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Paper 60

The Framework of Waste To Energy Technology Decision In Indonesia

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Abstract - **In 2016 and 2018, the Indonesian Government has issued a regulation through a Presidential Regulation to accelerate the growth of Waste to Energy (WtE) power plant (Pembangkit Listrik Tenaga Sampah, PLTSa). Though, until 2022, there are only two WtE power plant in operation. Several issues have appeared during the process of project development, which is one of the crucial one is determining the suitable technology. Selecting technology to reduce significantly Municipal Solid Waste (MSW) is a challenging effort as many criteria needs to be evaluated. Not only technical aspect during the operation, but also the financial viability and environment compliance of the project which affect the whole MSW management. This study examines the suitability of waste to energy technology to be deployed in Indonesia.**

Keywords – **development, technology, waste to energy**

I. INTRODUCTION

Household waste or more familiar called Municipal Solid Waste (MSW), which is included in the renewable energy category, has interesting prospects to be utilized. Every city has waste that can be utilized to be managed as a fuel supply to power plants. However, the use of waste is not an easy thing. One of the issues is the choice of technology to destroy waste or reduce the volume of waste in large quantities. Variations in the composition of waste are very diverse and cannot be burnt with other solid fuel technologies. Constraints on the choice of technology that can be applied, occur not only in developing countries, but also in developed countries. This is due to many factors that influence the selection of the technology, so it is not easy to implement.

In Indonesia, currently the Waste to Energy (WtE) project is getting priority along with the issuance of a Presidential Regulation which specifically regulates the utilization of waste into electrical energy [1]. This special program needs to be supported by providing studies to understanding and selection of technologies that can be used in WtE. According Indonesian Nationally Determined Contribution (NDC), MSW is the fourth largest of GHG emission source, after energy, agriculture and forestry sector [2]. Thus, preventive measure must be taken immediately to prevent from worse impact of carbon emission.

II. METHODOLOGY

The methodology used in analyzing the framework of waste to energy technology decision in Indonesia is:

1. To review the problem conditions of the development of WtE power plant.
2. Analyzing general waste composition in Indonesia.
3. Implement 3E (Energy, Economic and Environment) assessment method framework for WtE technologies selection.
4. To evaluate the competitive aspects of each technology.

The first step is reviewing the problem conditions of the development WtE power plants in Indonesia, i.e., technical and commercial aspect. Moreover, it also gathers information regarding operation management and commercial issues to establish WtE project in Indonesia. The following step is to evaluate the general waste composition in Indonesia. Then using 3E (Energy, Economic, and Environment) assessment framework for WtE technologies [3]. The data to implement 3E assessment is waste composition, technology operation and performance, capital cost, financial and environment.

III. RESULTS

A. Current MSW Management In Indonesia

The flow of waste material to the final waste disposal site or TPA (Tempat Pembuangan Akhir sampah), starts from households. The garbage that residents throw away in the trash can is unsorted and mixed. In the process of transportation to landfilling in the TPA, the majority of the waste is not treated, such as recycling, or composting [4].

In the process of going to the TPA, the private sector is in charge of collecting waste from trash cans at residents' homes and transporting it to temporary shelters. From this place it is then transported by the city cleaning service officer to the TPA. Garbage originating from residential areas, markets, and offices is temporarily stored in trash bins and then transported by a gradual relay process until it finally reaches the TPA.

Some cities that already have more advanced programs in the field of waste, such as Surabaya, Solo, Jakarta carry out special processes to reduce the volume of waste. The process carried out is by recycling some of the waste material and reducing the volume of waste in the landfill or WtE plant, by converting it into other energy. Based on data from the Ministry of Environment [5], the current heap of garbage in Indonesia is about 28,000,000 ton/year. From this amount, 15% of waste already reduced (Fig. 1).

