International Journal of Technology (2016) 8: 1445-1454
ISSN 2086-9614

TOWARDS SELF-SUFFICIENT DEMAND IN 2030: ANALYSIS OF LIFE-CYCLE COST FOR INDONESIAN ENERGY INFRASTRUCTURE

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(Received: November 2016 / Revised: December 2016 / Accepted: December 2016)

ABSTRACT

In 2015, the government of Indonesia launched the development of The 35,000 MW of power capacity. This project is required to stimulate economic growth and production in Indonesia. However, the project requires a huge financial investment, estimated to be about US$ 90.90 billion. Considering this situation, the construction of effective and efficient power plants based on energy potential in Indonesia is necessary. This research proposes alternative power plant development based on multiple linear regression and peak load analysis approaches. The results of this research show that 33% of the total power plants will be constructed in Java-Bali and the remaining 67% will be spread across Indonesia. Total energy demand in Indonesia is estimated at about 47.345 MW, with a total investment cost of about 1,813.32 trillion rupiah and operation and maintenance costs of about 289.13 trillion rupiahs per year. The research presented here also shows the use of renewable energy power plants increasing from 27% to 34% compared to the existing calculation.

Keywords: Energy; Financial analysis; Infrastructure; Planning

1. INTRODUCTION

Indonesia is located in Southeast Asia and consists of 17,504 islands, with a population of approximately 250 million. As a developing country, national electricity demand tends to increase about 8% to 9% annually. In 2013, Indonesia electricity consumption was about 188 terawatt-hours (TWh), divided into 41% for households, 34% for industries, 19% for commercial uses, and 6% for public demand. This indicates that every year, an additional capacity of 5,700 MW of power generation must be constructed in order to meet the increased electricity demand (Ministry of Energy and Mineral Resources, 2014). Regarding these needs, the Indonesian government has initiated the construction of 35,000 MW power plants throughout the Indonesian archipelago. This mega-infrastructure project aims to improve people’s lives by providing them with better connectivity and better access to electricity (Berawi et al., 2015).

The 35,000 MW program is a mega-project development in the electricity sector that aims to

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Permalink/DOI: https://doi.org/10.14716/ijtech.v7i8.6882

deliver energy supply across the country of Indonesia. It is initiated by the President of Republic of Indonesia in 2015 and projected to reduce energy crisis in near future, improve industry competitiveness and accelerate national economic growth. The project will be divided between PT Perusahaan Listrik Negara (PT. PLN) and Independent Power Producer (IPP). PT PLN will be responsible for the construction of 10,000 MW (30%) while 25,000 MW (70%) shall support from the IPP.

PT. PLN as a leading state-owned enterprise in the electricity sector has mapped the needs of electricity in Indonesia. Approximately 53%, or 18,706 MW, of the total electricity needs will be installed on Java Island, 26% (9,219 MW) for Sumatera Island, 6% (1,935 MW) for Kalimantan, and 1% (407 MW) for Nusa Tenggara and Maluku. The rest will be distributed to other required locations. A detailed energy map is given in Figure 1.

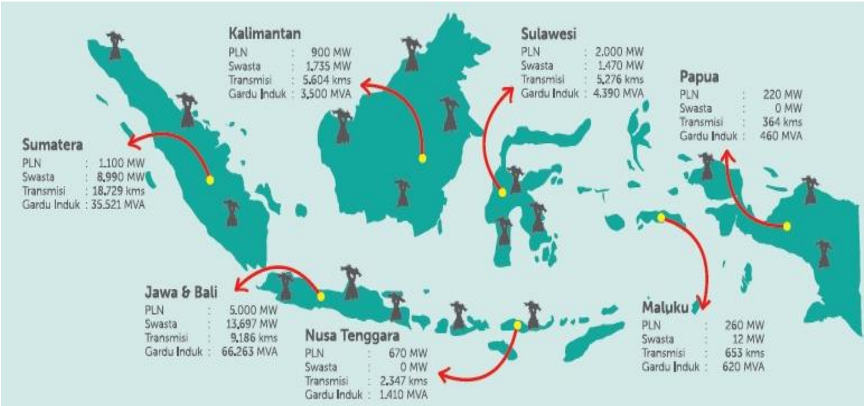

Figure 1 Existing mapping of power plant development totaling 35,000 MW (in Indonesian).
Source: Ministry of Energy and Mineral Resources (2015)

According to Figure 1, Java Island dominates the construction of electricity power plants and transmission networks. In contrast, Java and Bali Islands have the lowest average growth in term of electricity sales compared to other areas such as Sumatera, Kalimantan, Sulawesi, and Maluku–Papua–Nusa Tenggara (PT. PLN, 2015a). Between 2009 and 2013, Java and Bali produced 7.8% of the average growth in electricity use, while other areas show higher figures from 9.4% to 12.7%. Details of electricity sales are given in Table 1.

