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Waste to Energy: Towards Energy Independence and Zero Waste in Indonesia

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ABSTRACT: Utilization of waste as an energy source for Waste-to-Energy Power Plants is an implementation of Waste to Energy (WtE). This research begins by calculating the potential waste generation in each province in Indonesia based on data from the National Waste Management Information System in 2024 and the projected waste generation in 2025. The calculation of electrical power is based on the assumption that every 1000 tons/day of waste has the potential to be converted into energy of 20 MW. The results of the calculation of electrical power from the potential waste generation in 2025 of around 60-65 million tons obtained electrical power of around 3,655 MW or 3.655 GW. Based on the volume of waste generation, the potential for electrical power is divided into 5 (five) categories, namely the Very Large category for West Java, East Java and Central Java with an electrical power of 350-550 MW, the Large category with a power of 160-350 MW in Jakarta and Banten, the Medium category in Aceh, North Sumatera, Bali and South Sulawesi with an electrical power of 60-180 MW and the Small category with a potential electrical power of 20-80 MW in Riau, West Sumatra, Jambi, South Sumatra, Lampung, Yogyakarta, NTB, NTT, West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan and North Sulawesi. The remaining 14 of the 38 provinces are in the Very Small category with an electrical power of only 0-20 MW. The number of Waste Power Plants that has the potential to be built is around 34 units, namely 5 units in West Java, 4 units in East Java, 3 units in Jakarta and Central Java, 2 units in Banten and South Sulawesi and 1 unit each in 15 provinces with a Smal category power. The availability of continuous waste generation and in sufficient volume so that the waste-to-energy power plant continues to operate is an important thing that needs to be considered in this Waste to Energy program.

KEYWORDS: Waste to Energy, Waste Generation, Waste Power Plants, Power Category

1. INTRODUCTION

According to data from the National Waste Management Information System, waste generation is around 60-70 million tons/year and continues to increase every year. Only about 40% of waste is managed properly. Plastic waste is estimated to increase by 30%. However, on the other hand, the Presidential Regulation on the National Strategic Project on Waste to Energy (WtE), which is an implementation of the 2025-2029 National Medium-Term Development Plan, targets 100% of waste to be managed by the end of 2029. This gap will be reduced by plans to build Waste Power Plants in 33 provinces, with a target completion date of the end of 2027. This is a government program to achieve energy independence while improving the quality of the environment and the circular economy. To achieve this target, several important things need to be considered, including:

a) Strong and good political will from the government to realize Waste to Energy and Zero Waste.
b) Sustainable planning, not partial and segmental.
c) Good governance based on honesty, transparency, and fairness, especially in sharing the financing of waste-to-energy plant construction and determining the price per kWh of production.

The development of waste-to-energy plant in Indonesia is still in its early stages. The first waste-to-energy plant was built in Cilacap (Nusa Kambangan), followed by Palembang, Jakarta, Bekasi, Tangerang, South Tangerang, Bandung, Solo, Semarang, Surabaya, Denpasar, Makassar, and Manado. The only waste-to-energy plant that are fully operational are waste-to-energy plant Benowo (Surabaya) and waste-to-energy plant Putri Cempo (Solo), each with a production capacity of 9 MW. The potential of organic waste as a source of power for waste-to-energy plant is relatively smaller than that of inorganic waste. Organic waste

tends to be wetter, so it requires a drying process to reduce its water content so that it is ready to be used as fuel in waste-to-energy plant. The above conditions require adjustments to the waste-to-energy plant machines commonly used abroad if they are to be used in Indonesia (Agustin et al., 2023; Aqilah, 2023; Kinasih et al; Ramadhan et al., 2021; Unwaru et al., 2022). There has been a global paradigm shift from viewing waste as waste material to becoming a resource (Cucchiella et al., 2017; Makarichi et al., 2018; G Tyler Miller & Spoolman, 2016; Scarlat et al., 2019). Municipal waste has great potential for material and energy recovery (Arafat et al., 2015). Thus, WTE has the advantage of producing electrical energy and minimizing the waste that is stockpiled (Putu, Romianingsih, and Indonesia 2023). This study aims to calculate the electrical energy potential from waste accumulation in all provinces in Indonesia, then design waste-to-energy plant according to its energy potential. Based on this, it is then determined which areas are potential for the construction of waste-to-energy plant with electrical power that matches its electrical power potential, as well as areas that are not yet feasible for construction because the waste accumulation is not yet suitable for operating waste-to-energy plant.