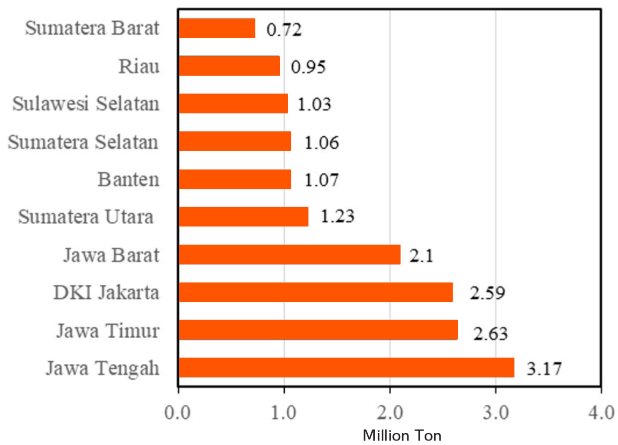

Fig. 1. National Heap of Waste in Several Cities [6]

B. Challenges Of The WtE Development

The few numbers of WtE plant in operation in Indonesia is due to obstacles and problems that hinder its project development. Several Government Regulations have been issued to support this power plant development: the first was in 2012: Minister of Energy and Mineral Resources Regulation No. 4 of 2012 concerning the Purchase Price of Electricity by PT PLN (Persero) from Power Plants Using Small and Medium Scale Renewable Energy or Excess Electricity, and the latest is Presidential Regulation Number 35 of 2018 concerning Acceleration of Construction of Waste Processing Installations into Electrical Energy Based on Environmentally Friendly Technology, but still the progress is below expectation. Technology selection difficulties is one of the main issues in the WtE power plant [8].

Several issues had been raised after the project or program announcement which caused the delay or termination of the project. Another challenge is that the condition of waste delivered to TPA is unsorted and with high moisture content, up to 60%. Furthermore, modern technology to harness waste into energy is considered a new subject, which result in confusion to determine which one is suitable for the available waste in their city.

C. Lesson Learned from The Commercial WtE Projects In Indonesia

1. Suwung 2 MW WtE power plant, Bali

The technology used for this project is landfill gas. Financial factor was the main consideration in choosing this technology. Considering that there was no support for special tariffs for electricity from waste, while the average electricity production rate for PLN and private IPP was lower than 700 IDR/kWh. Suwung WtE had been in operation since 2008, then stopped operating in 2010. This short operating period was caused by the lower estimated revenue than planned. In the initial financial planning, the IPP Company assumed that it would receive income from the sale of carbon credits, but it did not meet expectations. Attempts to obtain a tipping fee from the local government were also unsuccessful, so it was finally decided to stop operating. Regional waste management policies that were not synchronized at that time between districts and provinces also caused the support for providing tipping fees to not be realized.

2. Bantargebang WtE 14 MW, Bekasi

Landfill and thermal technologies are planned to be applied to the Bantargebang WtE power plant. Waste disposal by landfill was built first, and then thermal technology would be developed after the first one. Landfill gas technology construction was started in 2011 and had reached an operational capacity of up to 14 MW, until 2017. Electricity from the Bantargebang WtE with landfill technology is sold to PLN at a rate of 820 Rp/kwh or 9.1 cent at USD/IDR 9000 exchange rate.

At the beginning of the development of the Bantargebang PLTSa, it was constrained by the less-than-optimal gas production from piles of waste in landfills. Foreign experts who are brought in were not able to provide a landfill design that was in accordance with the conditions of waste, soil and climate in Indonesia. But in the end, thanks to the relentless efforts of the Developer, the electricity production capacity of this project was able to reach the optimum according to the electricity purchase contract with PLN, which was 14 MW.

The development of the Bantargebang waste processing capacity with thermal technology had terminated. The contractual issue of waste management between the Bekasi local Government, the Bantargebang Project Owner and the DKI Jakarta Government, as well as the cost of waste processing assistance were the main obstacles to the development of the thermat unit. Waste that was managed in Bantargebang, 5000 tons/day comes from Jakarta and 1000 tons/day comes from Bekasi. The tipping fee received by the WtE Developer only came from the DKI Regional Government. Until this study was conducted, the electricity production output of the Bantargebang PLTSa still delivered to grid, but continue to decline, and is now below 1 MW. This waste processing project has no longer received operational funding support from the DKI Regional Government.

