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LITERATURE REVIEW

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ANALYSIS OF POTENTIAL WASTE-TO-ENERGY PLANT IN FINAL WASTE DISPOSAL SITES IN INDONESIA TOWARDS SDGs 2030 (A LITERATURE REVIEW)

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Abstract

Introduction: *Waste processing in Final Disposal Sites (FDS) in Indonesia is still dominated by open dumping. This condition causes health and environmental problems and inhibits the achievement of Sustainable Development Goals (SDGs) 2030. Waste is biomass that can be converted into electrical energy through the Waste-to-Energy Plant (WtE Plant) installation. This article aimed to illustrate the potential of WtE Plant in the FDS in Indonesia in supporting the achievement of SDGs 2030.* ***Discussion****: Most waste in the FDS are dominated by organic waste with the high-water content of 60-70% but have a calorific value almost equivalent to sub-bituminous coal. Most studies show the WtE Plant uses a thermal method (incinerator) than other technologies because it has a superior value in the technical aspects (easy operation and high generated energy around 9.86%), economy aspects (medium investment value, but high profit with moderate payback period around 6.5 years) environmental aspects (reduction of waste up to 70-80% and emissions), and lower public health impacts than those produced by open dumping and coal systems. For environmentally safe optimal results, it is necessary to reduce wastewater content, increase pollution control units, and implement an integrated monitoring system.* ***Conclusion****: The implementation of WtE Plant can accelerate to achieve the SDGs 2030, especially the 7th, 8th, 12th, and 13th goals concerning clean and affordable energy, decent jobs and economic growth, responsible consumption and production, and addressing climate change, respectively.*

INTRODUCTION

Waste is a problem that often arises in developing countries, including Indonesia. The increase in the volume of waste, types and characteristics of waste is influenced by the population growth rate and the development of urban residential areas (1). Reported from the Indonesian Ministry of Environment and Forestry in 2020, the waste disposal per day was 3,402.5 m^3 per 1,360,987 residents. In 2019, the amount of waste transported per day only reached 68.38%, and the rest were burned, dumped in rivers/sewers, and buried (2). On the other hand, 247 Final Disposal Sites (FDS) in Indonesia have been currently dominated by open dumping (26%), controlled landfill (25%), sanitary landfill (23%), semi-controlled landfill (3%), waste-to-energy (WTE) (1%) and unrecorded sites (22%). Based on the preliminary studies, the amount of waste in the Air Dingin FDS, Piyungan FDS, and Putri Cempo FDS has exceeded the maximum capacity limit, thereby potentially accelerating the lifetime of the landfill use and reduce the processing efficiency (3–5). This shows that waste management in the FDS currently cannot solve the waste problem and does not follow the Law No. 18 of 2008 which prohibits the use of open dumping methods in the FDS.

Waste management that does not comply with the standards will cause interference and impacts on the environment, including physical and chemical (water and air quality), biological, social, economic, cultural components, and environmental health (4). Waste decomposition in open landfills contributes to CO_2 and CH_4 emissions in forms of greenhouse gases that cause global warming. Methane gas has a hazard level of 23 times greater than CO_2, and thus pollution caused by the small amount of emissions, especially with long-term exposure, may have an impact on the environmental and public health (5). In 2019, the Final Processing Sites (FDS) contributed 10% of CH_4 gas from the total CH_4 gas in the atmosphere, and in the previous year, Indonesia was ranked the10th largest CH_4 emitter out of 34 countries with total emission up to 370 metric tons of carbon dioxide equivalent ($MtCO_2$ eq) (6). This problem is certainly an obstacle for Indonesia to achieve the Sustainable Development Goals (SDGs) 2030 because it does not comply with the responsible consumption and production and climate action as stated in SDGs 12 and 13. Thus, improvement and optimization of waste management methods are required to reduce the volume of waste that keeps increasing sharply and minimize its negative impacts (7).

