to Indonesia, where municipal waste contains substantial organic and moisture fractions alongside plastics and other combustible materials. Research on Indonesian municipal waste consequently cautions against treating the entire waste stream as a homogeneous energy resource (Wahyono et al. 2021). The implication is fundamental: the existence of waste does not automatically establish the environmental justification for burning it. WtE becomes more defensible when applied to genuinely residual waste after higher-value prevention, reuse, recycling, and biological-treatment options have been considered.

From a climate-policy perspective, this distinction exposes a weakness in the increasingly common narrative that WtE is inherently a form of clean or renewable energy. The technology can generate electricity while simultaneously producing greenhouse-gas emissions, particularly when fossil-derived materials such as plastics are combusted. Life-cycle analyses therefore emphasize that the relevant comparison is not between "WtE" and "nothing," but between alternative waste-management pathways (Astrup et al. 2015; Laurent et al. 2019). If WtE replaces an uncontrolled landfill that generates substantial methane emissions, it may produce an important environmental benefit. If it instead replaces high-quality recycling or material recovery, the climate and resource implications may be less favorable. Consequently, claims concerning the climate benefits of PLTSa should always be based on a transparent counterfactual scenario. Without this comparison, the label "climate solution" risks becoming a technological assumption rather than an empirically demonstrated conclusion.

The Indonesian regulatory framework provides a useful foundation for this differentiated approach. Law No. 18 of 2008 establishes waste reduction and waste handling as interconnected elements of national waste policy, while Presidential Regulation No. 97 of 2017 establishes national and regional strategies for household waste reduction and management. Presidential Regulation No. 35 of 2018 subsequently accelerated environmentally friendly waste-processing facilities capable of producing electricity. These instruments should not be interpreted as establishing combustion as the highest priority within the waste system. Rather, PLTSa should be understood as one possible downstream treatment technology within a hierarchy that continues to prioritize reduction and recovery. The distinction is crucial because large-scale WtE infrastructure can generate path dependency: once substantial capital, contracts, and institutional arrangements have been committed to combustion, reducing the amount of waste available to the facility may become economically and politically difficult.

This possibility creates a fundamental tension between waste reduction and waste throughput. A successful waste-reduction policy should decrease the amount of residual waste entering treatment facilities. However, a capital-intensive WtE plant requires a sufficiently stable feedstock to operate economically. The potential conflict is therefore structural rather than merely operational. If the financial viability of a facility depends upon a guaranteed volume of waste, there may be pressure to maintain waste supply even when higher-order waste-management policies are beginning to reduce it. This concern has also appeared in the broader WtE literature, where scholars have questioned whether dependence on continuous waste flows can weaken incentives for prevention and recycling. Caferra, D'Adamo, and Morone (2023), for example, demonstrate that public acceptance of WtE exists alongside concerns about the implications of the technology for broader waste-management behavior. The appropriate policy response is therefore to design PLTSa around residual-waste treatment rather than waste-generation targets.

A justice-oriented approach also changes how the success of WtE should be measured. Conventional assessments tend to emphasize tonnes of waste processed, megawatts generated, landfill volume avoided, or operational efficiency. These indicators are useful but insufficient. An environmental-justice assessment must additionally ask: Who receives the benefits? Who experiences the risks? Who participates in decision-making? Whose knowledge is recognized? And who has the institutional capacity to demand remediation when something goes wrong? These questions move the analysis from technological efficiency toward distributive, procedural, and recognition justice.

Recent empirical research from Indonesia illustrates why this broader framework is necessary. Astuti et al. (2025), examining the Benowo WtE facility in Surabaya, found that the project generated perceived environmental and socioeconomic benefits, including cleaner surroundings, infrastructure development, economic opportunities, and green jobs, while residents continued to report occasional odors and concerns relating to environmental impacts. The significance of the Benowo case is precisely that its outcomes cannot be classified simply as either positive or negative. The facility simultaneously produces benefits, risks, acceptance, and continuing environmental concerns. A sophisticated environmental-justice analysis must be capable of recognizing these contradictory outcomes rather than reducing the case to a binary judgment.

