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Waste to energy in Indonesia: opportunities and challenges

Ni Putu Wulan Romianingsih [1*]

[1] School of Environmental Science, Universitas Indonesia; Jakarta, Indonesia.
* Correspondence: wulanromia@gmail.com

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Abstract
Municipal solid waste management ideally targets reducing the volume of waste stockpiled while recovering as many resources as possible because waste is one of the renewable and biomass energy sources that can generate electricity through the conversion process. Utilizing waste-to-energy (WTE) is one of the waste processing methods recommended by the Indonesian government. As a renewable energy, waste has unlimited availability to be an alternative to fossil fuels. This study aims first to describe the legal basis and policy of WTE in Indonesia; second, to analyze the potential of waste as renewable energy in Indonesia; third, to identify the 2030 SDGs that may be achieved following the WTE Plant installation; fourth, to analyze the challenges in developing WTE in Indonesia. This study is a literature review on secondary data obtained from the Google Scholar and Scopus academic databases. Seeing the characteristics of waste in Indonesia, WTE can be done by thermal or biochemical conversion methods. Both of these methods require pre-processing because the quality of Indonesian waste still needs to improve, which is characterized by high water content and needs to be sorted appropriately.
Keywords: management; renewable energy; rubbish; waste to energy

1. Introduction

Indonesia has the fifth largest population globally, with 270.20 million people in the 2020 census (Central Bureau of Statistics, 2021). Indonesia's economy also grew by 3.24% in the third quarter of 2021. With population growth and an improving economy, Indonesia's waste production has also increased and reached 91,324.49 tons per day. However, this is accompanied by more than adequate infrastructure development. Waste management techniques in cities in Indonesia are still carried out conventionally, using the open dumping method (60%) and the sanitary landfill (10%) (Damayanti et al., 2021; Hermawan, 2017; Ministry of Energy and Mineral Resources, 2015). Even though Law. 18 of 2018 requires all TPA and TPA to be converted into sanitary TPA; only a few cities adhere to the rules. Waste that is not managed correctly creates significant social, environmental, and health problems (Cucchiella et al., 2017; Jambeck et al., 2015; Kaplan et al., 2009; Verma et al., 2016). The decomposition of waste in open landfills contributes to CO2 and CH4 emissions in the form of greenhouse gases which cause global warming.

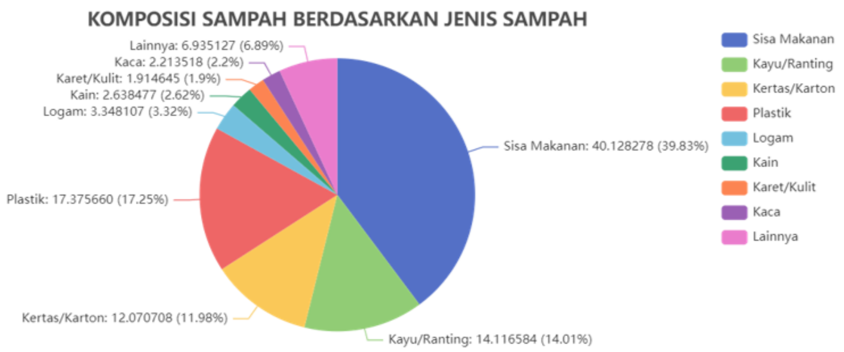
Contrary to the fact that waste is a problem, waste is a source of biomass and renewable energy that can generate electricity through a conversion process (Ministry of Energy and Mineral Resources, 2015; Saraswati et al., 2021; Tozlu et al., 2016). Municipal solid waste management ideally targets reducing the volume of waste stockpiled while recovering as many resources as possible (Arafat et al., 2015). The utilization of waste for energy is one way of processing waste recommended by the Indonesian government. As a renewable energy, waste has unlimited availability to be an alternative to fossil fuels.
Indonesia has the potential to produce 2,066 MW of electricity from urban waste. However, until now, there has been no commercial WTE Plant facility operating in Indonesia, except

for the 100 tons/day pilot WTE Plant facility in Bantargebang and the development of a 2,200 tons/day incinerator in Sunter as the first commercial WTE Plant. (Damayanti et al., 2021; Hermawan, 2017). This indicates that there is still much potential for electricity from biomass that needs to be utilized. Therefore, this study aims to:

1. Describe the legal basis and WTE policies in Indonesia,
2. Analyze the potential of waste as renewable energy in Indonesia,
3. Identify the 2030 sdgs that may be achieved following the WTE Plant installation, and
4. Analyze the challenges in developing WTE in Indonesia.