3. Benowo WtE 11 MW power plant, Surabaya

The total capacity of the Benowo PLTSa in Surabaya is 11 MW consisting of 2 MW with Landfill technology, which consumes 600 tons of waste and 9 MW of thermal gasification and combustion technology, with a consumption of 1000 tons of waste. The sale of electricity from these two technologies to PLN is carried out using two separate PPA contracts. The process to get to the PPA contract has been carried out since 2013. Benowo Landfill WtE operated in 2015, and is still operating reliably. However, Benowo WtE with thermal technology has just been operating in 2021. The main obstacles to the Benowo WTE thermal project are changes in regulations during the procurement process for selling electricity from WtE, including tariff issue which affected to technology decision, discussing PPA contracts and the covid pandemic which caused the construction process to be delayed. In 2021, the Benowo PLTSa thermal technology have started to operate commercially.

Monitoring from the field showed that this WtE project can operate according to the plan, which is to reduce significantly 1000 tons of waste. All air emission parameters comply the quality thresholds that have been set by the Ministry of the Environment. During operation, there were no disturbances due to machine selection errors, or incompatibility with climatic conditions in Surabaya.

In the process of procurement of Power Purchase Agreement (PPA) of the Benowo WtE project, there have been regulatory changes, namely four changes to the Regulation of the Minister of Energy and Mineral Resources and two changes to the regulation of the Presidential Regulation. Perhaps, this project is the only renewable energy project in Indonesia that can still survive during the PPA contract procurement after struggling through six times regulation changes. These regulations, namely:

- Minister of Energy and Mineral Resources Regulation No. 4 of 2012 concerning the Purchase Price of Electricity by PT PLN (Persero) from Power Plants Using Small and Medium Scale Renewable Energy or Excess Electricity.
- ESDM Ministerial Regulation No. 19 of 2013 concerning the Purchase of Electricity by PT Perusahaan Listrik Negara (Persero) from Municipal Waste-Based Power Plants.
- ESDM Ministerial Regulation No. 44 of 2015 concerning the Purchase of Electricity by PT Perusahaan Listrik Negara (Persero) from Municipal Waste-Based Power Plants.
- ESDM Ministerial Regulation No. 50 of 2017 concerning the Utilization of Renewable Energy Sources for the Provision of Electricity.
- Minister of Energy and Mineral Resources Regulation No. 4 of 2020 concerning the Second Amendment to the Regulation of the Minister of Energy and Mineral Resources No. 50 of 2017 concerning the Utilization of Renewable Energy Sources for the Provision of Electricity.
- Presidential Regulation Number 18 OF 2016 concerning Acceleration of Construction of Waste-Based Power Plants in DKI Jakarta Province, Tangerang City, Bandung City, Semarang City, Surakarta City, Surabaya City and Makassar City.
- Presidential Regulation Number 35 OF 2018 concerning Acceleration of Construction of Waste Processing Installations into Electrical Energy Based on Environmentally Friendly Technology.

4. Putri Cempo WtE 5 MW, Solo

This WtE run on gasification technology, which will eliminated approximately 90% of 276 tons waste supplied. The latest progress of this WtE project, i.e, has operated successfully the first stage of engine testing, and planned to start commercial operation by the end of year 2022.

IV. DISCUSSION

A. Waste to Energy Technology

The aim of waste to energy project is to reduced significantly the volume of waste at the disposal area. This technology has similarity to biomass technology in the term of main process as the majority composition of MSW is categorized as biomass. The others materials in MSW may contains elements which can cause corrosion, dangerous air emission in which common biomass or coal boiler is not capable to handle [9].

There are many different types of WtE technology, but three most largely used technologies are thermal conversion, biological conversion and landfilling, as shown in Fig 2. Thermal conversion engines require combustible materials with moisture content less than 60% to be burn completely. Any material with higher waste content need to dried before supplied to furnace. The incoming waste may or may not treated, depending on the capability of the WtE technology.

The thermal conversion process as seen in Fig 2 consists of Incinerator, Pyrolysis, and Gasification. The main difference between the process conditions and the resulting product can be seen from Table I. In the Incinerator, it can consume raw waste, in contrast to gasification which requires pre-treatment of the waste before it is supplied to the combustion chamber.

