A Techno-Economic Evaluation of Municipal Solid Waste (MSW) Conversion to Energy in Indonesia

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Abstract: Municipal solid waste (MSW) processing is still problematic in Indonesia. From the hierarchy of waste management, it is clear that energy recovery from waste could be an option after prevention and the 5R (rethink, refuse, reduce, reuse, recycle) processes. The Presidential Regulation No 35/2018 mandated the acceleration of waste-to-energy (WtE) plant adoption in Indonesia. The present study aimed to demonstrate a techno-economic evaluation of a commercial WtE plant in Indonesia by processing 1000 tons of waste/day to produce ca. 19.7 MW of electricity. The WtE electricity price is set at USD 13.35 cent/kWh, which is already higher than the average household price at USD 9.76 cent/kWh. The capital investment is estimated at USD 102.2 million. The annual operational cost is estimated at USD 12.1 million and the annual revenue at USD 41.6 million. At this value, the internal rate of return (IRR) for the WtE plant is 25.32% with a payout time (PoT) of 3.47 years. In addition, this study also takes into account electricity price sales, tipping fee, and pretreatment cost of waste. The result of a sensitivity analysis showed that the electricity price was the most sensitive factor. This study reveals that it is important to maintain a regulated electricity price to ensure the sustainability of the WtE plant in Indonesia.

Keywords: techno-economic analysis; waste to energy; municipal solid waste; Indonesia

1. Introduction

Municipal solid waste management (MSWM) is gaining higher public concern due to a rapid increase in urban population. According to the hierarchy of waste management, MSWM should be started with the highest priority by preventing the generation of waste, followed by rethink, refuse, reduce, reuse, and recycle (5R) programs [1]. The following preferred stage is energy recovery using waste-to-energy technology. The last option in the waste hierarchy is direct waste disposal in a landfill [2].

Through the Waste Wise Cities program, UN-Habitat has also addressed the 12 key principles for handling MSW [1]. These principles extended the scope of waste hierarchy by involving stakeholders as well as aligning the MSWM to achieve SDGs. Despite numerous initiatives led by the UN to tackle MSWM problems, the implementation of MSWM in many parts of the world is still problematic, especially in developing countries with limited access to investment and social problems. Hence, it is always interesting to investigate the MSWM approaches in various developing countries as a part of their effort to reach SDGs.

The challenge of MSWM in developing countries is typically characterized by problems related to unsorted waste at source, limited access to a waste collection network, excessive use of landfills, uncontrolled release of leachate, and gas emission from landfills [3]. Due to limited and higher prices for landfills, as well as increased social pressure, the use of landfills is becoming less attractive. This is also accompanied by a growing sense of urgency to apply a higher waste hierarchy such as WtE. WtE technology is often viewed as an attractive option as it eliminates waste and also facilitates energy recovery.
Furthermore, WtE also plays a role in reducing global warming emissions as compared with traditional landfills [4]. It is also important to note that the implementation of WtE does not hinder reuse and recycle activities [5]. As a result, numerous studies on WtE application in developing countries have been reported in the present literature such as India [6] and Pakistan [7].

The implementation of WtE in developing countries faces numerous challenges and obstacles from social and economic aspects. There are also several additional factors that have to be considered such as identification of waste characteristics and volume, appropriate tariff system regulations, adequate human resources, ability to cover huge investments and operational costs, as well as appropriate regulatory support from the government [8]. Despite the large investment for WtE, it is also important to note that WtE is not a silver bullet for solving MSW problems and it should be combined with reliable 5R programs.

2. Current Status of Waste to Energy (WtE) in Indonesia

Indonesia is one of the most populous developing countries, with more than 270 million people in 2020 [9]. Almost half of the population live in urban areas, which results in high municipal waste production. However, municipal waste management is still problematic in many parts of Indonesia due to the overcapacity of existing landfills. On average, 81% of households still directly disposed of their waste without sorting or reutilization, eventually ending up in landfills [10].

Since landfills still play a major role for MSWM in Indonesia, the current practice contradicts the principle of waste management. Since 2008, the government of Indonesia has initiated a series of actions to reduce the use of landfills. It was started by a Legislative Act no. 18, in 2008, which obligates the central and municipal governments to suppress the growth of waste generated by the adoption of 5R initiatives [11,12]. Moreover, the act also encourages waste management to use eco-friendly products and environmentally friendly technology. Furthermore, in 2012, the central government produced an executive order that considers waste as an alternative resource to be further reprocessed directly or indirectly [13].