The municipal waste consists of household, market, yard, and street waste, which can be solid, liquid, or gaseous (Moya et al., 2017; Ogunjuyigbe et al., 2017). Small amounts of industrial and construction waste can sometimes end up in municipal solid waste (Cheng et al., 2007). The waste generation rate is strongly influenced by population and income, as well as the level of industrialization, the socio-economic status of residents, and the dominant type of commercial activity in the area (Malinauskaite et al., 2017).

A report from the World Bank estimates that currently, 2.01 billion tonnes of waste is generated annually worldwide, and by 2050, this amount will increase to 3.40 billion tons per year (Kaza et al., 2018). Indonesia produces 91,324.49 tons of waste per day, or the equivalent of 33,333,439.86 tons per year, which will increase yearly (KLHK, 2021). Indonesians are estimated to generate 0.68 kg of waste per capita per day (Kaza et al., 2018). Furthermore, as presented in Figure 1, the national waste composition is dominated by food waste (39.83%), plastic (17.25%), wood/branches (14.01%), and paper/carton (11.98%), where most of this waste is generated in the household (46.07%) and market (22.19%).



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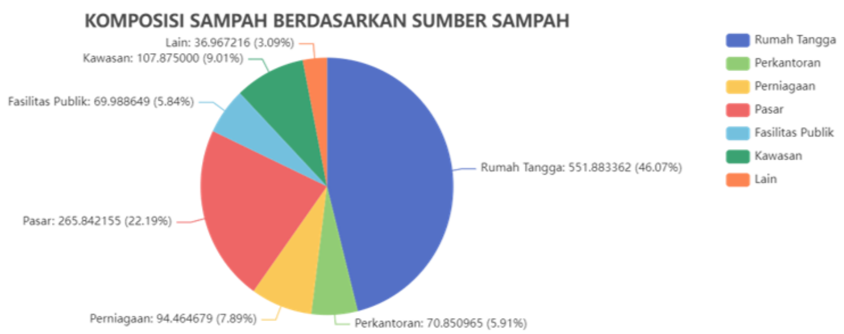

b

Figure 1. Indonesia's solid waste composition based on (a) type and (b) source

Urban waste that is not managed correctly causes significant environmental, health, and socio-economic impacts in Indonesia. The identified impacts include greenhouse gas emissions, environmental pollution (water, air, soil), the spread of water and airborne diseases, and disturbance to domestic animals and wildlife biodiversity, both on land and sea (Cucchiella et al., 2017; Jambeck et al., 2015; Kaplan et al., 2009; Verma et al., 2016).

Waste management is a systematic, comprehensive, and sustainable activity that reduces and handles waste (UU No. 18 of 2008). Municipal waste management options are often presented through a "waste hierarchy" (Figure 2), which was introduced by the European Union through the EU Framework Directive on Waste in 1975 (Jamas & Nepal, 2010) and then widely adopted by other countries in the world, including Indonesia. This hierarchy places prevention at the top and removal at the bottom. This hierarchy serves as flexible principles rather than rigid requirements for waste policies.

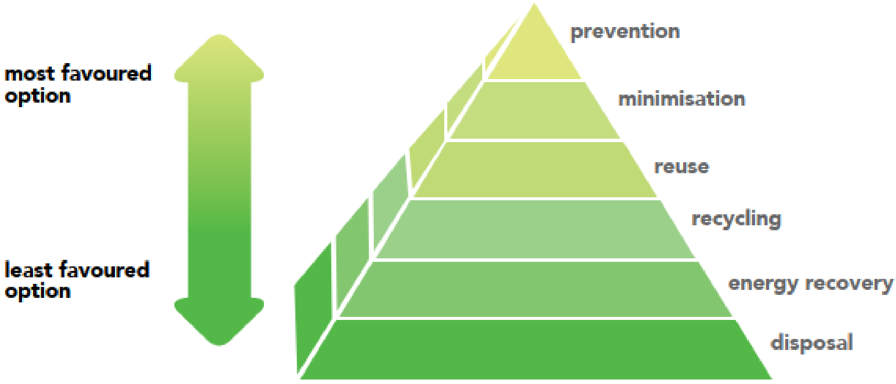

Figure 2. Hierarchy of waste management
Source: Ministry of Energy and Mineral Resources, 2015