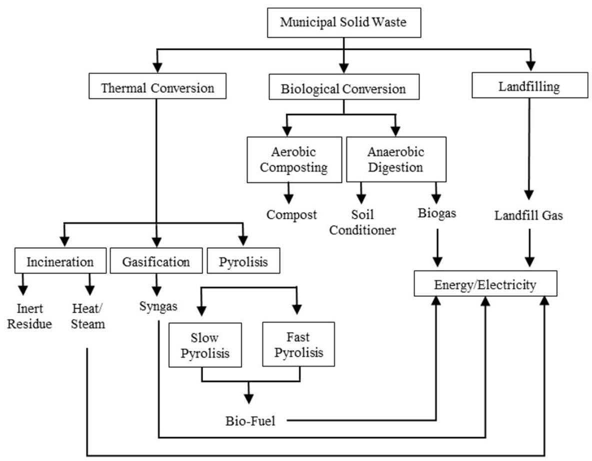

Fig. 2. Municipal Solid Waste Technology [10]

Table 1 - OPERATION PARAMETERS IN THERMOCHEMICAL TECHNOLOGY [10]

	Pyrolisis	Gasification	Combustion
Temperature (°C)	250-900	500-1800	800-1450
Pressure (bar)	1	1-45	1
Atmosphere	Inert/Nitrogen	Gasification agen : O_2, H_2O	Air
Stoichiometric	0	<1	>1

Gasification and pyrolysis technologies require less air than incinerators to carry out waste energy conversion reactions. Biological conversion is a process based on the decomposition of waste with the help of bacteria. This technique is usually used to treat waste with high organic and water content. If the water content is above 60%, the thermal conversion technology cannot be applied to destroy the waste.

There are two types of waste decomposition using biological conversion, namely composting and anaerobic digestion. Landfilling is disposal of waste on the land which is managed to produce methane gas and controlled the leachate as by product. The capital cost for this technology is the lowest compare to others, but land requirement is the largest.

B. MSW Composition In Indonesia

MSW in the final disposal comes from various sources. Three biggest waste volume is from households, office areas, and market, as seen in the Fig 3. Meanwhile, the majority materials in Indonesian MSW are organic, about 58%, which consist on food waste, wood residues, paper and leather. If combustible material is used as categorization, then maximum 88% material can be used as feedstock in the thermal engine. Furthermore, the elements of waste material that can affects energy conversion and equipment lifetime, such as chlorine, potassium, heavy metal may vary among the cities. Water content in the waste material can also play important role to the performance of WtE technology. The new coming MSW could has water content 60%, in which required drying process, otherwise the electricity output from engine will be lower, due to heat loss carried out to stack by water vapor.

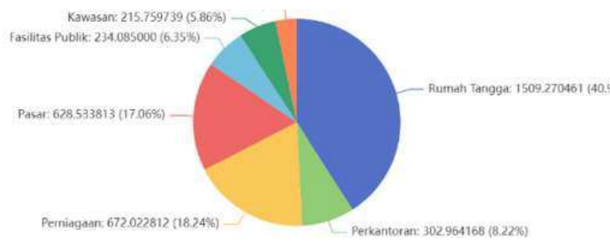

Fig. 3. Source of common MSW in Indonesia [5]

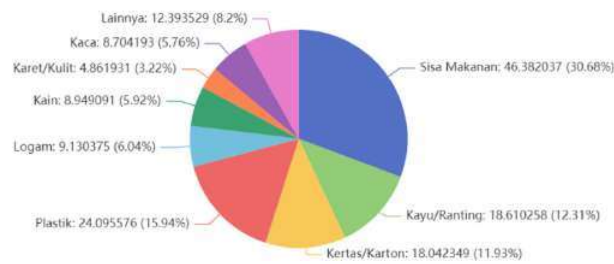

Fig. 4. Waste Composition [5]

Compliance with environment regulation will require MSW to be analyzed detail, not only its composition, and combustible material, but also elements that can generate dangerous air emission, such as dioxin furan, SOx, NOx and acid gas. Even though WtE engines may release environmentally unfriendly flue gas, but high-quality air pollution control equipment will filter this dangerous emission to meet the regulation standard.

C. The Capital Cost for WtE

For the same capacity of WtE, the capital cost varies [10] The level of efficiency, the air pollution control and the control instrument operation contribute to the final cost of technology. The below table (TABLE II) shows ranges of capital cost for incineration, pyrolysis, gasification, anaerobic digestion and landfilling. For the same type technology, there could be variation in price, which is affected by differences in ease of operation and performance. The country of origin of production also determines the price of a machine, even with the same brand. This is due to the different production quality. The trend of WtE technology deployment in the world also affected by its capital cost of it. Only high-income countries can have various choices of WtE technologies with high efficiency, as seen in the Fig 4.

