LPEM-FEBUI Working Paper - 073
November 2022

ISSN 2356-4008

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LPEM-FEB UI Working Paper 073

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ISSN 2356-4008

Potential and Cost of Electricity Generation from Municipal Solid Waste Incineration in Pekanbaru Municipality

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Executive Summary
Municipal solid waste (MSW) management remains a challenge in in Pekanbaru. To avoid the negative externalities associated with improper waste disposal, the development of waste-based power plant (or PLTSa), including through incineration technology, is increasingly viewed as an attractive option. This study estimated that electricity generation potential from MSW in Pekanbaru could reach 0.021 MW/ton MSW and levelized cost of electricity (LCOE) from incineration PLTSa is around 21.03¢ per kWh. Waste calorific value and feedstock supply are essential to maintain the cost competitiveness of incineration PLTSa in Pekanbaru.

JEL Classification: Q42; Q48; Q55

Keywords
municipal solid waste — energy potential — waste power plant — incineration — levelized cost of electricity

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1. Introduction

Waste management becomes an emerging challenge for fast developing countries (Liu et al., 2021). The improper waste management bring consequences to environmental problems which ultimately result in social and economic losses. piles of untreated waste are an eyesore for the environment, particularly in densely populated areas (Flores, 2008). It creates negative nuisance effects such odor, unattractiveness, noise, and other visual disadvantages (Reichert et al., 2020; Zeiss & Atwater, 2008). These nuisance impacts could aggravate community resistance since it triggers more serious concerns about impacts on community health, both short and long-term effect (Zeiss & Atwater, 2008). Congenital anomalies, asthma, and respiratory infection (Kumar & Prakash, 2020) are such examples of short-term effects while chronic respiratory and cardiovascular diseases, cancer and even brain, nerves, liver are described as long-term health effects related to waste (Vrijheid, 2000). More recently, there is a finding of global contribution of IQ loss to the damage cost of waste (Rabl et al., 2008). A strong correlation was found between the house market price and both nuisance and health indices. Waste issue had severe adverse impacts on selling price and marketability that result in reducing house prices up to 7% in areas bordering untreated waste piles (Reichert et al., 2020) as well as the quality of public health and environment. Given the respective complexities, global cost of waste is anticipated to climb up to $375 billion, with the cost rising most severely in developing countries (World Bank, 2012).

Considering the aforementioned externalities, effective waste management is crucial to be implemented. One alternative is converting waste to energy. Currently, waste-based power plant, or more commonly known as Pembangkit Listrik Tenaga Sampah or PLTSa in Indonesian, is often viewed as an attractive option as it eliminates waste while also facilitating energy recovery (World Bioenergy Association, 2016). Furthermore, PLTSa plays a greater role in reducing carbon emissions by offsetting the need for energy from fossil fuel sources and reduces methane generated from landfills (IPCC, 2007). Therefore, the promotion of PLTSa as a part of sustainable waste management aligns to achieve SDGs, which are to guarantee equal access to adequate, safe, and affordable solid waste collection services, to stop uncontrolled disposal and open burning, and to achieve sustainable and environmentally sound management of all waste, particularly hazardous types, by 2030.

Compared to other PLTSa technologies, such as gasification, anaerobic digestion, and landfill gas, incinerations are utilized more extensively throughout the world (Sarasati et al., 2020). The technology could thus be considered to have a more prominent role in overcoming the waste management issue. In spite its barriers (Moon, 2018; Karim & Corazzini, 2019), it ranks highest in terms of effectiveness in reducing waste volume (Liu et al., 2020). Incineration could decrease waste volume by an estimated up to 90% (Arvanitoyannis, 2013) , where only a very small amount would be disposed of at landfill sites. Simultaneously, it contributes to the reduction of hazardous waste (Liu et al., 2020). Currently, more than a thousand incinerators powerplant have been developed around the world, while there are fewer than 20 plants dedicated to other technologies (Qodriyatun, 2021).