Waste management techniques in cities in Indonesia are still carried out conventionally, using the open dumping method (60%) and the sanitary landfill (10%) (Damayanti et al., 2021; Hermawan, 2017; Ministry of Energy and Mineral Resources, 2015). Other techniques are burning (5%), recycling (7.5%), and not handling 8.5% (Damayanti et al., 2021; Hermawan, 2017). It can be concluded that national waste management is still in the low category, dominated by disposal.

Municipal solid waste management should target reducing the volume of waste stockpiled while recovering as many resources as possible (Arafat et al., 2015). Following the hierarchy in waste management, shown in Figure 2, energy recovery, another term for WTE, is the treatment chosen after efforts to reduce and utilize waste have been carried out. The waste management hierarchy also shows that WTE is prioritized over landfill waste. Furthermore, WTE facilities can be grouped as a form of waste processing facility and can also be applied to landfill sites.

There has been a global paradigm shift from viewing waste as waste material to becoming a resource (Cucchiella et al., 2017; Makarichi et al., 2018; G Tyler Miller & Spoolman, 2016; Scarlat et al., 2019). Municipal waste has great potential for material and energy recovery (Arafat et al., 2015). Thus, WTE has the advantage of producing electrical energy and minimizing the waste that is stockpiled.

There are three basic types of WTE technology (Ministry of Energy and Mineral Resources, 2015; Sarasati et al., 2021; Tozlu et al., 2016): (i) thermal conversion methods (incineration, pyrolysis, and gasification), (ii) landfill gas, and (ii) biochemical conversion. In thermal conversion technology, incineration is the most widely used method (Brunner & Rechberger, 2015; MEMR, 2015; Perrot & Subiantoro, 2018; Scarlat et al., 2019; Xin-Gang et al., 2016). The "Incineration" method is known as "mass combustion" at high temperatures (850°C – 1200°C), where the heat from the combustion process is used to convert water into hot steam, which is then used to drive a steam turbine generator to produce electricity (Jain et al., 2014). The burning method can reduce around 80% of the total waste volume (Jain et al., 2014; Ministry of Energy and Mineral Resources, 2015; Tozlu et al., 2016). The second method of thermal conversion, "gasification," is a process that converts municipal waste into syngas, which occurs by reacting the waste at high temperatures (>700 °C), without combustion, with controlled amounts of oxygen and steam and producing flammable gas (syngas), such as CO, CO2, H2O, char, tar, and H2 (Perrot & Subiantoro, 2018; Rajaeifar et al., 2017). A derivative of gasification is pyrolysis technology, where partial combustion is held at a lower temperature than gasification under anaerobic conditions to produce bio-oil that can be used as fuel for power plants (Ministry of Energy and Mineral Resources, 2015; Perrot & Subiantoro, 2018; Tozlu et al., 2016). The potential for waste reduction by incineration, gasification, and pyrolysis is 80 – 90% (Ministry of Energy and Mineral Resources, 2015).

The second type of WTE technology is biochemical conversion using the anaerobic digester (AD) method. This method decomposes organic matter in sewage under the influence of microbes in an anaerobic environment to produce biogas. The chemical reaction here is similar to that in landfill gas. The difference is the higher CH4 composition and lower CO2 composition and digestate as one of the by-products (Perrot & Subiantoro, 2018). Methane can power internal combustion engines for electricity generation, and digestate is a nitrogen-rich fertilizer (Ogunjuyigbe et al., 2017).

This article will discuss WTE with thermal and biochemical conversion technologies. Landfill gas (LFG) was not included in the discussion for several reasons (Ferraz de Campos et al., 2021; MEMR, 2015; PLN, 2021; Tozlu et al., 2016):

- The LFG method requires a considerable area, so in the future, it will be challenging to develop it, considering that land is increasingly limited;
- The application of LFG technology does not support upstream segregation of resources, so it does not promote better waste management;
- The LFG method does not reduce the weight and volume of waste so that the amount of waste that ends up in TPA remains large;
- LFG technology is only able to capture 30-40% of methane gas from the total methane gas produced by landfills; And
- LFG technology is not included in the technology options in the General Electricity Procurement Plan (RUPTL) 2021 – 2030.