Contradicting with the fact that waste is a problem, it is one of the biomass and renewable energy sources that can produce electricity through the conversion process (8-9). The utilization of waste to energy through the installation of WtE Plant in the FDS is one of the waste processing methods recommended by the Indonesian government (8). As renewable energy, waste has unlimited availability and thus can be an alternative to fossil fuels as the currently main fuels that decrease instead. The energy sources are produced from coal (50%), natural gas (29%), renewable energy (14%), and petroleum (7%) (9). Nationally, biomass, including municipal solid waste, has the potential to generate 49,810 Mega Watt (MW) of electricity. In 2015, power plants installed on-grid (interconnected to the State Electricity Company network) could generate an energy capacity of 91.1 MW while those installed off-grid produced an energy capacity of 1.626 MW. This indicates that there is still 48,092.9 or 96.55% of the potential electrical energy from biomass that needs to be generated. Thus, this study aimed to 1) describe the potential of waste as a renewable and substitute energy from fossil fuels in Indonesia; 2) study the process of converting solid waste into electrical energy; 3) analyze the potential energy that WtE Plant can generate and its economic benefits; 4) analyze the environmental and public health impacts of the WtE Plant installation and its management; 5) identify SDGs 2030 that possibly can be achieved according to the WtE Plant installation.

DISCUSSION

The Potential of Waste as a Renewable Substitute Energy for Fossil Fuels in Indonesia

A study on the potential of waste as a renewable energy can be done by identifying the characteristics and availability of waste. Waste as fuels for power generation can affect the performance of power plants and the generation capacity of electricity. Characteristics of waste become a benchmark in choosing the appropriate method to convert waste into electrical energy (10). Meanwhile, information about the amount of waste is necessary to measure the electrical energy produced by the Waste-to-Energy Plant and the continuity of electricity supply (8). In the thermal methods, the utilization of organic waste which is hardly decomposed by microbes and inorganic waste with low water content will increase combustion efficiency (11–14). While in the biochemical method, the utilization of organic waste will improve the optimization of the digestion process, and thus methane gas is produced in large quantities or reaches the maximum pressure (5).

Characteristics of waste in the FDS based on the previous studies are available in Figure 1.

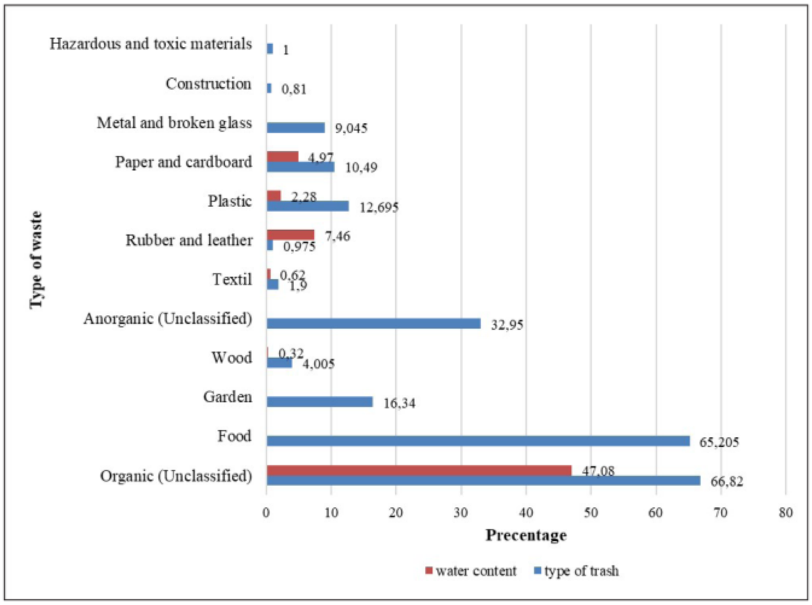

Figure 1. Characteristics of Waste in Final Disposal Sites in Indonesia
Source: (5,11,12,17,20,26,28,29,33,34,37)

The figure shows the source of waste affects the characteristics and physical properties of the litter (14). In general, waste can be divided into two types, namely organic and inorganic materials. In the FDS, organic waste is the most dominant at around 64%. Some organic waste including food, dried leaves and woods. The high amount of organic materials in waste in the FDS may be dominated by the waste from the households, traditional markets, offices, hospitals (nonmedical), industry, garden/parks, hotels, schools, and tourism (3,10,11,15). While the least waste in the FDS is inorganic waste at around 36%. Varieties of inorganic waste are textiles, rubber and leather, plastic, paper and cardboard, metal and broken glass, construction, and hazardous toxic materials. In addition to waste resources, as Indonesia is located in the tropical climate zone, it also affects the nature of waste which generally tends to get wet. On average, waste in the FDS has a water content of 60-70% (14). More dominant organic waste in the FDS affects the water content. The greater the amount of organic materials in waste, the higher the water content.