Table 1 PT. PLN electricity sales in 2009–2013 (TWh)

Region	2009	2010	2011	2012	2013	2014	Average (%) (2009–2013)
Indonesia	133.1	145.7	156.3	172.2	185.7	197.3	
Growth (%)	*4.3*	*9.4*	*7.3*	*10.2*	*7.8*	*6.3*	*7.8*
Java & Bali	104.1	113.4	120.8	132.1	142.1	149.9	
Growth (%)	*3.3*	*8.9*	*6.5*	*9.3*	*7.6*	*5.5*	*7.1*
Sumatera	17.6	19.7	21.5	24.2	25.8	27.9	
Growth (%)	*7.2*	*11.6*	*9.3*	*12.6*	*6.4*	*8.2*	*9.4*
Kalimantan	4.7	5.1	5.7	6.4	7.0	7.8	
Growth (%)	*9.7*	*10.3*	*10.1*	*12.9*	*9.6*	*11.8*	*10.5*
Sulawesi	4.6	5.1	5.6	6.4	7.3	7.8	
Growth (%)	*8.8*	*10.7*	*11.0*	*13.7*	*13.3*	*7.7*	*11.5*
Maluku, Papua & NT	2.2	2.4	2.7	3.1	3.6	4.0	
Growth (%)	*9.7*	*10.7*	*13.0*	*16.1*	*13.8*	*11.4*	*12.7*

Based on the table above, there is a huge gap between electricity sales and the construction of power plants. For instance, Sumatera had growth of 9.4% but is only supported by 5.2% of the additional power plant capacity, Kalimantan saw growth of 10.5%, supported by only 1%, and Sulawesi had growth of 11.5% followed by only a 2.7% power plant capacity annually. This situation has led to an energy crisis in those areas. In the short term, the government has to lease power plants from the domestic private entity in order to balance the electricity gap. For the longer term, new power plants must be built throughout Indonesia.

However, construction of power plants requires not only consideration of the location but also the type of power plant, that is, whether it uses fossil energy or renewable energy. Many countries have been attempting to convert their energy production to sustainable sources, such as wind energy, tidal energy, solar energy, and geothermal energy among many others (Kaygusuz, 2012; Kristoferson & Bokalders, 2013). Sustainable energy will play a significant role in the future for energy demand issues and has the potential to reduce Indonesia's electricity problems. Despite the enormous benefits that can be gained from renewable energy, the investment and construction period is a major obstacle that may hinder the realization of the project (Varho et al., 2016; Li et al., 2015).

In regards to the current situation, where Eastern Indonesia has a major gap between installed electricity capacity and needs, this research aims to analyze the projected energy needs in Indonesia by 2030 and its implications with regard to the investment cost of the project. It is expected that this paper can be used as an alternative concept in developing energy mapping in the energy sector and may be used as input for related stakeholders in the strategic decision-making process.

2. METHODOLOGY

This research was carried out in two stages. At the first stage, an evaluation of secondary data is carried out. It aims to generate the energy consumption from every province in Indonesia by considering the gross regional domestic product (GRDP), population, and the number of subscribers. This data is then processed using multiple linear regression methods before the energy demand is analyzed and mapped for Indonesia. The second stage aims to estimate investment costs of the construction of the 35,000 MW project. It conducted by using a benchmarking process and time value analysis. The result will map energy distribution and estimated cost for the project development.

The following variables have been identified and were processed using SPSS software:

- Household subscribers growth (X_1)
- Industrial subscribers growth (X_2)
- Business subscribers growth (X_3)
- Public subscribers growth (X_4)
- Population growth (X_5)
- Gross Regional Domestic Product (GRDP) growth (X_6)

These data are expressed as a matrix using the following formula:

$$Y= \beta X + e \tag{1}$$

Matrix Y can be calculated by submitting the value of β in the above equation to produce the following formula:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots + \beta_k X_{ki} \tag{2}$$

To find out more about how much electricity generation capacity is required to support future electrical usage, peak load was calculated. Peak load calculations can be made using the following equation (Wood & Wollenberg, 2012):

$$\text{Peak Load (MW)} = \frac{EPTt\ (GWh)}{8.76 \times Lft} \tag{3}$$

where

$$\text{Lft} = \left(0.45 \times \frac{ERt}{ETSt}\right) + \left(0.55 \times \frac{EKt+EPt}{ETSt}\right) + \left(0.7 \times \frac{EIt}{ETSt}\right) \tag{4}$$

$$\text{EPTt} = \frac{ETSt}{1-(LTt+PSt)} \tag{5}$$

The variables defined as follows;

Lft : weighting factor in year *t*
ETSt : total energy sales in year *t* (GWh)
ERt : household energy sales in year *t* (GWh)
EKt : commercial energy sales in year *t* (GWh)
EPt : public energy sales in year *t* (GWh)
EIt : industry energy sales in year *t* (GWh)

Expert validation through in–depth interview was then conducted to evaluate the reliability and validation of the research output (Creswell, 2013; Mertens, 2014). Three experts from the directorate-general of electricity, Ministry of Energy and Mineral Resources, were selected to provide input to and discuss this research.

3. RESULTS AND DISCUSSION

3.1. Analysis of Energy Demand

The first stage of this research is to generate the energy demand by taking into consideration population, GRDP, and energy sales to households, industry, business and the public. The existing data was then used to forecast energy needs in 2030 by using multiple linear regression methods. Table 2 summarizes the results for the five provinces with the highest energy consumption and the five provinces with the lowest energy consumption.