Since the enactment of Law 18 of 2008 concerning Waste Management, there has been a shift in the waste management paradigm from collect-transport-dispose to reduce at-source and resource recycling (Ministry of PUPR, 2018). This regulation mandates waste management to improve public health and environmental quality and to turn waste into a resource. Apart from Law No. 18 of 2008, various laws and regulations related to waste management, renewable energy development, and environmental control support the application of WTE-based waste processing in Indonesia.

a. Waste management

The waste management policy stops in Law No. 18 of 2008. In order to transform the strategy, strengthen the application of 3R (reduce, reuse, recycle) and increase waste to value, the government issued Government Regulation 81 of 2012 concerning the Management of Household Waste and Waste Similar to Household Waste. It is explained here that the abovementioned waste management includes waste reduction (limitation of generation, recycling, and reuse) and handling (sorting, collection, transportation, processing, and final waste processing). Furthermore, the Ministry of Public Works issued Minister of Public Works Regulation No. 3/PRT/M/2013 concerning implementing Waste Management Facilities in Handling Household and Household-like Waste.

b. New and Renewable Energy Development

WTE is supported by the mandate of Law No. 30 of 2007 concerning Energy, which states that the government and regional governments must increase the use of new energy and renewable energy. One type of renewable energy in question is bioenergy from waste. After that, the government issued Government Regulation Number 79 of 2014 concerning the National Energy Policy, which encourages the use of New and Renewable Energy and reduces the use of fossil energy sources. As a derivative regulation, the Ministry of Energy and Mineral Resources issued several regulations requiring PT PLN (Persero) to purchase electricity from power plants that utilize renewable energy sources. In providing sustainable electricity, the waste-to-energy policy as part of developing new and renewable energy is also stipulated in Presidential Regulation No. 35 of 2018 concerning the Acceleration of the Development of Waste

Processing Installations into Electrical Energy Based on Environmentally Friendly Technology. Further explained in the presidential regulation, the government is targeting the construction of waste management installations (PLTsa) in twelve major cities, namely: DKI Jakarta Province, Tangerang City, South Tangerang City, Bekasi City, Bandung City, Semarang City, Surakarta City, Surabaya City, Makassar City, Denpasar City, Palembang City, and Manado City. The Regional Government will carry out the PLTSa procurement process through auctions or direct appointments to Business Entities. The Presidential Decree above also regulates the purchase of electricity by PLN, where for a PLTSa with a capacity of ≤ 20 MW, it is USD 13.35/kWh, while for a capacity > 20 MW, the purchase price is calculated by: Purchase price (USD cent/kWh) = 14.54 – (0.076 x the amount of PLTSa capacity sold to PT PLN)

c. Environmental controls related to WTE facilities

The construction of WTE facilities has environmental risks. The umbrella regulation for environmental protection in Indonesia is Law No. 32 of 2009, concerning Environmental Management and Protection, and Government Regulation No. 22 of 2021, concerning the Implementation of Environmental Protection and Management. Studies report that WTE with the thermal conversion method can produce CO2 emissions and other air pollutants and can produce B3 waste in the process (Arafat et al., 2015; Ferraz de Campos et al., 2021; G.T. et al., 2016). To mitigate this risk and to ensure environmental capacity, the Minister of Environment and Forestry Regulation No. 70 of 2016 concerning Quality Standards for Business Emissions and Thermal Waste Treatment Activities. The management of B3 waste is regulated in Ministerial Regulation No. 6 of 2021 concerning Procedures and Requirements for the Management of Hazardous and Toxic Waste.

The Indonesian government encourages the use of energy derived from municipal waste to solve the waste problem in cities experiencing a waste emergency (PLN, 2021). The utilization of waste for energy still needs to be improved. At the same time, the potential is around 2,066 MW (Ministry of Energy and Mineral Resources, 2015), so there is still a lot of waste potential that has yet to be utilized. In order to find out which WTE technology is appropriate for use in cities in Indonesia, it is necessary to identify the characteristics and availability of waste in these cities. The characteristics of waste are a benchmark in choosing the correct method to convert waste into electrical energy, while data on the amount of waste is needed to measure the electrical energy produced by the Waste-to-Energy Plant and the continuity of electricity supply (Hermawan, 2017; Sarasati et al., 2021; Soleh et al., 2020). In the thermal method, using organic waste that is difficult to decompose by microbes and inorganic waste with low water content will increase combustion efficiency. In contrast, in the biochemical method, using organic waste will improve the optimization of the digestion process, producing large amounts of methane gas or achieving maximum pressure (Hermawan, 2017; Kaplan et al., 2009; Tozlu et al., 2016).