Information about the calorific value of waste can estimate the amount of energy produced. In the thermal methods, the range of calorific value needed to support the conversion process is >1,200 kcal/kg (16). The previous studies explain the average amount of calorific value of waste in the FDS is 2,783.22 kcal/kg, meaning it has met the calorific value needed for the conversion process. Even in the Piyungan FDS, the waste has a calorific value of 4,730 kcal/kg which is almost equivalent to the calorific value of sub-bituminous coal (17). Despite the amount and type of waste in Figure 2, the large calorific value is influenced by the water content in the waste. The lower the water content, the higher the calorific value to facilitate the combustion process in the thermal methods. Thus, reducing the water content is required to achieve the optimum results (13). Some alternatives for reducing the water content will be explained in the next part of the discussion.

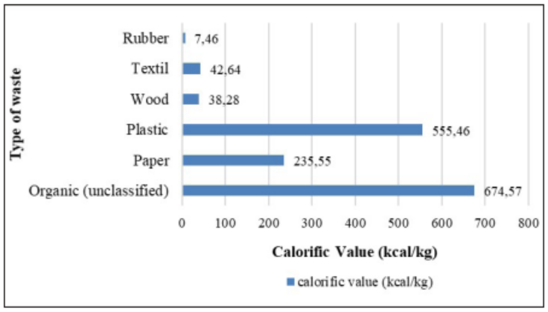

Figure 2. Calorific Value per Type of Waste in Final Waste Disposal Sites in Indonesia
Source: (15)

Based on Table 1, the relationship between the areas of FDS and the amount of waste is not visible . Several FDS have small land areas, while the amount of waste is huge. Likewise, several large FDS have little waste. The differences in the conditions might occur due to several factors, such as coverage of FDS management services, the appropriateness of the collection and transportation processes, and compliance with reporting (18-19).

The Process of Converting Solid Waste into Electrical Energy

Waste-to-energy conversion methods are divided into two: thermal methods (incineration, pyrolysis, gasification, and hydrothermal) and biochemical method (anaerobic digestion) (15,20). The accuracy of technology as a power plant will affect the effectiveness and efficiency waste-to-energy conversion and reduction. The results of the previous studies conclude there are five conversion methods studied to be implemented in the FDS in Indonesia.

The thermal methods may produce optimal waste-to-energy conversion by reducing the water content in waste as pre-treatment. This step may be in forms of anti-bacterial spraying to suppress bacterial development and anaerobic decomposition process, (8) draining and channeling leachate into landfills (11,21), and stirring (13). Incineration is the most widely applied technology in the FDS due to its easy application and high efficiency. Using the incinerator technology, the conversion of waste to electrical energy begins by reducing the water content until 20% remained. After that, the waste will be chopped, and the conveyor will put it in a boiler. In the boiler, the waste will be burned at a temperature of more than 1,000°C, and then it produces ash as residue. Water vapor from the hot boiler will be used to drive a generator turbine and generate electricity (22). Pyrolysis is a combustion process without involving oxygen. This stage starts at a temperature of around 300°C when the lignin components in biomass and volatile material in coal are thermally unstable, broken, and evaporating along with other components. Evaporated liquid products contain tar and PAH (Poly Aromatic Hydrocarbon). The pyrolysis results consist of light gas (H_2, CO, CO_2, H_2O, and CH_4), tar, and charcoal. Gasification is a complex process that involves some chemical reactions. The gasification process includes some processes. At first, the lignocellulosic fuels will oxidate partially with gasification agents (e.g., air, oxygen, water vapor, or CO_2), and then volatile materials are released when the fuel is heated through partial oxidation which produces H_2O and CO_2 combustion products. Volatilization and separation of some materials depends on the combination and structure of the initial materials. Afterwards, water in the biomass will evaporate. Then, the pyrolysis process will continue if the materials continue to be heated. For the next reaction, the thermal decomposition and partial oxidation of pyrolysis gases occur at higher temperatures and produce CO, H_2, CO_2, CH_4, H_2O, other hydrocarbon gases, tar, charcoal, inorganic elements, and ash (23-24). The stages of the gasification process consist of drying, pyrolysis, oxidation, reduction, cleaning of the gasified gas (syngas), and delivery of clean syngas to the generator (17,24–26). With the conventional gasification technology, the conversion process produces syngas or synthetic gases that are not completely oxidized and have a calorific value. Gases in the syngas include carbon monoxide (CO), hydrogen (H_2), and methane (CH_4) which are organic fractions and act as fuels for power plants. In the plasma gasification, organic and inorganic fractions are produced, while the inorganic fractions cannot dissolve and are safe to dispose of or become construction materials (11,27). In its implementation, the use of oxygen as a gasification agent also increases the production costs (26). In the hydrothermal technology, waste as raw materials that go into a reactor and saturated steam is injected at a temperature of 200°C and a pressure of 2 Megapascal Pressure Unit (MPa). Furthermore, stirring is carried out in the reactor for an hour at the same temperature and pressure. This process produces sludge that has a heating value equivalent to that of lignite coal. The sludge is then dried to be used as a heating fuel for the reactor which can produce thermal energy and convert it into electrical energy (28).