Waste recycling and reuse practices in Indonesia are still progressing slowly due to social and technical challenges. However, several initiatives such as the creation of “waste banks”, have been implemented in several areas in Indonesia, for example, in Surabaya [14]. This initiative is often managed by a local community in Indonesia. Waste banks encourage people to sort their waste and incentivize selling the waste to waste banks. Nonetheless, there are also limitations associated with the current practice of waste banks in Indonesia. Many waste banks have not been managed properly with a lack of funding and facilities making it difficult to process the collected waste efficiently. Furthermore, a large part of society still does not appreciate the presence of these ‘facilities’, thereby reducing the incoming waste to waste banks [15].

The slow progress in the 5R has encouraged the Government of Indonesia to implement large-scale WtE technology as part of MSWM. The application of WtE technologies is considered to be feasible for tropical MSW, even without any additional fuel [16]. The 2008 Regulation No. 18 was followed by a newer Presidential Regulation No. 18/2016, which aimed to accelerate the construction of Pembangkit Listrik Tenaga Sampah (PLTs) or waste-to-energy plants in seven cities. According to this regulation, the minimum size of the WtE plant was capped at a minimum of 1000 tons of waste per day [17]. However, this regulation did not provide any additional support for private or state-owned enterprises other than a statement that assigned the Perusahaan Listrik Negara (PLN) or State Electricity Company to buy the electricity generated from waste. The lack of incentives was further proven by the slow development of the new WtE plants in Indonesia (only one pilot plant was completed from 2016 to 2019). The slow progress of WtE plant adoption in Indonesia is often associated with the lack of government guarantees in tipping fees and electricity prices.
Subsequently, the government renewed the Presidential Regulation No. 18/2016 by releasing a newer President Regulation No. 35/2018. The new regulation encouraged the development of WtE plants in 12 cities by providing more detailed incentives to operate a WtE plant. The regulation mandated the central government to provide an incentive (known as tipping fee) to the local government as high as USD 33.78 (equivalent to Indonesian Rupiah (IDR) of 500,000) for each ton of waste processed in the WtE plant. Furthermore, the new regulation also stated a distinctive tariff for each kWh of electricity sold from the WtE plant to PLN, which was around USD 13.35 cent/kWh for a plant under 20 MW and USD 14.54 cent/kWh for a plant above 20 MW with a correction factor.

However, since the enforcement of President Regulation No. 35/2018, only one pilot plant out of 12 WtE plants has been operating since 2018, known as PLTSa Merah Putih in Bantar Gebang, Jakarta. Recently, in May 2021, a WtE plant in Benowo, East Java Province, started to operate by processing 1000 tons of waste/day with an electricity capacity production of 11 MW as the first large-scale WtE plant in Indonesia [18]. Despite a series of government regulations to support the development and operation of WtE plants in Indonesia, the construction of WtE plants in Indonesia is still considered to be slow. One of the most critical factors influencing the establishment of WtE plants is the debate over electricity price, which is higher than that of conventional coal-based electricity.

The present study aimed to investigate the techno-economic evaluation of a commercial WtE plant in Indonesia. Here, the effect of President Regulation No. 35/2018 on our techno-economic evaluation was also examined. Fixed capital and operating costs were both considered. At the same time, income from sold electricity, tipping fees, and recyclable waste were also taken into account. To justify the economic attractiveness of the project, the internal rate of return (IRR) and payout time (PoT) as economic feasibility parameters were introduced. Furthermore, sensitivity analyses were also performed to obtain the influence of critical factors on the IRR and PoT parameters.

3. Methodology
3.1. Estimation of Capital Investment

A capital investment estimation was made based on documents published by United Nations. It has been determined that in developing countries, a 150,000 ton per year WtE plant would typically cost around USD 35.2 million and this value was used in the present study [21]. For comparison, the World Bank has estimated that a typical WtE plant costs around USD 190/annual ton of waste incinerated [22]. From this estimation by the World Bank, a WtE plant at the same capacity (150,000 ton/year) would cost around USD 33.5 million. Afterwards, the initial capital investment was determined by using the standard six-tenths rule [23,24].