At the national level, the Government of Indonesia (GoI) has encouraged the implementation of large-scale PLTSa as part of sustainable waste management. The 2008 Regulation No. 18 was followed by the more recent Presidential Decree No. 18/2016, which aimed to accelerate the construction of PLTSa in seven prioritized cities. Subsequently, the GoI renewed this regulation by releasing Presidential Decree No. 35/2018, which encouraged the development of PLTSa in 12 cities by providing more detailed incentives for their operation. The regulations prioritize the usage of thermal technologies, particularly incineration, to accelerate PLTSa development in Indonesia.

Although Pekanbaru is not listed as one of the prioritized cities in the national PLTSa development plan, PLTSa development in Pekanbaru could help the city to address its limited waste management infrastructure. Waste issue has been an inconvenience for Pekanbaru inhabitants since 2016. Local population generated 1,052 tons of waste every day, equivalent with 384,039 tons of waste per year, in 2020, putting Pekanbaru as the second largest waste producer in Riau Province. However, the collection rate of domestic waste only reached 73.5 percent while composting, recycling and reutilizing rate by waste banks were still detained at 0.007 percent. The issue has become worse for the last couple of years as used plastics and putrid leftover food items were left to accumulate for weeks in markets, roadsides, as well as a few intersections and arterial roads (*detik.com*, 2022).

Incineration PLTSa is expected to be able to improve waste treatment process in Pekanbaru and reduce the volume of waste pile in the landfill. From institutional point of view, PLTSa, which involves energy recycling from waste, has been acknowledged by local government Local Regulation of Pekanbaru No. 8/2014 on Waste Management as an alternative waste management strategy that can be implemented in the city. There has been also a growing discussion about the planning of the PLTSa development in Pekanbaru (Pekanbaru.go.id, 2019). Acknowledging the prospect of incineration PLTSa as another instrument to reduce inordinate waste pile in the landfill, this study is aimed to investigate the techno-economic evaluation of electricity generation from waste incineration in Pekanbaru.

2. Methodology

2.1 Study Area

With a total coverage area of 632.26 km2, Pekanbaru is located on a strategic location as a transit city that connects the major cities of Sumatra. Over the last decade, the economy of Pekanbaru has persistently grown by 4% per year on average. Wholesale and retail trade; repair of cars and motorcycles; and processing industry have contributed to more than 70% of Pekanbaru's gross domestic regional product. By 2020, Pekanbaru was home to 983,356 people and the city's population has grown by 0.9% annually since 2010. With a population density equals to 1,555 people/km2, the city has been recorded as the third most populated city across Sumatera Island. Unsustainable practices of waste management across Riau Province, including Pekanbaru, still exist at household level. Based on Basic Health Research (*Riset Kesehatan Dasar* or Riskesdas) 2018, majority of household waste were treated through waste burning (64%) and direct disposal into water bodies (4%).

Waste management infrastructure in Pekanbaru is still limited. Muara Fajar Landfill is the only the final waste disposal sites in Pekanbaru. It was established in 1987 over 8.6 hectares of land in the Rumbai area. The landfill is managed by the Municipal Government of Pekanbaru. During the beginning stage of land clearing, Muara Fajar Landfill applied the controlled landfill method which was indicated by the presence of drainage channels to control rainwater, leachate collection channels (leachate), holding ponds, methane gas control facilities and others. Excess capacity of waste prompted Muara Fajar Landfill to re-apply open dumping. By 2020, more than 80% of Muara Fajar Landfill's total capacity has been utilized for waste disposal purpose.

2.2 Thermal Incineration Technology

Through incineration-based electricity generation, the heap of waste will be used as fuel to heat water in a boiler, where the water vapor from heating the water will be directed to turn a generator. The rotation of the turbine in the generator will produce electrical energy. This process is similar to generating electricity in a coal-fired power plant, but the difference between the two is the fuel used.

The detailed illustration of the process of generating electricity through incineration technology is described as follows (Table 1):

2.3 Waste Sorting

Waste sorting is performed because energy potential from all types of municipal solid waste (MSW) is not identical. Throughout this process, MSW in Pekanbaru was collected from the fresh pile, weighed, and separated by using hand based on their material characteristics. This study adopted waste fractions from Information System of National Waste Management (*Sistem Informasi Pengelolaan Sampah Nasional* or SIPSN), i.e.: food residue; wood, leaves, or branches; paper and carton; plastic; metals; fabric, including sanitary napkins and diapers; rubber; leather materials; glass; electronic waste; and others[1].