Using the biochemical methods, especially anaerobic digestion technology, the process undergoes the utilization of methane fermentation and landfill. Products used for energy are landfill gas or biogas which sides products are produced from the decomposition process by piles of waste in a sanitary landfill (29). The implementation begins by laying, flattening, and compressing waste into the hole and then covering it with flabby soil continuously until it forms layers (29). This technology includes the installation of pipe system to capture every gas formed. A biogas component composer contains 55-75% Methane (CH_4), 22-45% Carbon dioxide (CO_2), 0-0.3% Nitrogen (N_2), 1-5% Hydrogen (H_2), 0-3% Hydrogen sulfide (H_2S), and 0.1-0.5% Oxygen (O_2). The characteristics of flammable methane make it have a great contribution to produce energy. The greater the composition of methane in the biogas, the greater

Table 1. Recapitulation of the Potential Feasibility of WtE Plant (Reduction of Waste, Generated Energy, and Economy)*

FDS	Technology	Land Area (Ha)	Total Waste (ton)	Calorific Value (kcal/ kg)	Efficiency	Waste Reduction (ton/day)	LFG Product (ton)	Generated Energy (MW)	Produced Energy (kWh)	Project Period (Year)	Investment Cost (Rp)	NPV (Rp)	IRR (%)	BCR	PP (Year)	Feasibility	Ref
Riau																	
Muara Fajar	Gasification	-	-	-	42.6%	-	-	39,06	39.000.621.6/ year	25	314.335.287.296,8	9.481.791.765.570	10,9	-	12,86	Feasible	(11)
West Sumatera																	
Air Dingin	Anaerobic digestion	18	0.24/year	-	-	-	10.405,76/ year	0,0032	28.167.259,47	20	40.089.591.065	62.709.95,336	22,2	12,3	1,13	Feasible	(29)
Muaro Kiawai	Incineraion	10	1,462.7/ year	-	-	-	-	-	3.056.044,2/ year	20	5.756.705.539,02	41.441.798.111	-	-	1,7	Feasible	(20)
South Sumatera																	
Muara Fajar (a)	Incineration	9,8	407,33/ day	2.500	85% (boiler); 25% (steam turbine); 90% (generator)	-	-	9	-	-	-	-	-	-	-	Feasible	(8)
Muara Fajar (b)	Incineration	6,6	714,05/ year	-	20%			12.85/ year	22,518,452.19/ year	25	131,004,566,935	80,061,249,724	-	-	8	Feasible	(46)
Central Kalimantan																	
Km 14	Incineration	-	69,482-371,258	-	-	-	-	-	179,507-278,443,854	-	-	-	-	-	-	-	(47)
	Anaerobic digestion	-	69,482-371,258	-	-	-	-	-	21,742,835-352,695,548	-	-	-	-	-	-	-	
East Kalimantan																	
Sambutan	Anaerobic digestion	-	7,519.5/ year	-	-	-	29.9x10^9	-	2,822,107.61	15	25,092,450,601	17.539/868,600	19	1.67	3.4	Feasible	(40)
Banten																	
Cilowong	Thermal	-	120/day	2.543,67	-	-	-	2.19	-	-	-	-	-	-	-	-	(16)
	Anaerobic digestion	-	120/day	2.543,67	-	-	-	1.09	-	-	-	-	-	-	-	-	
West Java																	