3.2. Economic Feasibility Study Parameters

Techno-economic usually resulted in a few economic parameters such as net present value (NPV), return on investment (RoI), payout time (PoT), and internal rate of return (IRR). These parameters are widely accepted and have been implemented in many WtE techno-economic studies [25–29]. However, the NPV only indicates the absolute value of a project which greatly differs at different scales. The second parameter, RoI, indicates the ratio of annual profit to capital investment. This value also varies considerably between the scales of assessed projects, and thus is difficult to compare. Therefore, to assess the feasibility of this project, the IRR and PoT were used.

The IRR (Equation (1)) demonstrates the rate of return of a specific investment, whereas PoT (Equation (2)) expresses the time needed to recover the initial investment [30]. These
two parameters have been widely accepted in many techno-economic works in the literature such as a feasibility study on heat exchanger replacement [31], a feasibility study on a WtE industry in China [29], and a feasibility study on gasification and anaerobic digestion WtE plants in Saudi Arabia [27]. Additionally, the IRR and PoT are two of the most easy-to-compare parameters available. They can give value to investment interest and the time span needed to recoup the capital cost. They can be represented as follows:

\[
I = \sum_{j=1}^{N} \frac{C_j}{(1 + IRR)^j}
\]

(1)

\[
PoT = I / C
\]

(2)

where \(I\) stands for initial investment which comprises the total investment made, \(C\) is the net cash flow which comprises the difference between operating incomes and operating expenses, and \(j\) is the number of years. The income and expenditures highly rely on season, regulation, and operating conditions. However, to simplify, these values were assumed to be constant over the lifetime of the WtE plant.

4. Results and Discussion

4.1. Estimation of WtE Plant Capacity

In general, a WtE plant uses a direct incinerator, air gasifier, or plasma gasifier to generate energy in the form of heat or volatiles. The scale of electricity generated is strongly correlated to the calorific value of waste. It has been suggested that a WtE plant should be supplied with feed that contains no less than 6 MJ/kg calorific value [21]. Subsequently, the calorific value of MSW was assumed to be 6.5 MJ/kg. The calorific value is not directly related to the actual energy generated due to heat loss. Typically, the conversion of heat to electricity varies around 35%, which was taken as an assumption in this study.

In this study, a WtE plant with a capacity of 1000 tons of pretreated waste per day or around 20% more than the average municipal waste in Indonesia [32] was examined. Furthermore, from 1000 tons per day of feed, 75% of it was fed to the incinerator. At the same time, the remaining (25%) feed was processed as a recyclable waste that could be sold to a third party. Hence, the plant could handle 750 tons of waste per day and generate 19.7 MW capacity or equivalent to ca. 474 MWh electricity per day.

\[
Purchased\ Equipment\ Cost = \left(\frac{365,000\ ton}{150,000\ ton}\right)^{0.6} \cdot (USD\ 35,270,270.27)
\]

(3)

\[
Purchased\ Equipment\ Cost = USD\ 60,135,337.24
\]

Using Equation (3), the initial investment to build this plant at the intended capacity of 1000 tons of waste per day is estimated at around USD 60 million. However, this value does not include the cost to purchase the land and the maintenance of the land. Therefore, this value was assumed to be around 70% of the purchased equipment cost or around USD 42.1 million. Thus, these values were summed and regarded as the fixed capital, valued at USD 102,230,073.31.

4.2. Estimation of Operating Expenses

To maintain the production of electricity from waste incineration, a few expenses should be considered. Operational expenses usually include pretreatment costs, salaries for 80 employees, and other ordinary chemical plant expenses such as maintenance costs, taxes, and asset depreciation. The pretreatment cost is intended to pay for the sorting process of waste and the drying process. This cost is due to the nature of MSW in Indonesia which usually has high water content and mixed type of waste. Here, the pretreatment cost was set at USD 6.76 per ton of waste, and this value could vary regionally, depending on waste condition and composition.
As seen in Table 1, pretreatment cost accounts for more than 20% of total operational cost. This ratio highlights the importance of the sorting process in the source of waste, especially to separate the organic from the inorganic waste.