Waste sorting was conducted directly in Muara Fajar Landfill, Pekanbaru, from August 16th, 2021 to September 8th, 2021. Based on Israel (1992), the minimum sample size of MSW was determined by the following formula:

$$n = \frac{\left(\frac{z^2 \hat{p}(1-\hat{p})}{\varepsilon^2}\right)}{\left(1+\left(\frac{z^2 \hat{p}(1-\hat{p})}{\varepsilon^2 N}\right)\right)} \tag{1}$$

where n is sample size (in ton); z is z-score; $\hat{p}$ is population proportion (assumed to be equals to 0.5); ε is margin of error; and N stands for annual MSW delivery to Muara Fajar Landfill, equals to 283,523 ton[2]. There were 11 tonnes of sample MSW being sorted throughout this phase to achieve 90 percent confidence level and 25 percent margin of error.

2.4 Estimation of the Electrical Power Generation from Municipal Solid Waste

Thermal incineration power plant could process almost all types of MSW, except metals, glass, and electronic waste[3]. Therefore, this estimation would ignore power generation potentials from those three waste fractions. According to

[1] Electronic waste is added by the research team due to its absence in the SIPSN's waste classification.

[2] The respective figure is the official data provided by Muara Fajar Landfill's management body.

[3] This statement is concluded from team's interview with an environmental engineering expert from Universitas Indonesia and operational staff in Bantar Gebang Waste Power Plant.

Table 1. The Process of Generating Electricity Through Incineration Technology

Phase	Detail Activities
Pre-treatment	1. Waste is sorted based on type (to remove glass, metal, and electronic waste) as well as size (to adjust for the diameter of the opening of the incinerator). Waste shredding may be performed if necessary. 2. All types of waste are mixed as a form of homogenization of the characteristics of the waste that will be incinerated. 3. After mixing and dividing the waste, it is dried in open air to decrease its moisture and to increase its average calorie level before its insertion into the incinerator.
Incineration	1. The waste is incinerated in a furnace at temperatures above 850oC. Ideally, the waste is left inside the furnace for no more than 60 minutes. 2. Air supply must remain adequate for the duration of the incineration to ensure that the incineration process takes place correctly. 3. A commonly used incinerator system is the moving grate incinerator. 4. The incineration process will result in flue gas at high temperatures.
Energy recovery	1. The heat carried by the flue gas is used to heat water in a boiler. The vapors that appear due to this process will be used to power turbines. 2. Electricity is generated by the rotation of the turbines.
Handling flue gas	1. If not properly handled, flue gas can cause significant negative effects on the health of the surrounding population due to containing fly ash, SOX, HCl, NOX, heavy metals, as well as dioxins and furan. 2. An air pollution control (APC) system is needed to reduce air emissions caused by flue gas discharge.

Source: Yuliani, 2016

Ibikunle et al. (2019), energy potential recovery from MSW is calculated as in Eq. (2).

$$EP_{msw} = LHV'_{msw}.w_{msw}.K \tag{2}$$

where EP_{msw} is energy potential from MSW (MWh/year), w_{msw} is the weight of MSW (ton/year), and K is conversion factor from MJ to MWh (1 MWh = 3.600 MJ).

Lower heating value (LHV), or lower calorific value, can be defined as the energy being released during MSW combustion. LHVs being used in this paper were adopted from (Zhen et al., 2019). LHV theoretically tend to be higher if MSW's water content can be reduced (Kuleape et al., 2014). Therefore, all LHVs in this paper were elevated because MSW would be air-dried by power plant operators prior to combustion process. According to (Triyono et al., 2018), LHV of air-dried MSW, on average, is 87 percent higher than pre-treated MSW. The following table shows all LHVs being used in this study.