Bantargebang (a)	Incinerator Siemens SST-050	120,3	866,658	-	52.1%	-	-	4.16	-	-	-	19,123,917,412	23	-	7	Feasible	(10)
	Incinerator Siemens SST-040	120,3	808,92	-	52.1%	-	-	-	-	-	-	14,771,474,353	21	-	7	Unfeasible	
Bantargebang (b)	Anaerobic digestion	120,8	2,251,987/ year	-	75%	-	17.308/ year	15.6	-	-	-	-	-	-	-	-	(34)
Bantargebang (c)	Incineration	-	50/day	-	-	-	-	0.4	-	-	-	-	-	-	-	-	(13)
Ciniru	Thermal	5,8	1,300/day	1,359.23	25.88	-	-	154	-	-	-	-	-	-	-	-	(35)
	Anaerobic digestion	5,8	1,300/day	1,359.23	32.49	-	39.12/day	2.1	-	-	-	-	-	-	-	-	
Central Java																	
Muarareja	Incineration	-	348.9	-	-	-	-	0.115	-	-	-	-	-	-	-	-	(15)
Mojorejo	Pyrolysis/ Gasification	3,58	131,85	-	Fast	>50	-	-	-	-	-	-	-	-	-	Unfeasible	(28)
	Incineration	3,58	131,85	-	Moderate	21-30	-	-	-	-	-	-	-	-	-	Unfeasible	
	Hydrothermal	3,58	131,85	-	Very fast	>50	-	-	-	-	-	-	-	-	-	Feasible	
	Anaerobic digestion	3,58	131,85	-	Very slow	<10	-	-	-	-	-	-	-	-	-	Unfeasible	
Jatibarang (a)	Incineration	46	-	-	-	-	-	0.46	-	-	-	-	-	-	-	-	(33)
Jatibarang (b)	Anaerobic digestion	46	1,270/ day	-	-	-	-	1.3	-	-	-	-	-	-	-	-	(36)
Piyungan (a)	Incineration	-	480/ day	4,730	-	-	-	-	316/ton	-	-	-	-	-	-	Unfeasible	(17)
	Conventional gasification	-	480/ day	4,730	-	-	-	-	769/ton	-	-	263,494,038,842	26.8	-	7.57	Feasible	
	Plasma gasification	-	480/ day	4,730	-	-	-	-	941/ton	-	-	279,501,194,961	24.2	-	7.79	Feasible	
Piyungan (b)	Incineration	16	536/ day	-	Very fast	>100	-	25	-	-	-	-	-	-	-	Feasible	(22)

FDS	Technology	Land Area (Ha)	Total Waste (ton)	Calorific Value (kcal/kg)	Efficiency	Waste Reduction (ton/day)	LFG Product (ton)	Generated Energy (MW)	Produced Energy (kWh)	Project Period (Year)	Investment Cost (Rp)	NPV (Rp)	IRR (%)	BCR	PP (Year)	Feasibility	Ref
	Pyrolysis	16	536/ day	-	Moderate	21-30	-	-	-	-	-	-	-	-	-	Unfeasible	
	Hydrothermal	16	536/ day	-	Very fast	50-100	-	-	-	-	-	-	-	-	-	Unfeasible	
	Anaerobic digestion	16	536/ day	-	Very slow	<10	-	-	-	-	-	-	-	-	-	Unfeasible	
Putri Cempo (a)	Plasma gasification	-	450/ day	-	-	-	-	10-15	-	-	-	1,502,724,992,382	8.174	-	15	Feasible	(3)
Putri Cempo (b)	Thermal	17	164,200/ year	-	80% (boiler); 25% (steam turbine); 90% (generator)	-	-	8.57	30,843,039.76	19	-	1,149,211,633,140	-	-	-	Feasible	(48)
East Java																	
Benowo	Incinerator	-	1,500	-	-	75-80%	-	9	-	-	-	-	-	-	-	Feasible	(12)
Supit Urang	Anaerobic digestion	405,7	405,727.5	-	40%	-	30.64×10^8	1.04	-	17.3	-	-	-	-	-	Feasible	(21)
Bali																	
Suwung	Anaerobic digestion	-	-	-	-	-	-	6.66	-	-	-	-	-	-	-	Feasible	(7)
Bangkala	Anaerobic digestion	-	165	-	-	-	-	2	-	-	-	-	-	-	-	Feasible	(37)
West Papua																	
Makbon	Anaerobic digestion	2,42	119,064	-	-	-	2.58×10^5	-	$1,685 \times 10^6$	14	-	-	-	-	-	Feasible	(5)