Table 2 - COST COMPARISON OF WtE TECHNOLOGIES

WtE Technologies	Capital Cost (US$/tonne of MSW/year)	Operational Cost (US$/tonne of MSW/year)
Incineration	400-700	40-70
Pyrolisis	400-700	50-80
Gasification	250-850	45-85
Anaerobic Digestion	50-350	5-35
Landfilling With Gas Recovery	10-30	1-3

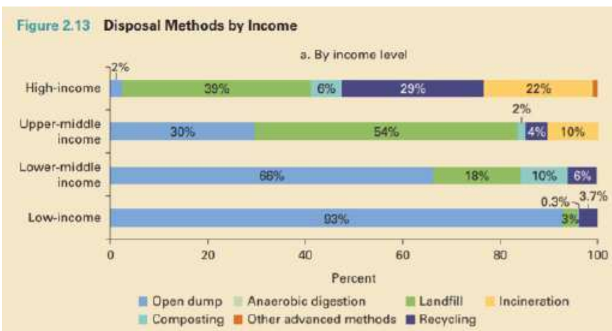

Fig. 5. Technology for MSW in the World by Income Level [11]

D. Waste Reduction Capability

Each type of waste to energy technology has different capability of material reduction. They depend on what chemical reaction occurs during the conversion energy process in the power plants and the properties of waste material. The material that can be processed by thermal reaction in short time, less than an hour, could be reduced volume up to 90%. Combustible material may benefit by its properties, which can be burnt and reduced significantly its volume, leaves ashes as inert material. Organic material, due to its high moisture content up to 60% facing difficulties to proceed chemical reaction in the general combustion furnace. However, anaerobic digestion and landfilling technologies decomposed any organic material with high moisture content in six weeks. Another type of technology implemented in waste reduction in Indonesia is RDF (Refused Derived Fuel). However, as RDF technology is categorized as solid fuel preparation, not as energy conversion technology, has limitation to eliminate waste. The factors that hinder RDF to reduce waste in large percentage are technical and commercial aspects. From technical view, the final product standard and drying process would present challenges.

The current Indonesian standard for RDF: SNI 8966:2021 requires organic volume by 90%. Based on MSW composition in Indonesia, there would be many MSW left, as organic waste only contributes 58%. Approximately about 24% of waste will remain at the final disposal which consist of plastic (16%) and others inorganic combustible (8%).

Meanwhile based on RDF project in Cilacap plant, drying process of new waste will last 28 days. This drying times is much longer, compare to MSW drying process in the Benowo WtE, Surabaya, Indonesia, which takes only 5 days.

The commercial aspects challenges RDF is to acquire potential buyer. RDF, as upgraded solid waste fuel, can be fed to boiler of CFPP (Coal Fired Power plant) at certain prerequisite. As the capacity of CFPP in Indonesia varies, there is a concern that RDF production may not be able to supply the CFPP demand at fixed percentages of daily fuel consumption.

Table 3 - PERCENTAGE OF WASTE REDUCTION BY TECHNOLOGY TYPES

Type of Technology	Percentage of Waste Reduction	Type of Waste Can Not Be Reduced
Thermochemical ; Incinerator and Gasification	90%	Inert waste material such glass, metal
Landfilling	50%	Inorganic material
RDF	70% maximum, depends on the standard to produce RDF and the availability of land to produce RDF	It refers to SNI 8966-2021 about RDF, which requires organic volume by 90% in the RDF, thus there are still many MSW left, i.e., 24% consist of plastic (16%), and others combustible (8%)
Biogas	50%	Inorganic material

The second thing is that there is not yet price standard for RDF, therefore the sustainability of this fuel supply chain is questionable as too high RDF price will reduce buyer's interest. Moreover, the RDF buyer should be firmed that their boiler has the capability to burn RDF during the years of operation, without any modification in the boiler. Transportation of RDF product to CFPP plant would be another challenge. As final MSW disposal is located near the city, meanwhile CFPP location is more far away from the city. Therefore, the truck to transport RDF will pass through the main city road. This transportation would need special license from local Government.