Table 2. LHV Reference Value (in MJ/kg)

Waste Fraction	Pre-treated	Air dried
Food residue	2,69	5,04
Wood/leaves/branches	8,38	15,69
Paper/carton	7,65	14,33
Plastic	24,26	45,41
Fabric	11,92	22,31
Rubber	24,26	45,41
Leather materials	24,26	45,41
Others	11,92	22,31

Source: Zhen et al. (2019)

Thermal incineration will convert energy potential from MSW (EP_{msw}) to electricity. According to Darmawan et al. (2021), electrical power potential from MSW is calculated as in Eq. (4).

$$EPP_{msw} = \frac{EP_{msw}.\iota}{24} \tag{3}$$

where EPP_{msw} is electrical power potential (MW/year), EP_{msw} is energy potential from MSW (MWh/year), and ι is the conversion efficiency, equals to 20 percent (Anshar et al., 2014). Eq. (4) also assumes that the incineration power plant would be active for 24 hours. Power loss is almost certain when the electrical power is transmitted into power grid. Power to grid is obtained through Eq (5).

$$GP = EPP_{msw}.\iota_g.\iota_p \tag{4}$$

where GP stands for power to grid, ι_g is the generator efficiency being assumed at 85 percent (Ibikunle et al., 2019) and ι_p is the transmission efficiency, assumed to be 70 percent[4].

2.5 Forecasting Future Electricity Generation

This study utilizes projection of population growth (popgr) in Riau Province, produced by BPS (2018), to forecast the electricity generation from incineration PLTSa in Pekanbaru up to 2040[5]. Future MSW-based electricity generation is estimated as in Eq (5).

$$Q_t = \sum_{t=2022}^{2040} pop_{t-1}.popgr_t.wastecap.collect.50\%.\overline{GP_{msw}} \tag{5}$$

MSW production per capita (wastecap) is assumed to be constant at 0.39 ton/year, annual rate of MSW delivery from residents of Pekanbaru to Muara Fajar (collect) is assumed to stay at 74 percent, and GP from one ton of MSW ($\overline{GP_{msw}}$) is assumed to be constant up to 2040. This study also assumes that the waste fraction in Muara Fajar landfill remains unchanged and 50 percent of annual MSW in Muara Fajar landfill would always be available for electricity generation from 2021 onwards.

2.6 Estimating Cost of Electricity Generation

This study also calculates the estimated cost of electricity generation—also commonly known as levelized cost of electricity (LCOE)—from waste-to-energy plant. The information and assumptions related to investment and operational expenses are gathered from literature review, in-depth interview with operators of existing plant in Bantar Gebang and independent power producer.

The calculation of the cost of electricity production per kilo watt-hours (kWh) requires two main information; (1)

[4]By adopting Ibikunle et al. (2019), transmission efficiency figures similar to turbine efficiency.

[5]Average population growth in Riau Province from 2022 to 2040 is around 1.42 percent per year.

the present value (PV) of all electricity production costs, including investment costs, operational and maintenance costs, and fuel costs (if any); and (2) the present value of the estimated electricity production. The calculation of the current value of electricity production costs is carried out using the following formula (IRENA, 2020).

$$LCOE\ IP = \frac{\sum_{t=0}^{n}(I_t + M_t + F_t)/(1+r)^t}{\sum_{t=0}^{n} E_t/(1+r)^t}$$

where:

LCOE IP : *LCOE Incineration power plant*;
I_t : investment cost during period t;
M_t : operational and maintenance expenses during period t;
F_t : fuel cost during period t;
E_t : electricity generated during period t;
r : discount rate;
n : expected project lifetime.

The Presidential Regulation No. 35/2018 stated that the tipping fee is allowed, maximum IDR500,000 (around USD34.84) per ton. However, this study assumed no tipping fee. Moreover, the LCOE calculation has not yet considered financial costs[6] and corporate taxes.

2.7 Sensitivity Analysis

The subsequent step after the LCOE calculation is undertaking sensitivity analysis that will indicate the variation of cost of electricity generation due to the modified parameters. The range of variation then specified to indicate the parameter's uncertainty, which is assumed 50% of above and below the mean value in this study. This study uses the One-at-a-Time (OAT) method in which one parameter varied at a time while holding others fixed (Hamby, 1994). The obtained result is presented in a table summarizing the percentage of LCOE variation based on change of parameters ($\pm$50%). This will indicate which parameter has significant influence on LCOE. The higher absolute value of LCOE variation range shows that LCOE more responsive to the variable compared to others. While the positive and negative sign only denote correlation between certain parameter and LCOE (Lerch et al., 2018).