**The evaluation of the method appropriateness in each FDS WTE PLANT is purely the assessment of the studies analyzed.*

Notes:

FDS : Final Disposal Site
Ha : Hectare
LFG: Landfill Gas
MW: Megawatt
kWh : Kilowatt-hours
Rp : Rupiah
NPV: Net Present Value
IRR: Internal Rate of Return
BCR: Benefit-Cost Ratio
PP : Payback Period
% : Percentage
Ref : Reference

the energy formed (5). To improve the composition of methane in Landfill Gas (LFG) products, the high water content (7) and fat content (21) will give a great effect.

In the conversion, pre-treatment can improve the efficiency of the process (30). A pre-treatment form that can be applied in general is sorting waste based on the types and uniformity of material size. The selection of waste by types becomes an obstacle in the current condition of waste management since the waste disposal by types cannot be implemented optimally in the community. Although several waste collection points by types spread throughout the city centers, such as near parks, offices, and others, the separation of waste has not been made by types, and facilities for the temporary dumping site and available means of waste transfer are not differentiated by types (31-32). The selection of waste by types is mainly carried out in the FDS, in turn requiring extra efforts and time for its operation to make the waste management less efficient. Meanwhile, the uniformity of material size can be done through the destruction of materials to facilitate the process of burning materials in the thermal methods or the decomposition of materials in the biochemical method.

Based on the characteristics of waste in Figure 1, the WtE Plant using the biochemical method guarantees more sustainability because the availability of waste as a material for LFG production is quite large. Nonetheless, the use of WtE Plant with the thermal methods still has sustainability potentials as long as it applies the pre-treatment. The use of organic waste as fuels requires a decrease in water content in advance not to reduce combustion efficiency. To support the availability of waste as raw materials, excavation of the passive zone in dumpsite can be done (33). Several other factors to be considered in choosing a suitable conversion method are the amount of energy that can be generated, economic benefits, and its impacts on the environment and public health.

The Potential Energy Generated by WtE Plant and Its Economic Benefits

The studies on the potential for energy generation show the thermal methods can generate more energy than the biochemical method. The use of gasification energy can generate the largest electrical energy compared to other technologies at 39.06 MW (conventional) and 10-15 MW (plasma). While the incineration technology can produce power at 9.86 MW. In comparison, the anaerobic digestive technology is capable of producing 5.45 MW of energy. Meanwhile, the hydrothermal and pyrolysis technologies do not state how much power can be generated. The anaerobic digestion technology generates a lot of energy in LFG products and accumulates a large amount of waste. On average, of the 62.66×10^4 tons of waste disposed, the LFG product is at 2.076×10^{11} tons (3,7,20,34-35). Compared to the anaerobic digestive technology, the thermal technology can produce greater electrical energy. The downside of the anaerobic digestive technology is that LFG harvesting cannot be done directly, but it has to wait some time and requires bacterial growth control (17). As the waste remains fewer than 10 years, it is estimated that the accumulated waste can form a gas up to 6 m^3/year/ton (29). Gas production can last for 10 years from the beginning with 50% of methane gas produced by LFG in the fifth year. In several other studies, CH_4 emissions are expected to increase from 6 months to 12 months and reach the maximum duration value after the year-endclosure of FDS, and then they decrease in the 30-50th year (5). Under certain conditions, there may be obstacles in the production of LFG. One of the causes for the obstacle is the inhibition of the extraction and transport of gas from the cells of FDS to the gas well. Obstruction of LFG flow is caused by crust and dirt in piping installations as well as the lack of depth of planting gas catchment pipes so that the gas formed in the bottom layer of waste cannot be caught (36).