E. Framework Of Waste to Energy Technology Decision

Technology suitability studies need to be carried out to select the appropriate WtE technology. High variation in the content of the processed waste, the influence of the local climate on the water content of the waste, and the emission demands from the waste destruction process are the factors to be considered. Another important factor is the availability of financial support for WtE operations. The higher the financial facilities obtained by the WtE project, the easier the choice of technology, because the options to choose are wider. To simplify the decision of technology selection, 3E (Energy, Economic and Environment) assessment framework is used to analyzed the available information and parameter.

1. Energy

a. Waste Characterization

This analysis is required to understand the quality and the quantity of waste. The resulted analysis data then used to match with the available engine capability and performance based on the proposed MSW. The analysis to carry out, i.e., proximate and ultimate analysis, ash analysis, and trace metal analysis. Then, discuss with technology provider to understand the suitability of waste towards proposed engine.

b. New or Old Waste

The new waste contains high moisture content, up to 60%, particularly food waste. Further drying process may be needed before supplying to WtE thermal technologies. In fact, there is a need to install special drying equipment for new waste as thermal technologies is only capable handling waste with maximum 45% water content [13]. Old waste may benefit in shorter energy conversion process as the drying process already occurred by the assist of sun shining during the open dumping disposal for years. Based on Putri Cempo WtE in Solo, old waste can be fed to gasifier without the need of the drying facility.

c. Waste Reduction Capability

As mention in Table III, each technology has different capability of waste reduction. Though, how much waste should be eliminated also depends on whether massive waste reduction is compulsory or not in the MSW project contract.

d. Waste Processing Time

The period of waste processing, started from the incoming waste at final disposal, up to the final process that generate thermal energy or final product, also have impact on WtE project performance. As new MSW delivered daily to final disposal, any delay or long processing time could increase the waste heap.

e. Net Electricity Sales

Some of the electricity produced from generator, will be used as internal consumption and the remaining, is delivered and sold to grid. Each technology may have different electricity consumption for auxiliary equipment. The failure to know in detail will affect in the project income.

2. Economic

The electrical parameters of the WtE project are shown in Table IV.

The formula for calculating the Levelized Cost of Electricity (LCOE) is based on equation (1).

Table 4 - FINANCIAL PARAMETER FOR ELECTRICITY FROM WtE

Main Financial Parameter	Unit	Value
Contract Duration	Year	20
Availability Factor	%	80
Debt/Equity		70/30
Cost Escalation	%	3
Interest Rate	%	10
Discount Factor	%	12
Payback Period	Year	7
Income Tax	%	22
IRR	%	14

Where is :

a. Electricity Tariff Sales

$$LCOE = \frac{sum\ of\ costs\ over\ life\ time}{sum\ of\ energy\ produced\ over\ lifetime}$$

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (1)$$

Where is :

It : Investment expenditures in the year t, and Mt for Operations and maintenance expenditures in the year t

Ft : Fuel expenditures in the year t

Et : Electrical energy generated in the year t

r : Discount rate, and n for expected lifetime of system or power station

The selling rate of electricity from PLTSa with a capacity of up to 20 MW, based on Presidential Regulation No. 35 of 2018 is 13.35 usd cent / kWh, for a contract period of 20 years. By entering the financial parameters as shown in the Table IV, for the calculation of electricity tariffs, and by using the levelized cost of electricity formula in Fig 5, it is found that the investment of WtE power plant that can reach an IRR of 14% with 13.35 usd cent / kWh tariff is 4 million USD/MW. So that this capital cost of WtE technology is an indication of the maximum price of electricity from the WtE without financial assistance from any party. If the potential WtE developer decides to choose a technology with capital cost higher than 4 million USD/MW, then other financial support is needed, such as a tipping fee.

b. Tipping Fee

The tipping fee or gate fee is the cost per ton of waste, which is intended as the cost of operational assistance for the WtE project. In developed countries, the percentage of WtE project revenues from tipping is the largest, up to 50%, compared to electricity sales from waste energy [13] The following Table V provides information on the amount of tipping fees for WtE projects. The amount of this tipping fee is usually related to electricity tariffs. If the IRR on Project value of a project is less than 14%, then a tipping fee is required to ensure the continuity of WtE operations.

c. Project Capacity

Larger engine capacity will benefit from the final price, as there is a discount price per MW. Thus 20 MW WtE generate profit better than smaller one.

d. Land Requirements

Land plays an important role in WtE. Acquisition of land for large projects is not easy, not only the problem of higher land prices, but also the potential for conflict with the surrounding community or the need for permits. High project land prices can reduce financial income.

e. Water

The project developer needs to determine the type of water quality required. Is the water quality demineralized water or just groundwater? This affects the need for investment costs because of the additional costs for water treatment equipment.

f. Delivery Time

High-efficiency WtE power plant equipment requires longer design times. This is conducted to evaluate the suitability of the composition of the waste to the type of machine to be designed.