Figure 1 shows that waste in landfills is dominated by food waste, wood, and twigs, meaning waste with high water content. Apart from the source of waste, because Indonesia is located in a tropical climate zone, it also affects the nature of waste, which generally tends to be wet (Hermawan, 2017; Lokahita et al., 2019; Sudibyo et al., 2017) an average moisture content of 60-70% (Sarasati et al., 2021). Moisture content is a crucial parameter to increase process efficiency. This wet waste condition can also be caused by the absenneed fordequate upstream-to-downstream waste management system (Hermawan, 2017). People need to realize the importance of sorting waste in their homes. Garbage that is still mixed between organic waste (high water content) and non-organic (low water content) makes waste segregation downstream (WTE Plant) also ineffective. The following discussion section will explain several alternatives to reduce the water content.

In addition to water content, the heating value is crucial in determining the WTE method. Information about the calorific value of waste can estimate the amount of energy produced. In the thermal method, the range of calorific values needed to support the conversion process is > 1,200 kcal/kg (Johri et al., 2011). Previous studies have explained that the average calorific value of waste at landfill is 2,783.22 kcal/kg (Sarasati et al., 2021), meaning that it meets the calorific value required for the conversion process.

Table 1. Technical Feasibility Parameters for WTE Development

No	Technology	Component	Composition
1	Thermal Conversion	Water content	<45%
		Volatile levels	>40%
		Fixed carbon	<15%
		Total inerts	<35%
		Net calorific value	>1,200 kcal/kg
2	Biochemical conversion	Water content	>50%
		Volatile levels	>40%
		C/N ratio	25-30

Source: Johri et al., 2011

2. Methods

This study is a literature review on secondary data obtained from the Google Scholar and Scopus academic databases. The two databases explore publications relevant to the theme of Waste to Energy and Municipal Solid Waste in the Indonesian context. The search was limited to work published after 2010 to map the most recent research in the field. Scopus and Google Scholar are two database searches frequently used by researchers in various disciplines (Martín-Martín et al., 2018; Paez, 2017). The author also conducts "snowballing" in the data tracking process to improve a comprehensive review. The author uses references and excerpts from papers to identify more literature that is considered relevant to this research. Authors also include general Google searches because some regulations, reports, and guidelines may not be found in the scientific literature. Gray literature will strengthen and complement the review while providing a balanced picture of the available evidence (Paez, 2017).

3. Results and Discussion

Jakarta municipal waste is dominated by organic waste (53.75%), paper (14.91%), and plastic (14.02%) (DKI Jakarta Environment Agency, 2011), with waste characteristics as shown in Table 3. When comparing DKI Jakarta's waste characteristics with the technical feasibility parameters development of WTE, the thermal conversion method can be implemented with pre-treatment conditions to reduce the water content to <45%. Another alternative is the biochemical method because the volatile content is >40%.

Table 2. Composition of Waste in DKI Jakarta Province

Garbage component	Composition (%)	Mass (Tons)
Organic	53.75	1.134,50
Paper	14.92	314,86
Plastic	14.02	295,93
Wood	0.87	18.38
Fabrics/Textiles	1.11	23.45
Rubber/Faux Leather	0.52	11.05
Metal/Metals	1.82	38.39
Glass/ cup	2.45	51.61
Demolition Garbage	0.01	0.13
B3 waste	0.56	11.80
Etc	9.98	210.60

Source: DKI Jakarta Sanitation Office, 2011

Table 3. Characteristics of waste in DKI Jakarta Province

No	Component	Composition
1	Specific gravity	0,2036 kg/liter
2	C/N Ratio	74,81
3	Water content	47,97 %
4	Ash content	14,95 %
5	Calorific value	3424,63 Kkal/kg
6	Volatile content	82,77 %