Some economic studies were conducted considering several parameters, including the investment value of the projects, Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PP). NPV describes the total revenue received from the beginning of the projects. IRR is the level of profit to pay off capital loans. BCR is the ratio between the total revenue received during project operations and the cost of the initial investment. Meanwhile, PP is the length of time it takes to return the investment funds (29). Based on the results of some studies, hydrothermal and gasification technologies have shortcomings from the economic aspect because they require too high capital costs for operations and maintenance (10,15,20). In contrast, the incinerator technology as a power plant in the FDS has economic advantages due to lower installation and operation costs required (8,10,11,37-38). Besides, to return the investment funds for WtE Plant development in the short term, the efficiency of boilers, turbines, and generators also needs to be improved. According to Table 1, the greater the efficiency of the machine, the faster the period that the WtE Plant needs to refund the investment funds. On average, with a mechanical efficiency of 36.5%, the PP value of time for incineration-based WtE Plant to payback is 6.5 years. Studies on the economic aspect of anaerobic digestive technology also show that WtE Plant projects are economically profitable. On average, with a mechanical efficiency of 40%, the time for the anaerobic digestive-based WtE Plant to return relatively shorter capital than thermal technology is 1.13 years. At the end of the project period, WtE Plant's remaining equipment and buildings have a sale value of about 10% of their cost (3,26). Based on Table 1, the incineration technology provides greater economic benefits than other technologies. Although the PP value or required payback period is in the moderate category, the IRR value or benefits of the incineration technology are the greatest compared to other technologies.

In the implementation of WtE Plant, through community-based waste management, the community can be involved in the input stage and the activation process. The input stage includes waste sorting/sorting activities. Meanwhile, at the processing stage, the community can be empowered as technicians in the waste shredding/cutting, waste burning, steam collection, turbines, and generation process. Of course, the community has been previously given training and education. In addition to improving the knowledge and skills of the community around the WtE Plant, the economic condition in the community may also increase (39).

The Environmental and Public Health Impacts Due to WtE Plant Implementation and Its Management

In general, all of the technologies used in the WtE Plant can reduce the waste pile. However, they have different capacity in reducing the waste, depending on how it is processed, the efficiency of the machine, and the characteristics of the waste. In the thermal methods, the reduction potential is higher due to the high temperature that burns all the materials (10,15,40). The percentage of waste reduction potentially achieved through gasification technology is 75%. The incineration technology can reduce up to 70-80% of the total volume without sorting (12). In the anaerobic digestive technology, the reduction can reach up to <1.86% of the total pile (4,15) as the only waste that can be used is homogeneous organic (5). By reducing waste piles, the lifespan of FDS can last longer because the WtE Plant applications do not require large areas (17). In generating emissions, biomass burning is considered more environmentally friendly than coal, natural gas, and petroleum burning. Biomass combustion results in lower CO_2 and shorter cycles so as not to affect the CO_2 equilibrium in the atmosphere (9,41-42). In some previous environmental studies, gasification technology is the safest technology due to combustion carried out in seals, thereby forming no emission (11). However, other studies have shown that conventional gasification, plasma gasification, and incineration technologies are environmentally good enough because they produce more CO_2 emissions that exceed the standards of the Environmental Protection Agency (EPA) (17). In the incineration technology, the combustion process may have the opportunity to emit CO_2 gas and other toxic gases if the incinerator is not standardized. In standardized units, a study shows the emission reduction achieved with incineration technology is 300,000 tons of CO_2 per year (12). While in other studies, it is mentioned that the incineration technology can reduce CO_2 emissions by up to 0.18 kg/s (33). While in the anaerobic digestive technology, the risk of environmental contamination can also arise because, in its operation, this technology uses soil as land cover. Lack of soil density can pose the risk of gas leaks including CH_4 emissions and even explosion (3). Further impact is contamination of groundwater, river water, and food products (43). However, a study on the WtE Plant evaluation of Bantargebang FDS using the biochemical method, the WtE Plant could reduce greenhouse gas emissions, such as CH_4 up to 284,130 tons and CO_2 up to 17,640 tons in the first year, which will then continue to decrease in the following years (34).

Seen from the public health impacts, the exposure pathways identified include dermal contact, fish consumption, meat, milk, vegetables, water, and inhalation. In general, the WtE Plant implementation has a lower health impact than open dumping and fossil burning. Contamination of ammonia in leachate in food, such as vegetables and fish, is the most contributing factor to the occurrence of poisoning. Besides, there is also another carcinogenic risk of dermal contact with contaminated water due to the presence of BTEX (benzene, toluene, ethylbenzene, xylene). While the risk of exposure to dust particulates, NOx (nitrogen oxides), and dioxins is still below the threshold, and thus the danger level is low (43). In other studies, the normal operation of WtE Plant installation does not cause adverse health effects. This indicates that the public health impacts depend on the WtE Plant installation during the operation (44).