1. DATA, MATERIALS AND METHODS

This research is quantitative in nature and will be qualified in the discussion and conclusions. The data is secondary in nature, obtained from previous research, the National Waste Management Information System, articles and journals, websites, and other sources that are valid and relevant to the topic of this research. Data processing and analysis were then carried out to obtain new data to support this research.

2.1 Composition and Volume of Waste

Figure 1 shows global infographic of waste composition and their percentages. Household waste is dominated by food and green waste, accounting for 44% of the total waste volume.

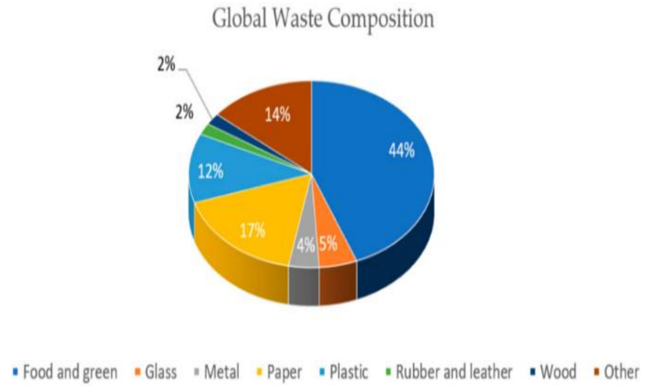

Figure 1 Infographic of waste composition and their percentage (https://www.visualcapitalist.com/a-visual-breakdown-of-global-waste-by-type)

Waste-to-energy programs require large capital investments because they are high-tech and have not been widely implemented in Indonesia. A comprehensive and in-depth analysis is needed to ensure the continuity of the energy transition program from fossil fuels to new and renewable sources, and to ensure that it runs in accordance with the government's program of energy independence and zero waste. From Waste generation volume in Indonesia in 2024 showed in Figure 2 is dominated by West Java, East Java, Central Java, DKI Jakarta, and Banten. Based on the infographic, the potential waste generation is around 1 million tons in 2025 and subsequent years, with a volume of over 1 million tons/year occurring in North Sumatra, Aceh, West Sumatra, Riau, South Sumatra, Lampung, Bali, NTB, NTT, West Kalimantan, South Kalimantan, East Kalimantan, South Sulawesi, and North Sulawesi. Waste production, especially organic waste, is directly proportional to the population and household consumption patterns. In addition, waste from markets, offices, businesses, and other areas also contributes to waste generation, especially plastic waste. Waste-to-energy programs require large capital investments because they are high-tech and have not been widely implemented in Indonesia. A comprehensive and in-depth analysis is needed to ensure the continuity of the energy transition program from fossil fuels to new and renewable sources, and to ensure that it runs in accordance with the government's program of energy independence and zero waste.