Source: DKI Jakarta Sanitation Office, 2011

(Hermawan, 2017) examined the application of WTE technology to the planned development of the Intermediate Treatment Facility Sunter, North Jakarta, using waste characteristic data from the DKI Jakarta Sanitation Service in 2011. The study shows that the potential for organic waste processed using anaerobic digestion technology is estimated to produce electrical energy of 5,604.42 kW or 13.48% of the total waste potential. As for the thermochemical process of the gasification method, the total electrical energy that can be generated is 19,230.99 kW. The highest potential for waste to become electrical energy is inorganic plastic-type waste, which is 5,829.85 kW or 14.02% of the total waste potential, followed by paper waste, which is 6,202.75 kW or 14.92% of the total waste potential. This study also found that the thermal conversion process generates more electricity than the biochemical process, with a lower waste life. Hermawan further concluded that there are two alternatives for PLTSa in Sunter, namely (1) PLTSa with a thermal conversion system and (2) PLTSa with a biochemical system. The drawback of option 1 is that the organic waste (paper/cardboard) must still be mixed with inorganic waste to meet the caloric needs. In addition, to increase efficiency, pre-treatment is required in the form of a drying facility before entering the gasification installation (pre-treatment process) because the characteristics of the waste are still relatively wet. Option 2 generates low electricity, so additional raw materials are needed to meet the 20 MW target. The main obstacle of the two processes above is waste that needs to be correctly sorted when it arrives at the waste processing site, thereby reducing efficiency in the energy conversion process.

3.1. WTE in Achieving the Sustainable Development Goals (SDGs)

The WTE Plant or PLTSa installation aligns with the 7th SDGs goal: to provide clean and affordable energy because it can produce electrical energy and operates in an environmentally friendly manner. Strengthening PLTSa in each region will strengthen regional capacity to realize the decentralized deployment of renewable energy technologies. The community's economic status can also improve through employment opportunities and community empowerment regarding PLTSa operation, as mentioned in the 8th SDGs, to provide decent jobs and economic growth. The PLTsa installation also aims to realize the 12th SDGs concerning responsible consumption and production because the waste generated by urban activities can be processed independently in the TPA of each region. In addition, the PLTSa installation aims to achieve the 13th SDG on climate change management. That waste becomes renewable energy and reduces CO2, CH4, and NOx emissions, contributing to global warming.

3.2. Challenges of WTE Plant Development in Indonesia

Currently, there are no commercial WTE Plant facilities operating in Indonesia, except for a 100-ton/day pilot WTE Plant facility in Bantargebang and the development of a 2,200 ton/day incinerator in Sunter as the first commercial WTE Plant (Damayanti et al., 2021; Hermawan, 2017). The establishment of WTE facilities in Indonesia needs to be improved by various challenges, both from an economic, environmental, and social perspective. Economic challenges are usually related to inadequate electricity feed-in tariffs and tipping fees. In addition, the characteristic of Indonesian effluent, which has a high moisture content of up to 60%, causes the need for additional pre-processing facilities, further increasing costs. The existence of illegal landfills as a cheap option for waste disposal makes WTE technology unattractive. There are also social challenges in the form of opposition from people concerned about the potential impact of pollution on their health and the environment. Such opposition can result in uncertainty surrounding the construction approval process.

4. Conclusions

Municipal solid waste is a resource with excellent material and energy recovery potential. Thus, WTE has the advantage of producing electrical energy and minimizing the waste that is stockpiled. To support the implementation of WTE-based waste processing, the Indonesian government has issued various related laws and regulations, ranging from waste management, and renewable energy development, to environmental control for WTE facilities. Seeing the characteristics of waste in Indonesia, WTE can be done by thermal or biochemical conversion methods. Both of these methods require pre-processing because the quality of Indonesian waste is still low, characterized by high water content, and has not been correctly sorted. The thermal conversion method is more recommended for the WTE process because the work efficiency and power generated are high and profitable. The thermal method can reduce waste more quickly than the biochemical method because the high temperatures in the thermal method can burn all incoming material. Installing a WTE Plant can accelerate Indonesia's steps toward realizing goals 7, 8, 12, and 13 of the Sustainable Development Goals. However, despite all its benefits, establishing WTE facilities in Indonesia still needs to be improved by economic, environmental, and public acceptance factors.

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Author Contribution

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Ethical Review Board Statement

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Informed Consent Statement

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Data Availability Statement

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Conflicts of Interest

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