### Table 1. Annual operating expenses of a 1000-ton-per-day WtE plant in Indonesia.

| Component                | Specific Value            | Annual Value (in USD) | Percentage |
|--------------------------|---------------------------|-----------------------|------------|
| Pretreatment costs       | USD 6.76 Per ton waste    | 2,466,216.22          | 20.37      |
| Employee salaries        | USD 46,047.30 Per month   | 552,567.57            | 4.56       |
| Maintenance costs        | 2% Fixed capital          | 2,044,601.47          | 16.89      |
| Plant Supplies           | 15% Maintenance costs     | 306,690.22            | 2.53       |
| Royalties and patent     | 1% Sales                  | 292,603.45            | 2.42       |
| Utilities                | 100% Maintenance costs    | 306,690.22            | 2.53       |
| Direct Operational Cost  |                           | 5,969,369.14          | 49.30      |
| Payroll overhead         | 15% Salary                | 82,885.14             | 0.68       |
| Laboratory              | 10% Salary                | 55,256.76             | 0.46       |
| Plant overhead           | 50% Salary                | 276,283.78            | 2.28       |
| Indirect Operational Cost|                           | 414,425.68            | 3.42       |
| Depreciation            | (Capital-Salvage Value)/(Plant Lifetime) | 3,680,282.64  | 30.39      |
| Property taxes          | 1% Fixed capital          | 1,022,300.73          | 8.44       |
| Insurance               | 1% Fixed capital          | 1,022,300.73          | 8.44       |
| Fixed Operational Cost  |                           | 5,724,884.11          | 47.28      |
| Operational Cost        |                           | 12,108,678.92         | 100.00     |

### 4.3. Operating Incomes

Incomes from the operation of the WtE plant in this study come from three primary sources: electricity sales, government tipping fees, and the sale of recyclable waste, which were assumed to account for 25% of total waste. The electricity sales and government tipping fees are based on President Regulation No. 35/2018 [33]. In addition, the sale of recyclable waste was estimated to be USD 0.02 per kg of recyclable waste sold.

As seen in Table 2, electricity sales account for more than half of the income in the WtE plant, followed by tipping fees at ca. 30%, and recyclable waste sales at ca. 15%. Hence, it shows that the price of electricity is critical, and assumed to remain the same as the committed price from the government. Furthermore, the current tipping fee at USD 33.78/ton of waste also played an essential role in recouping the investment and operational costs. Thus, it is crucial to assess the sensitivity of economic parameters to the tipping fees and electricity prices, as provided later in Section 4.5.

### Table 2. Operating incomes of a 1,000-ton-per-day WtE plant in Indonesia.

| Income           | Value per Day | Specific Value       | Amount (in USD per Year) | Percentage |
|------------------|---------------|----------------------|--------------------------|------------|
| Electricity      | 473,958.33 kWh| USD 0.1335/kWh       | 23,094,804.69             | 55.53      |
| Tipping fees     | 1000 ton      | USD 33.78/ton        | 12,331,081.08             | 29.65      |
| Recyclable waste | 250 ton       | USD 0.02/kg          | 6,165,540.54              | 14.82      |
| Total (in USD per year) | 41,591,426.31 |                      |                           | 100        |

### 4.4. Economic Evaluation for the Base Case

The feasibility study conducted accounts for ten years of operating to obtain IRR and PoT values comparable to other projects. Additionally, the plant is assumed to have salvage value, valued at 10% of the initial capital investment cost after 25 years of operation (plant lifetime). From the cashflow analysis of a 1000-ton-per-day WtE Plant in Indonesia,
which produces about 470 MWh of electricity per day (Figure 1), the plant will reach the economical even point or payout time at 3.44 years after the inception. At the same time, the IRR of the plant reaches 25.59%.

Figure 1. Feasibility study cash flow of a 1000-ton-per-day WtE plant in Indonesia.

The comparison of the present results to other studies is presented in Table 3. The value of the PoT and IRR found in this study is quite attractive and indicates a more favorable environment for WtE plant operation in Indonesia than in other countries. However, other studies do not necessarily include a substantial amount of tipping fees or special prices on electricity sold as promised by the government.