The same evidence also demonstrates why social acceptance is not equivalent to environmental justice. Acceptance can increase when residents receive compensation, infrastructure, employment opportunities, or improvements in their physical surroundings. These benefits are important and should not be dismissed. However, a community's willingness to accept a facility does not establish that the decision-making process was fully participatory or that environmental risks are equitably distributed. Indeed, acceptance may partly reflect the socioeconomic context within which communities make decisions. Where employment and infrastructure opportunities are limited, a project offering these benefits may understandably be viewed positively even when environmental concerns remain. Justice therefore requires analysis of the conditions under which consent or acceptance is produced.

This distinction becomes particularly important in the context of compensation. Compensation can play a legitimate role in addressing unavoidable impacts, but it should not become a mechanism through which environmental risk is effectively transferred to communities with fewer economic alternatives. A community should not be placed in the position of choosing between environmental protection and basic economic opportunities. A just approach instead requires risk minimization before compensation, followed by equitable benefit-sharing where residual impacts remain. Compensation should therefore supplement environmental safeguards, not substitute for them.

The evidence concerning public acceptance also supports the importance of trust and institutional credibility. Lahl and Zeschmar-Lahl (2018), comparing experiences in Germany and Indonesia, emphasize the importance of modern pollution-control technology, safe residue management, trustworthy government institutions, and independent scientific measurement in generating public confidence. This is consistent with broader research on contested environmental infrastructure, which shows that public acceptance is influenced not only by perceptions of technology but also by trust in institutions, procedural fairness, and expectations concerning local benefits and risks. Wьstenhagen, Wolsink, and Bьrer (2007) similarly distinguish between community acceptance, socio-political acceptance, and market acceptance in the development of renewable-energy technologies. These distinctions are useful for WtE because a project may be politically authorized and economically viable while still lacking strong local legitimacy.

The health dimension further complicates the climate narrative. Waste incineration has undergone substantial technological improvement, particularly in relation to emission-control systems. It would therefore be inaccurate to equate modern regulated WtE facilities with poorly controlled historical incinerators. At the same time, the scientific literature does not justify ignoring health concerns. Tait et al. (2020), in a systematic review of health impacts associated with waste incineration, identified evidence of associations with several adverse outcomes while emphasizing uncertainty arising from differences in technology, exposure, facility age, and study design. The appropriate conclusion is therefore one of qualified precaution: modern technology can reduce environmental exposure, but continuous monitoring and strong regulatory enforcement remain necessary.

This has direct implications for Indonesian environmental governance. Regulatory compliance should be treated as a minimum requirement rather than as evidence that all environmental-justice concerns have been resolved. An emission standard defines a legally acceptable level of pollution; it does not answer the distributional question of who bears the remaining risk. Two facilities operating within the same regulatory limits may nevertheless produce different justice outcomes depending on population density, socioeconomic vulnerability, existing pollution levels, and the availability of alternative sites. This means that environmental regulation should incorporate not only pollution standards, but also spatial and cumulative-impact considerations.

The issue of cumulative impact is particularly important because communities surrounding waste facilities may already be exposed to multiple environmental pressures. A PLTSa facility should not be assessed as though it were the only source of environmental exposure in a particular area. Existing landfills, industrial facilities, traffic, wastewater infrastructure, and other activities may collectively contribute to local environmental burdens. An additional facility that appears acceptable when assessed in isolation could become problematic when its impacts are added to existing pressures. Environmental impact assessment should therefore move beyond a project-by-project approach toward a more comprehensive assessment of cumulative environmental burdens.

The distribution of benefits and risks is equally important at the metropolitan scale. Waste is generated throughout cities, but treatment facilities are spatially concentrated. This produces a form of metropolitan environmental asymmetry: the benefits of waste removal are distributed across a broad population, while certain environmental costs are concentrated around the host location. This is not unique to WtE; similar patterns occur with landfills, wastewater treatment facilities, ports, highways, and other forms of essential infrastructure. However, the WtE debate makes the asymmetry particularly visible because the facility is often promoted as benefiting the entire city through both waste reduction and energy production.

This spatial asymmetry raises a normative question: Why should particular communities bear localized environmental risks for a service consumed by an entire metropolitan population? There is no simple answer. Essential infrastructure must be located somewhere, and complete elimination of local impacts may be impossible. Environmental justice therefore does not necessarily require equal exposure in every location. Rather, it requires that the siting decision be justified, alternatives be seriously considered, affected populations be meaningfully involved, risks be minimized, and benefits be fairly distributed. The principle is not "no one may ever host environmentally burdensome infrastructure"; it is "no community should be treated as environmentally expendable."