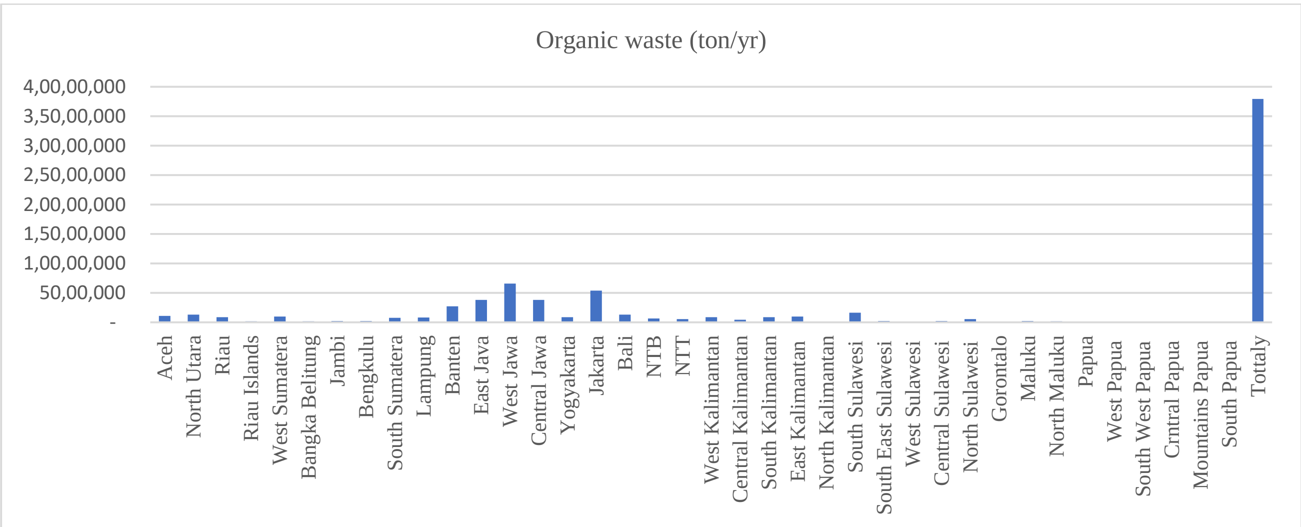

Figure 2. Waste Generation Volume in Indonesia in 2024 (The National Waste Management Information System)

2.2 Waste Management System

Waste management in Indonesia is currently being implemented, although it is not yet as advanced as in developed countries such as Singapore, Japan, Denmark, and Norway. In Indonesia today, the waste management process still uses traditional methods such as open dumping and burning in open areas as shown in the Figure 3. Municipal waste management options are often presented through a "waste hierarchy" (Romianingsih, 2023). In Indonesia several waste management methods, both simple (low tech) and high tech, are being implemented, including:

a) Pyrolysis process: processing plastic waste into diesel fuel (Refuse Derived Fuel) which is used by PLN, the cement and steel industry, and fishing boats/vessels.
b) Biodigester process: the process of converting organic waste into biogas which is used for household electricity.
c) Composter: a simple technology for converting waste into compost for the agricultural industry.
d) Shredder: a process of processing waste with a machine, the results of which are then processed into industrial fuel.
e) Electronic waste recycling: a special process for separating and recycling components from electronic waste to reduce hazardous waste.

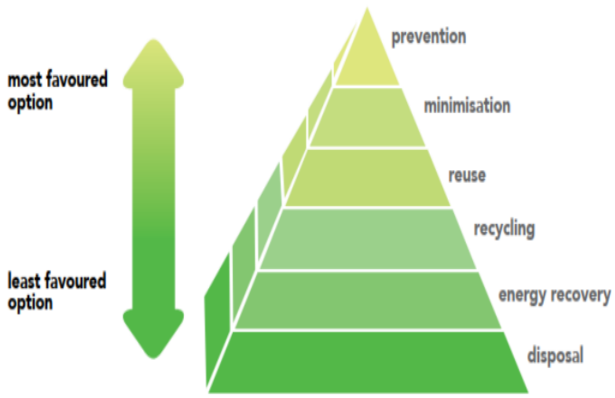

Figure 3. Hierarchy of Waste Management (Ministry of Energy and Mineral Resources, 2015)

Figure 4. Shredder Method (Bioenergy 2022)

The method of converting organic waste into energy can be explained as follows:

a) The moisture content of the waste will be reduced by draining it in a bunker (airless chamber) for 5 days.
b) Once the moisture content is reduced to 45%, the waste is fed into a combustion furnace and burned at a temperature of 8500C-9000C. The heat generated by this combustion heats a boiler and converts the water in the boiler into steam.
c) The steam is fed into a steam turbine, causing the turbine to rotate. Since the turbine is connected to a generator, when the turbine rotates, the generator also rotates.
d) The rotating generator produces electrical power that is transmitted to the PLN power grid. The steam that passes through the turbine loses heat and is channeled back to the boiler to be reheated, and so on (Harun and Lihawa, 2024).

2.3 Waste Power Plant and Its Power Potential

Waste Power Plant is a power plant that utilizes waste as its main fuel, both organic and inorganic waste. The power generation mechanism can be carried out in two ways, namely incineration and gasification, as shown in Figure 5.