3. Results

3.1 Distribution of Waste in Pekanbaru

Majority of waste gathered from Pekanbaru citizens are in the form of organic biodegradable waste, with food residue along with wood, leaves, and branches accounted for more than 60 percent of waste piles in Muara Fajar landfill. This finding is consistent with (*Kementerian Lingkungan Hidup dan Kehutanan*, Republik Indonesia, 2021) and SIPSN that also highlighted food residue as the most common waste type at national level.

3.2 Annual Electricity Generation

Average electricity output from waste incineration in Pekanbaru Municipality is expected to reach 0.021 MW/ton MSW. The respective figure is congruous with previous studies, ranging from 0.01 to 0.03 MW/ton MSW (Amulen et al., 2022; Escamilla-García et al., 2020; Tsai, 2014). The electricity output potential might be lower with higher share of organic matters in the domestic waste pile as organic waste contains more water and less burnable content (Kuleape et al., 2014). World Bank (1999) and Rand et al. (2000b) argue that lower heating value of incinerated waste should not fall below 6,000 kJ/kg to maintain efficient combustion in the furnace. Otherwise, additional fuel would be required during the incineration phase.

Power generation is directly proportional with the number of inhabitants in Pekanbaru Municipality. Figure 1 shows that it will be possible to recover approximately 93,19 MW of electricity annually, or 255 MW per day, by 2040 if the incineration power plant starts to operate from 2022. The respective incineration power plant would prevent the additional 29,9 million tonnes of fresh waste to pile up in Muara Fajar landfill by 2040.

3.3 Levelized Cost of Electricity

The levelized cost of electricity for the incineration PLTSa in Pekanbaru is estimated around 21.03¢ per kWh. The computed LCOE is consistent with resulting LCOE from Octavianthy & Purwanto (2019) that ranges from 15¢ to 20¢ per kWh, but still higher than the tariff set by central government. According to the Presidential Regulation No. 35/2018, electricity tariff for PLTSa is 13.35¢ per kWh for power plant with capacity lower than 20 MW and 14.45¢ per kWh for power plant with higher capacity.

3.4 Sensitivity Analysis

Proportion of allocated waste for PLTSa's feedstock, investment cost, along with operational and maintenance (O&M) cost are parameters of interest in this sensitivity analysis. LCOE variation range in Table 8 shows that LCOE of incineration PLTSa in Pekanbaru is more sensitive towards the fluctuation of allocated waste for feedstock compared to the investment or O&M cost. The negative sign on allocated waste's LCOE variation range indicates that feedstock supply is inversely related with LCOE's movement while positive relationship can be expected from the other parameters. LCOE of PLTSa would increase by 87% due to 50% reduction in allocated waste, fall by 33% due to 50% reduction in investment cost, and be 28% lower because of 50% reduction in O&M cost.

4. Discussion

As organic litter dominates MSW pile in Muara Fajar Landfill and energy potential from MSW is inversely related with its moisture, the availability of good MSW drying system in incineration power plant is mandatory. Good drying system will avoid significant reduction in output efficiency and the utilization of additional combustible fuel for incineration process during the rainy season. The most common drying method utilized worldwide to optimize MSW's quality as the main fuel for incineration power plant are bio-drying,

[6] The LCOE calculation in this study assumed that project financing sourced 100% from equity. Altering the proportion of equity and debt will eventually change the LCOE.