The Indonesian evidence from Benowo is particularly valuable in this respect because it demonstrates that local communities can experience both material benefits and environmental concerns simultaneously. Astuti et al. (2025) report improvements in local infrastructure and economic opportunities alongside concerns regarding odors and occasional environmental incidents. This suggests that environmental justice cannot be reduced to identifying whether a project produces "more benefits than harms." Such an aggregate calculation can conceal unequal distribution. A project could produce substantial net benefits for a city while still imposing disproportionate burdens on a small population.

A stronger analytical framework therefore combines distributive justice, procedural justice, and recognition justice. Distributive justice examines the allocation of benefits and burdens. Procedural justice examines who participates in decisions and whether participation can influence outcomes. Recognition justice examines whose interests, identities, experiences, and forms of knowledge are taken seriously. Together, these dimensions provide a more complete account of the legitimacy of WtE infrastructure than technical performance alone.

This framework also changes how communities should be represented in environmental decision-making. Residents should not be treated simply as potential sources of opposition that must be persuaded to accept a project. Their concerns may contain valuable information about local environmental conditions that cannot be fully captured by technical models. Odors, traffic patterns, seasonal flooding, informal waste practices, and changes in local livelihoods may be experienced by residents long before they become visible within formal monitoring systems. Meaningful participation can therefore improve not only democratic legitimacy but also the epistemic quality of environmental governance.

The same principle applies to informal waste workers. Indonesia's waste economy involves workers whose livelihoods depend on collecting, sorting, and recovering recyclable materials. A transition toward centralized WtE can alter the flow of recyclable materials and potentially displace some informal economic activities. Consequently, the justice question should include not only the residents surrounding the facility but also workers whose livelihoods are embedded in the existing waste system. A transition that reduces landfill dependence while eliminating vulnerable workers' income without compensation or alternative employment would represent an incomplete form of environmental modernization.

The climate-transition narrative must therefore be expanded from technological substitution to social transformation. The purpose of a just transition is not merely to replace one technology with another, but to ensure that the environmental benefits of the transition do not depend upon the sacrifice of particular groups. In the WtE context, this means integrating waste pickers, local residents, municipal workers, recyclers, and other affected actors into the transition strategy. Their participation should extend beyond consultation toward the design of employment, recycling, monitoring, and community-benefit programs.

Another critical issue is producer responsibility. WtE places substantial attention on the management of waste after it has been generated, but many environmental burdens originate upstream in production and consumption decisions. If producers continue to introduce difficult-to-recycle packaging and short-lived products into the market, downstream waste facilities—including PLTSa—will face increasing pressure. A just waste system should therefore distribute responsibility across the entire product life cycle rather than placing primary responsibility on municipalities and communities.

This argument reinforces the importance of extended producer responsibility, source separation, packaging redesign, and circular-economy policies. WtE may have a legitimate role for materials that remain genuinely residual after these measures, but it should not become a substitute for producer responsibility. Otherwise, the costs of managing unsustainable consumption patterns remain concentrated at the municipal and community levels while the economic benefits of production are captured upstream.

The broader political-economic implication is that WtE can either reinforce or challenge the linear economy. In a linear model, resources are extracted, transformed into products, consumed, and discarded. WtE changes the final stage by recovering energy from discarded materials, but it does not necessarily challenge the earlier stages. A circular model instead seeks to retain materials and value within economic systems for as long as possible. From this perspective, the key question is whether PLTSa contributes to managing unavoidable residuals or becomes a technological endpoint that allows linear production and consumption patterns to continue largely unchanged.

The distinction is especially significant in climate policy. A technology may reduce emissions relative to one waste-management option without addressing the structural drivers of resource consumption. Climate mitigation should therefore not be assessed only through avoided emissions at the end of the waste chain. It should also consider material efficiency, resource extraction, production, consumption, and recycling. WtE can provide a useful downstream function, but it cannot by itself constitute a comprehensive circular or low-carbon strategy.

The strongest interpretation of the Indonesian evidence is consequently conditional support with institutional safeguards. There is insufficient basis to argue that WtE is inherently incompatible with environmental justice. At the same time, there is equally insufficient basis to characterize every PLTSa facility as a climate solution simply because it generates electricity and reduces landfill volume. The environmental outcome depends on what is burned, how it is burned, what it replaces, where the facility is located, how emissions are controlled, how residues are managed, and how affected communities participate in governance.