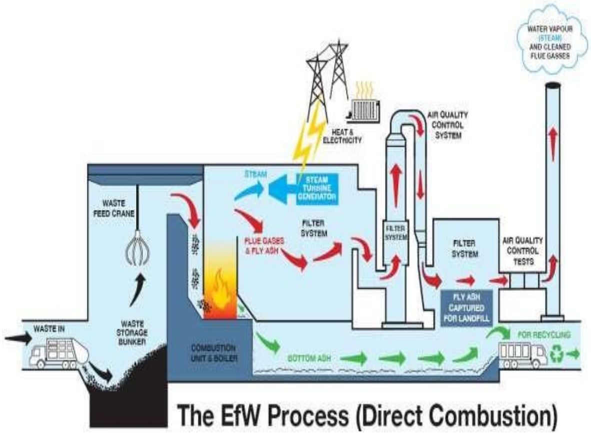

Figure 5. Solidification-Stabilization Process (Rajagukguk et al. 2020)

The following are several formulas used to calculate electrical energy using thermochemical methods.

$$ERP = NCV\ x\ w\ x\ \frac{1000}{860} \quad (1)$$

$$P = \frac{ERP}{24} \quad (2)$$

Assumption of 24-hour use

$$P,el = CE\ x\ P \quad (3)$$

Description:

ERP = Energy Recovery Potential (kWh)
NCV = Net Calorific Value (1625,24 kkal/kg
w = Total amount of waste (ton)
CE = Conservation Efficiency (25%)
P,el = Electric Power Potential (kW)

To obtain energy potential from waste production using biochemical systems, the following formulas are used:

$$VSD = w\ x\ VS\ x\ OBF\ x\ DE\ x\ 1000 \quad (4)$$

$$B = 0{,}8\ \frac{m^3}{kg}\ x\ VSD \quad (5)$$

$$ECP = B\ x\ \frac{CV}{860} \quad (6)$$

$$P = \frac{ECP}{24} \quad (7)$$

Assumption of 24-hour use

$$P,el = CE \; x \; P \quad (3)$$

Description:

VS = Volatite Solid (82,77%)

OBF = Organic Biodegrabale Fraction (66%)

DE = Digestion Efficiecy (55%)

VSD = VC Destroyed

B = Typical Biogas Yeild (m^3)

CV = Calorific Value of BiogaS (1.625,24 kkal)

ECP = Energy Recovery Potential (kWh)

Thermochemical systems for processing plastic waste account for about 14% of total waste, and paper waste accounts for about 15% of total waste. Biochemical systems for organic waste account for about 60% of total waste production, but only 13.5% can be converted into energy. Simply put, electricity per kWh can be calculated as follows (Unwaru, 2022)

Calculating daily calorie intake (K_h)

$$K_h = w \; x \; NCV \quad (8)$$

Calculating daily energy intake (E_h)

$$E_h = k \; x \; 0{,}00116 \quad (9)$$

Calculating the heat entering the boiler (Eb)

$$E_b = \frac{E_h}{24} \quad (10)$$

Assumption of 24-hour use

Calculating boiler heat capacity (K_p)

$$K_p = E_b \; x \; efisiensi \; boiler \quad (11)$$

Calculating boiler output (O_b)

$$O_b = K_p \; x \; Steam \; turbine \; efficiency \quad (12)$$

Calculating turbine output on a generator (P)

$$P = O_b \; x \; Generator \; efficirncy \quad 13)$$

Calculating daily electricity consumption (W)

$$W = P \; x \; t \quad (14)$$

Description:

NCV = 4,475 kcal (organic waste)

Boiler efficiency = 0.80-0.85 (0.825 used)

Steam turbine efficiency = 0.70-0.80 (used 0.75)

Generator efficiency = 0.35-0.50 (used 0.425)

Waste calorific value = 4,475 kcal/kg (organic)

t = Operating time (Assumption 24 hours)

3. RESULTS AND DISCUSSION

Based on data from previous studies, the following data on the potential and production of energy from waste processing is presented:

a. 1,000 tons of organic waste is needed to generate approximately 5 MW of electricity, but the same amount of inorganic waste can generate approximately 20 MW of electricity.
b. The feasibility of a waste-to-energy plant design for waste at the Bantar Gebang landfill in Bekasi is around 7,000 tons/day with an energy potential of 200 MW [11.]
c. The application of Waste to Energy Technology in the planned construction of the Intermediate Treatment Facility (ITF) in Sunter, North Jakarta, with a potential waste generation of 2000 tons/day and a maximum energy potential of 40 MW, divided into a thermochemical system (gasification technology) of around 20 MW and a biochemical system (anaerobic digester) of 5.6 MW.
d. Processing waste into electrical energy through a Refuse Derived Fuel (RDF) Plant in Jakarta with a waste generation of around 2,500 tons/day capable of producing 875 tons/day of energy. The energy is in the form of diesel fuel that can be used for the cement, steel, and power plant industries as well as for fishing boats.
e. The cost required for this investment is around 1.28 trillion rupiah(Refuse, Fuel, and Permasalahan 2025).