Good management of the WtE Plant installation control and maintenance significantly can prevent and minimize the environmental and public health impacts (45). Solving the emission or waste with the thermal technology, in particular, needs additional processing units as quencher to prevent the formation of dioxins and furans (13), scrubbing to absorb hazardous materials in exhaust gases (13), a bag filter to filter dust particles before exiting the chimney (10,13,40), and sewage treatment to treat leachate coming out of the bunker (13). Besides, the project is equipped with an instrumentation and control system by a Process Control System (PCS) or Distributed Control System (DCS) that is monitored automatically or manually. Therefore, the performance of WtE Plant is more efficient and secure (13), and the operation of the incinerator does not cause emissions and odors and sets the combustion temperature range of 800-1,000°C (10). Conversion of waste to thermal, on the other hand, also provides advantages because the products in the form of sludge are considered safe and provide added values for its capacity of resembles lignite coal and producing fertilizer and reusable animal feed which does not harm the environment (28). The utilization of increnator has the potential to secure wide land areas and reduce emissions and environmental burdens (27). While in the LFG processing, emission reduction can be supported by a combustion engine, which can be based on HCCI (Homogeneous Charge Compression Ignition). This machine has the advantage to reduce the levels of hydrocarbons (HC) and nitrogen oxides (NOx) in exhaust emissions and the risk of environmental pollution. The use of an HCCI motor engine also provides positive values for fuel efficiency because it can save fuel usage between 15-20% (21). Besides, the units that can be added to ensure the optimal operation of this conversion are the leachate collection system for pumping leachates out of the ground and cap system for reducing rainwater entering the landfills. Other units include gas ventilation system for controlling gas flow and concentration and preventing explosion, and monitoring system for detecting leaks (34,37).

The WtE Plant Installation in the Pursuit of SDGs 2030

The WtE Plant installation is considered in line with the 7th SDGs which is to provide clean and affordable energy because it can produce electrical energy and have environmentally friendly operation. Strengthening WtE Plant in each region will strengthen the regional capacity to realize the spread of decentralized renewable energy technologies. The economic status of the community can also increase through job opportunities and community empowerment in terms of the WtE Plant operation as the 8th SDGsmentions to provide decent jobs and economic growth. The WtE Plant installation also aims to bring about the 12th SDGsregarding responsible consumption and production as waste produced by urban activities can be processed independently in the FDS of each region. Besides, the WtE Plant installation aims to achieve the 13th SDGsregarding handling climate change. In relation to that, waste becomes renewable energy and reduces CO$_2$, CH$_4$, and NOx emissions, which contribute to global warming.

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CONCLUSION

Based on the analysis of some studies, more than half of the waste that goes into the FDS is organic waste with high water content but has almost equivalent calorific value to that of sub-bituminous coal. Waste may be an alternative to coal if its water content is reduced to obtain higher calorific values. Principally, the conversion of waste to electrical energy can be done in two ways: thermal methods (combustion, pyrolysis, gasification, hydrothermal) and biochemical method (anaerobic digestion). Among these three technologies, gasification technology has the highest ratings in generating electrical energy through the WtE Plant, and then the second and the third are combustion technology and anaerobic digestion, respectively. Although the thermal technology requires a higher investment cost than biochemical technology, from the economic analysis, the thermal methods provide more positive feedback than the biochemical method based on the IRR scores or project benefits. Combustion technology is widely recommended for the process of converting waste into electrical energy because the efficiency of work and power produced is quite high and profitable. The use of thermal methods can reduce more waste more quickly than the biochemical method because high temperatures in the thermal methods can burn all incoming materials. Environmental and public health impacts may arise due to installation conditions that do not meet the standards. However, the impacts are lower than the waste handling method using open dumping and fossil burning. With pre-treatment in the form of drying to reduce wastewater content, adding a pollution control unit and an integrated monitoring system that ensures controlled generator performance to achieve the optimal waste reduction and conversion. The improvement of waste management can be done expanding the scope of services, increasing the role and participation of the community through the Community Based Waste Management (CBWM), sorting waste sources by types to reduce the operational burden in the FDS. Therefore, the WtE Plant installation can accelerate the pursuit of SDGs 2030 regarding affordable and clean energy, decent jobs and economic growth, responsible consumption and production, and climate change.

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