Table 3. General Assumptions for Incineration PLTSa Pekanbaru, Riau

Assumptions	Value	Source
General		
Plant capacity	1,000 tons of waste per day	Presidential Regulation No. 18/2016
Plant working days	324 days	Prabowo et al. (2019)
Allocated waste per day	50% of waste collected	
Construction period	10-12 months	
Plant lifetime	20 years	
Salvage value	10%	Azis et al. (2021)
Financial		
Inflation rate	3%	2022 State Budget assumption
Exchange rate	IDR14,350 per USD	2022 State Budget assumption
Discount rate	10%	Escamilla-García et al. (2020)
Annual escalation rate of operating cost	3%	Equal to inflation rate

Table 4. Cost Component Assumptions for Incineration PLTSa Project in Pekanbaru, Riau

Cost component	Value	Source
Investment cost		
Engineering, Procurement, and Construction (EPC), including: cost of construction, machine installation, incinerator, water and air waste treatment technology, electricity transmission, contingency, and working capital	USD60,135,337.24	Azis et al. (2021)
Non-EPC, include but not limited to: land acquisition, interest during construction, and other cost related to permitting process	5% of the EPC cost	
Operating and maintenance cost (O&M cost)		
Purchase of raw water	38¢ per m^3	Prajogo (2019)
Fuel	85.6¢ per liter	
Insurance	1% of investment cost	
Spare parts	2.8% of EPC cost	
Maintenance fee	0.15% of EPC cost	
Fly ash treatment	USD17.12 per ton	
Bottom ash treatment	USD17.12 per ton	
Waste pre-treatment	USD6.76 per ton	Azis et al. (2021)
Raw chemicals for air pollution control	USD108,301 per year	Prajogo (2019)
Salary	USD502,443 per year	Novendra (2021)
Overhead	USD176,850 per year	Prajogo (2019)
Depreciation	USD2,841,395 per year	Azis et al. (2021)

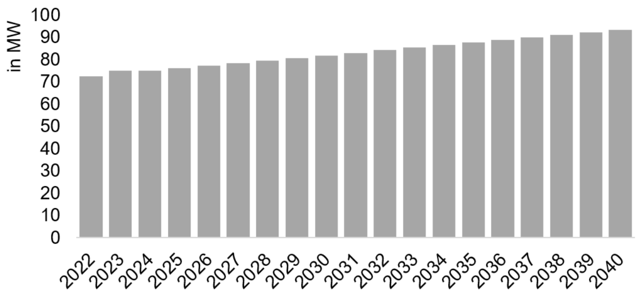

Figure 1. Power Generation Forecast from Incineration Power Plant in Pekanbaru (MW/year), 2022–2040

Table 5. Waste Fraction in Muara Fajar Landfill, 2021

Waste Category	Share
Food residue	55.3%
Plastic	14.5%
Fabric	12.4%
Wood/leaves/branches	10.9%
Paper/carton	2.8%
Rubber	1.2%
Leather materials	1.1%
Glass	1.1%
Metals	0.4%
Electronic wastes	0.2%
Others	0.1%

Source: Team's waste sorting

Table 6. Total Electrical Power Potential and Power to Grid from Incineration Power Plant by Using Waste Data in 2021

Waste Category	Wet weight (ton/year)	EPP_{msw} (MW/year)	GP (MW/year)
Food residue	156,399	1,825	1,086
Plastic	40,903	4,299	2,558
Fabric	35,049	1,81	1,077
Wood/leaves/branches	30,764	1,117	665
Paper/carton	7,863	261	155
Rubber	3,276	344	205
Leather materials	3,029	318	189
Others	337	17	10
Total			5,945
Average GP per ton of MSW (MW/ton)			0.021

Source: Team's waste sorting

bio-stabilization, thermal drying, and solar drying (Tun & Juchelková, 2019). Solar drying is suitable for the regions that receive enough solar radiation while thermal drying can be implemented by an external heat source or waste heat disposed from the power plants. Biodrying, which involves heat generated by organic waste decomposition, is considered to be better in reducing MSW moisture, but has been proven to be more costly (Tun & Juchelková, 2019). The selection of drying method should consider materials to be handled, size of materials, feed rate, heat source, quality of dried product, operation cost, as well as maintenance cost.