Based on data from previous studies, an analysis was conducted to calculate the potential energy that can be generated from waste accumulation throughout Indonesia, which is estimated to be around 60-65 million tons in 2025. The basis for consideration in the calculation used so that the results are not too biased and are sufficiently accurate are as follows:

a. For inorganic waste that will be processed into RDF, inorganic waste generation in industrial areas and the potential for industries that will use RDF products, assuming that inorganic waste accounts for 14% of total waste generation.
b. For organic waste, a value of 60% of the total waste for that year will be used, whereby Table 1 explains the data from 38 provinces in Indonesia as a reference for projecting the total amount of waste in 2025 to be around 60-65 million tons.
c. The formula listed in the research method of this paper will be used as a control to test the validity and accuracy of determining the amount of waste in each province, which has a direct implication on the amount of energy that will be generated from the waste processing.
d. The availability of continuous waste generation and in sufficient volume so that the waste-to-energy power plant continues to operate is an important thing that needs to be considered in this Waste to Energy program.

Table 1. Distribution of Waste Generation per Province and Potential Power Capacity

Provinces	Waste production (ton/day)	Energy Potential Capacity (KW)	Electric Power Category
Aceh	4.315,1	86,3	Middle
North Sumatera	5.326,0	106,5	Middle
Riau	3.550,7	71,0	Small

Riau Islands	776,7	15,5	Very Small
West Sumatera	3,994,5	79,9	Small
Bangka Belitung Islands	665,8	13,3	Very Small
Jambi	2.663,0	53,3	Small
Bengkulu	739,7	14,8	Very Small
South Sumatera	3.106,8	62,1	Small
Lampung	3.328,8	66,6	Small
Banten	11.095,9	221,9	Large
Jakarta	16.027,4	320,5	Large
West Java	27.074,0	541,5	Very Large
Central Java	18.345,2	366,9	Very Large
Yogyakarta	3.328,8	66,6	Small
East Java	22.191,8	443,8	Very Large
Bali	4.882,2	97,6	Middle
NTB	2.663,0	53,3	Small
NTT	2.219,2	44,4	Small
West Kalimantan	3.402,1	68,1	Small
Central Kalimantan	1,886,3	37,7	Small
South Kalimantan	3.328,8	66,6	Small
East Kalimantan	3.550,8	71,0	Small
North Kalimantan	241,6	4,8	Very Small
South Sulawesi	6.657,5	133,2	Sedang
Central Sulawesi	443,8	8,9	Very Small
South East Sulawesi	1.109,6	22,2	Small
Central Sulawesi	1.331,5	26,6	Small
Gorontalo	468,5	9,4	Very Small
North Sulawesi	2.219,2	44,4	Small
Maluku	887,7	17,8	Very Small
North Maluku	488,2	9,8	Very Small
Papua	212,1	4,2	Very Small
West Papua	244,1	4,9	Very Small
South West Papua	231,8	4,6	Very Small
Central Papua	443,8	8,9	Very Small
Mountains Papua	266,3	5,3	Very Small
South Papua	221,9	4,4	Very Small
Totally	39.069.000	3.277,6	

Description: Very Small = 0-20 MW, Small = 20-80 MW, Middle = 80-160 MW, Large = 160-350 MW, Very Large = 350-550 MW