The distinction between "waste-to-energy" and "energy-from-waste" is therefore conceptually useful. The former emphasizes the transformation of waste into an energy commodity; the latter can be understood as a narrower residual-waste recovery function. A justice-oriented policy should favor the second interpretation: energy recovery is a secondary function of residual-waste management rather than the principal justification for generating or maintaining waste flows.

The Indonesian WtE debate is a test of whether climate and environmental governance can move beyond technological solutionism. Technological solutionism assumes that complex social and ecological problems can be resolved primarily through better technologies. Yet the evidence reviewed here suggests that WtE raises questions that technology alone cannot answer: who should pay for waste management, who should host infrastructure, who should benefit from energy production, whose health should receive priority, who participates in decision-making, and who bears responsibility for waste generated by consumption.

A just WtE transition therefore requires a different starting point. Instead of asking "How can Indonesia convert more waste into electricity?", policy should ask "How can Indonesia minimize waste generation, maximize material recovery, safely manage unavoidable residuals, and ensure that no community bears a disproportionate share of the environmental costs?" Under that framework, WtE may remain part of the solution—but only as one component of a broader transformation in which prevention, circularity, environmental protection, and democratic participation remain the primary objectives. The ultimate measure of success should consequently be whether Indonesia can reduce the amount of waste requiring combustion over time while simultaneously improving the environmental and social performance of the residual-waste system. If that occurs, PLTSa can function as a limited transitional technology within a more circular waste economy. If waste volumes continue to grow while combustion capacity expands to absorb them, the country may achieve technological modernization without achieving ecological transformation. The difference between these two futures is not determined by the incinerator itself. It is determined by governance, accountability, distribution, and the political willingness to place environmental justice at the center of the transition.

Conclusion

Waste-to-energy (WtE) should not be regarded as an inherently clean or inherently harmful technology. Its climate and environmental value depends on the broader waste-management system in which it operates, including waste composition, energy efficiency, alternative treatment pathways, emissions control, and residual-waste management (Astrup et al. 2015; Laurent et al. 2019). In

Indonesia, where municipal waste contains substantial organic, moisture, plastic, and other mixed fractions, the assumption that all waste constitutes an efficient energy resource is problematic. PLTSa can provide benefits by reducing dependence on landfills and recovering energy from genuinely residual waste, but these benefits should be demonstrated through life-cycle assessment rather than assumed from electricity generation alone. Most importantly, WtE should remain subordinate to waste prevention, reuse, recycling, and other higher-order strategies rather than becoming an incentive for maintaining high volumes of waste.

The analysis further demonstrates that the question of WtE is fundamentally a question of environmental justice. The benefits of waste removal and electricity generation can extend across an entire metropolitan area, while environmental risks associated with emissions, transportation, odors, and residual waste may be concentrated in particular communities. Indonesian evidence shows that local socioeconomic benefits, infrastructure, communication, and perceived environmental improvements can increase acceptance of WtE, while concerns about pollution and environmental safety may persist (Lahl and Zeschmar-Lahl 2018; Suryawan et al. 2023; Astuti et al. 2025). Therefore, community acceptance cannot substitute for justice. A legitimate WtE system requires transparent monitoring, meaningful participation, equitable benefit-sharing, protection of public health, recognition of affected communities and waste workers, and effective mechanisms for accountability and remediation. Without these safeguards, WtE risks reproducing the same unequal distribution of environmental burdens that has historically characterized urban waste management.

Therefore, Indonesia's challenge is not simply whether to burn waste, but how to construct a waste system that produces less waste, retains more materials in productive use, and manages unavoidable residuals without transferring disproportionate risks to vulnerable communities. WtE may have a limited role within such a system, particularly where it treats genuinely residual waste and demonstrates a clear life-cycle environmental advantage over realistic alternatives. It should, however, be governed as a component of a broader just transition rather than as a stand-alone climate technology. A climate solution becomes socially and environmentally credible only when its benefits are real, its risks are minimized, its burdens are fairly distributed, and the communities affected by its operation possess meaningful power to participate in and challenge the decisions that shape their environment.

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