Table 7. The Summary Results

Indicators	Amount
Investment cost	USD63.14 million
EPC	USD60.13 million
Non-EPC	USD3 million
O&M cost (discounted)	USD80.4 million
LCOE	21.03¢ per kWh

Table 8. LCOE Variation Range

Parameter	Range of variance	LCOE (USD per kWh)	LCOE Variation Range
Allocated waste	-50%	0.3931	$ (0.244)
	0%	0.2103	
	50%	0.1494	
Investment cost	-50%	0.1414	$ 0.138
	0%	0.2103	
	50%	0.2793	
Operation & maintenance (O&M) cost	-50%	0.1514	$ 0.118
	0%	0.2103	
	50%	0.2693	

In addition to the waste calorific value, cost competitiveness of incineration PLTSa also heavily relies on the continuity of waste supply as the sensitivity analysis indicates that the movement of PLTSa's LCOE is very responsive to the change in allocated waste for feedstock. Ideally, the independent expert should carry out survey on waste composition and forecast of waste generation in the catchment area of PLTSa (Rand et al., 2000a). The amount of waste transported to the landfill will eventually determine the waste supply for PLTSa. In Pekanbaru, approximately 74% of waste is transported to the landfill and the rest is informally disposed. Securing waste supply does not only affect PLTSa financially, but also technically in terms of its minimum requirement in annual waste amount and percentage of waste supply weekly variations (Rand et al., 2000a).

Advanced technologies for air pollution control is imperative to be applied properly in incineration power plant to reduce direct environmental risks from electricity generation process. Typical air pollutants that must be controlled from are dust, nitrogen oxides (NOx), acidic gases, dioxins, and mercury (Takuma Environmental Technology Research Group, 2017). Typically, dust is removed by filtering, acidic gases are removed through chemical reaction with an alkali agent, and dioxins along with mercury are removed through absorption into powdered activated carbon (Liu et al., 2020). As being reviewed by de Titto & Savino (2019), atmospheric emissions from incineration power plant with indecent air pollution control might cause a wide variety of adverse health outcomes, notably cancer, chronic respiratory diseases, as well as increased blood levels of organic compounds and metals.

Not only higher than the regulated tariff in the Presidential Regulation No. 35/2018, computed LCOE of incineration PLTSa in this study is also higher than average LCOE of other renewable energies power plants and coal-fired power plants (Table 9). Diesel power plant is the only one which LCOE is considerably higher than incineration PLTSa. This finding highlights the possibility of incineration PLTSa to replace the diesel power plant surrounds Pekanbaru. Substituting diesel power plants, which are widely-used across Riau Province, with PLTSa could lower cost of electricity generation across Pekanbaru area and offer several co-benefits in the form of MSW pile reduction and lower dependence on fossil fuel to generate power (IRENA, 2012).

Table 9. Comparison of LCOE Across Various Technologies in Indonesia

Technology of Power Plant	LCOE (¢ per kWh)
Waste (PLTSa)	21.03¢
Diesel*	39.37¢
Wind shore	13.56¢
Small-scale hydro	10.66¢
Geothermal	9.04¢
Solar PV	8.26¢
Coal-fired	7.30¢
Biomass	7.23¢

Source: BloombergNEF (2022); PLN (2022)
Notes: * Based on average power plant operating cost from *PLN Statistics 2021*.
Assumed exchange rate is Rp15,000 per USD.

5. Conclusion

According to our findings, the incineration-based PLTSa could be a viable option for Pekanbaru in developing better waste management. During operational phase, it is critical for PLTSa to be supported by stable supply of waste feedstock, proper waste pre-treatment, and advanced technology for controlling air emissions. Moreover, as the average cost of PLTSa is lower than diesel power plant, the development of PLTSa should be considered in regions with a high proportion of diesel power plant, including Pekanbaru.

In spite of the opportunities and advantages, incineration-based PLTSa is just one potential alternative out of many in a functioning MSW system. According to the waste management hierarchy, priority is placed on prevention to reduce waste generation, followed by re-use and recycling. Incineration-based projects can be categorised as a type of complementary technology for the recovery of energy from any remaining non-recyclable MSW and should not compete with waste prevention management. To conclude, incineration-based PLTSa could not solve the existing waste problems by itself and a region's integrated MSW management plan should be used to decide whether incineration-based PLTSa is the right technology to be developed.

Acknowledgement

This research was funded by Municipal Government of Pekanbaru.

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