Plastic/inorganic waste with an estimated volume of approximately 9,116,100 tons per year, obtained from 14% of the estimated waste volume of approximately 63 million tons per day in 2025, is used to calculate the energy potential in the form of Refuse-Derived Fuel (RDF) using a thermochemical system. Equations (3) to (7) are used with the following steps:

$$VSD = 9.116.100x0,8277xO,66\ x0,55x1000$$
$$= 2.738.978.737,11 \text{ kg}$$

$$B = 0,8\ \frac{m^3}{kg}\ x\ 2.738.978.737,11 \text{ kg}$$
$$= 2.191.182.989,69 \text{ m}^3$$

$$ECP = 2.191.182.989,69 \text{ kg } x \frac{1.625,24}{860}$$
$$= 1.140.928.188,56 \text{ kW}$$

$$P = \frac{1.140.928.188,56}{24}$$
$$= 172.538.674,52 \text{ kWh}$$

$$P, el = 0,25\ x\ 172.538.674,52 \text{ kWh}$$
$$= 43.134.668,63 \text{ kWh}$$

Assumption of 24-hour use

$$P, el = \frac{43.134.668,63}{24}$$
$$= 1.797.277,86 \text{ kW}$$
$$= 1.797 \text{ MW} = 1,797 \text{ GW}$$

Calculation of the amount of energy produced from organic waste, which amounts to approximately 37,902,000,000 kg/year (60% of 63.171 million tons/year), follows formulas (8) to (14), with the following steps:

$$K_h = 37.902.000.000\ kg\ x\ 4,475\ kkalori/kg$$
$$= 169.614.135.000 \text{ kkalori}$$

$$E_h = 169.614.135.000x\ 0,00116 \text{ kkalori}$$
$$= 197.255.738,37 \text{ kkalori}$$

$$E_b = \frac{197.255.738,37 \text{ kkalori}}{24}$$
$$= 8.217.739,10 \text{ kkalori}$$

$$K_p = 8.217.739,10 \text{ kkalori } x\ 0,825$$

= 6.719.634,75 kkalori

$O_b = 6.719.634{,}75 \text{ kkalori } x \; 0{,}75$

= 5.084.634,07 kkalori

$P = 5.084.634{,}07 \text{ kkalori } x \; 0{,}425$

= 216.008,58 kkalori

Calculating daily electricity consumption

$P = 216.008{,}58 \text{ kkalori } x \; 24$

= 51.864.205,89 kkalori

To convert from kcal to kW, use a conversion factor of 0.8598452279.

$P = 51.864.205{,}89 \; x \; 0{,}8598452279$

= 44.864.205,89 kW

Used of 24-hour to be:

$$P, el = \frac{44.864.205{,}89}{24}$$

= 1.858.132,91 kW = 1.858 MW = 1,858 GW

The total potential electrical energy from inorganic and organic waste is around 3,655 GW. Table 1 shows waste generation in tons/day, potential electrical power, and waste-to-energy plant categories for all provinces in Indonesia, with a total potential power of around 3,655 MW or 3 GW. Table 1 distinguishes five Waste Power Plants categories based on the potential electrical power that can be utilized from waste management for energy. The Very Large category is found in the provinces of West Java, East Java, and Central Java, with an electricity capacity of around 350-550 MW. The Large category is found in Jakarta and Banten, with an electricity potential of around 180-350 MW. The Medium category is found in Aceh, North Sumatra, Bali, and South Sulawesi, with an electricity capacity of around 60-160 MW. The Small category is in Riau, West Sumatra, Jambi, South Sumatra, Lampung, Yogyakarta, NTB, NTT, West Kalimantan, Central Kalimantan, East Kalimantan, Southeast Sulawesi, Central Sulawesi, and North Sulawesi with a capacity of around 20-80 MW. The remaining 14 provinces out of 38 provinces have a potential capacity of less than 20 MW.

4. CONCLUSSIONS

a) The potential waste generation of around 60-65 tons in 2025 can generate around 3,655 MW or around 3 GW of electricity.

b) Waste-to-energy plant in 24 provinces with a capacity of around 20 MW can be achieved with a waste generation of 1000 tons/day. Considering equitable development, an additional 14 waste-to-energy plants with an electricity capacity of 5-10 MW can also be built in the provinces.

c) The regions with the largest waste generation and electricity capacity are West Java, East Java, Central Java, Jakarta, followed by Banten and South Sulawesi.

d) The number of potential waste-to-energy plant units to be built is 34, spread across 5 units in West Java, 4 units in East Java, 3 units in DKI Jakarta and Central Java, and 2 units in Banten and South Sulawesi. In Riau, West Sumatra, Jambi, South Sumatra, Lampung, Yogyakarta, West Nusa Tenggara, East Nusa Tenggara, West Kalimantan, Central Kalimantan, East Kalimantan, Southeast Sulawesi, Central Sulawesi, and North Sulawesi, there is 1 unit each.

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