Table 5 - TIPPING FEE FOR WtE PROJECT

Country	Average Tipping Fee For a WtE Plant (US$/t)	Average Tipping Fee For a Landfill Site (US$/t)
Sweden	84	193
United Kingdom	148	153
USA	68	44

Land plays an important role in WtE. Acquisition of land for large projects is not easy, not only the problem of higher land prices, but also the potential for conflict with the surrounding community or the need for permits. High project land prices can reduce financial income.

3. Environment

a. Emission compliance

Emissions from WtE must meet the emission quality standards from the Ministry of Environment Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No P.15/MENLHK/SETJEN/KUM.1/4/2019 concerning Emission Quality Standards for Thermal Power Plants.

b. Ash Disposal or Utilization Planning

Although waste technology is also called zero waste, it still leaves ash which is an inert material so it cannot react and decompose. The amount of ash remaining is up to 5% of the amount of waste supplied to the power plant. WtE planning needs to plan a landfill or utilization of ash from the waste which is the final product of the WtE plant.

c. Leachate (Liquid Waste)

Whether the WTE power plant project produces hazardous liquid waste needs to be discussed with the technology supplier. WtE thermal technology does not produce liquid waste that is harmful to the environment. This is different from the biological, which produce wastewater, namely leachate, which requires a processing unit to purify it.

V. CONCLUSION

The increase MSW at final disposal [5] presents pressure to Local Government to solve it with the most effective measure. Considering the competitive condition for respectively WtE technology will encourage the sustainable MSW Management in Indonesia, as well as supporting the implementation of President Regulation No 35 of the year 2018 concerning Acceleration of Construction of Waste Processing Installations into Electrical Energy Based on Environmentally Friendly Technology.

Technology selection is one of the important steps to develop WtE project [3]. As the availability of technologies varies, which depends on the waste composition and the financial ability, the process to analyze is not easy [8]. Based on best practice in other countries, such as Japan, Sweden, and USA [13], the electricity tariff will determine how much flexibility in technology selection. Each technology has different competitive aspect and crucial issues to deploy. The following Table VI provides competitive condition in which each WtE technology may benefit the most.

Table 6 - COMPETITIVE CONDITION FOR WtE TECHNOLOGY IN INDONESIA

Technology Type	Project competitiveness	Crucial Issues in Operation	Advantages in Operation
Incinerator	Minimum MSW supply is 500 tons/day, available tipping fee and 2 ha land for 10 MW capacity	Air pollution control must be monitored and controlled accurately	Capability to burn all raw waste with various compositions
Gasification	MSW supply is below 1000 tons/day, a tipping fee is necessary if the investment costs cannot take advantages of the economic of scale advantages of the project capacity	MSW must be separated, dried at 20% maximum water content and only handle household waste	Gasification system eliminates HCl and dioxin furan gas pollution without additional flue gas treatment, highest efficiency for the same WtE technology capacity, lower carbon emissions.
Pyrolysis	Waste supply is below 500 tons/day, a tipping fee is necessary in the event that the investment costs obtained cannot take the advantage of the advantages of economies of scale from the project capacity	MSW must be separated, dried at 20% maximum water content and only handle household waste	Capable of consuming up to 100% plastic waste and producing final products which consist of electricity and liquid/solid fuels
Landfill	No target for waste reduction up to 90%, large area available: 1 Ha/MW, the lowest WtE investment cost	Ensure that waste is tightly closed, leachate (waste water) management needed	No need drying process of MSW and less air emission control equipments
RDF	There is no target for waste reduction of up to 90%, 1 Ha/250 ton of waste is available, standby buyers are available who understand the impact of RDF when burned	Ensure the composition and quality of RDF waste according to the standard. Depending on how dry the existing MSW, it may require additional cost to achieve water content target.	Ease of transportation

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