Table 3. Comparison of WtE plant economic feasibility studies.

| Location of Study | Technology       | PoT, Years | IRR, % | Reference                     |
|-------------------|------------------|------------|--------|-------------------------------|
| Indonesia         | Thermochemical   | 3.44       | 25.59  | This study                    |
| Indonesia         | Thermochemical   | -          | 8.17   | Roswulandari and Daerobi [34] |
| Saudi Arabia      | Thermochemical   | 9.73       | 11.12  | Hadidi and Omer [27]         |
| Saudi Arabia      | Biochemical      | 4.94       | 25.22  | Hadidi and Omer [27]         |
| China             | Thermochemical   | 11.30      | 12.22  | Zhao et al. [29]             |
| China             | Thermochemical   | 5.40       | 21.19  | Guo [35]                      |
| South Africa      | Hybrid           | 8.40       | 18.49  | Mabalane et al. [26]         |
| England           | Thermochemical   | -          | 20     | Eke and Omwudili [36]        |
| Colombia          | Thermochemical   | -          | 11.18  | Alzate-Arias et al. [37]     |

In addition, it is also interesting to note that the WtE electricity price that has been used in the present study was USD 13.35 cent/kWh, which is higher than the average electricity
price of a typical household in Indonesia, which is around USD 9.76 cent/kWh. As a result, this may cause a substantial deficit to PLN. In addition, the tipping fees provided by the municipal government may not reach USD 33.78 per ton of waste. In East Java, the tipping fees are set at USD 10.14 per ton of waste, which largely impacts the WtE plant’s profitability [34].

4.5. Simulation Analysis

The sensitivity analysis of the economic parameters was conducted by changing the amount of tipping fees and price of electricity to the IRR and PoT values. The tipping fees were supposed to be set at a maximum of USD 33.78 per ton of waste processed. However, tipping fees vary significantly between municipal governments and are often far below the intended values.

As seen in Figure 2, a dividing line has been provided to indicate the zone where the combination of electricity price and tipping fees give an IRR above or below 10%. Thus, for example, tipping fees of USD 20.27/ton and an electricity price around the same as the electricity price of a typical household in Indonesia (USD 0.1001/kWh) give an IRR at 6.94%, which is comparable with the finding by Roswulandari et al. who studied 280 kWh/ton of waste and assumed the purchasing price by PLN to be around USD 0.1686/kWh [34].

![Figure 2. Values of internal rate of return at various tipping fees and electricity price combinations.](image)

Figure 3 shows the relative change in electricity prices and tipping fees to the IRR and PoT. As the figure suggests, the slope of the electricity price is steeper than the tipping fees. Hence, a change in electricity price give higher sensitivity than that of tipping fees to the IRR and PoT.

Figure 3a also shows an interesting result where the IRR value in the absence of tipping fees (−100% tipping fees or 0 tipping fees) gave an IRR value of 10%. This value of IRR corresponds to the operation scenario based on a very tight budget. A 40% decrease in tipping fees gives an IRR value around 20%. Whereas a WtE plant without a firm electricity price would eventually be forced to shut down as the IRR would reach under 15% after a 40% decrease in electricity prices. Therefore, the government and investors need to devise appropriate policy for electricity supply regulation in Indonesia. Especially in a challenging condition where the exchange rate to USD, crude oil price, inflation, and coal price change significantly [38].
5. Conclusions

Converting waste to energy could be a viable option for Indonesia, which has a significant urban population. Here, the influence of the current Indonesian government regulation (known as Presidential Regulation No. 35/2018) on the feasibility of a WtE plant in Indonesia was investigated. The WtE electricity price was set at USD 13.35 cent/kWh, which was higher than the average current household price at USD 9.76 cent/kWh. For a base case simulation, the economic feasibility of 1000 tons of waste/day to produce ca. 19.7 MW of electricity was assessed. The capital investment was estimated at USD 102.2 million. The annual operational costs were estimated to be USD 12.1 million and the annual revenue was estimated to be USD 41.6 million. At these values, the IRR of the WtE plant is 25.32% with a PoT of 3.47 years. By performing sensitivity analyses of tipping fees and electricity prices to the IRR and PoT, it appears that the electricity price was the most sensitive factor. This study reveals the importance of the government to regulate electricity prices for a WtE plant. The certainty of electricity prices would ensure the sustainability of the WtE plant in Indonesia.

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