Table 2 Energy consumption in 2030 (5 highest and 5 lowest provinces)

No	Provinces	Energy Consumption (MW)
1	West Java	9,088.20
2	DKI Jakarta	8,707.08
3	East Java	5,525.58
4	Central Java	4,193.73
5	Banten	3,455.50
6	Maluku	130.49
7	West Papua	95.95
8	Gorontalo	87.19
9	North Maluku	70.66
10	West Sulawesi	54.78

Table 2 shows that all five of the provinces with the highest level of energy consumption in Indonesia are located in Java Island, further showing how the demand is concentrated in this area. In contrast, the sixth through tenth provinces with the lowest energy consumption only account for about 54.78 MW to 130.49 MW, together totaling about 439.07 MW in energy use. This table also indicates that the development of energy consumption in a region is affected by the level of economic development. The highest consumption lies in the West Region of Indonesia, particularly the Java–Bali islands. The government has paid little attention to the eastern parts of Indonesia because of its low population and small economic contribution to national growth. If this situation continues, the electricity gap will remain large and equitable development between West and East will not be realized.

Following the identification of energy consumption in the 33 provinces in Indonesia, energy demand was analyzed by calculating load factor, energy production, and peak load. Ten provinces are used as case studies to visualize energy demand by 2030 from the five highest demand to the five lowest demand provinces. The details are presented in Table 3.

Table 3 Energy demand in 2030 of selected provinces in Indonesia

Province	Load Factor	EPTt	Peak Load	Power Production Capacity	Energy Demand
DKI Jakarta	0.80	9556.67	12000.75	3228.0	-8772.75
East Kalimantan	0.14	587.74	4283.66	474.5	-3809.16
North Sulawesi	0.10	392.68	4113.00	327.0	-3786.00
West Java	0.87	9974.97	11442.57	7919.0	-3523.57
West Sumatera	0.68	755.56	3772.26	690.0	-3082.26
Gorontalo	1.20	95.93	79.84	49.0	-30.84
D.I. Yogyakarta	0.54	530.75	987.37	965.0	-22.35
Kepulauan Riau	0.54	188.82	2.68E-10	172.3	172.30
Bangka Belitung	0.65	231.47	675.83	167.0	508.83
Banten	2.97	3792.67	1276.73	5892.0	4615.27

Energy demand is derived in Table 3 by subtracting from peak load to the power production capacity of the power plants in each province. A negative value of energy demand in Table 3 shows that the area is experiencing an energy deficit. Provinces one to five have the most energy demand and are spread across Java, Kalimantan, Sumatera, and Sulawesi. Meanwhile, the eight through tenth provinces show a positive value, which means they are in an electricity surplus condition. Therefore, installing additional power plants in these areas will be useless. The energy demand is visualized in the Indonesian map shown in Figure 2.

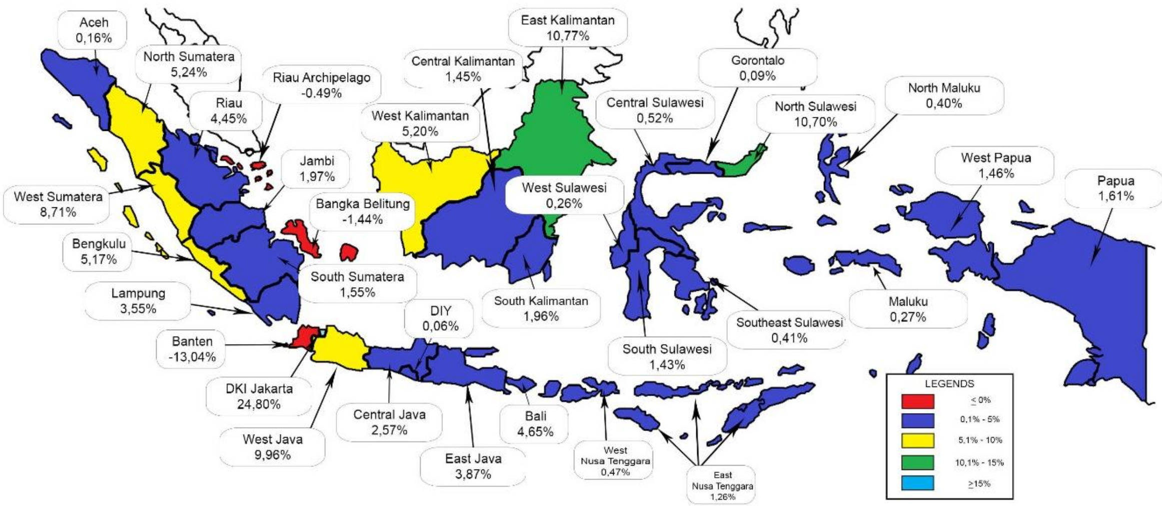

Figure 2 Map of projected 2030 energy demand across Indonesia

Figure 2 shows that almost every province in Indonesia will experience an electricity crisis by 2030 if new power plants are not constructed during the next decade. The results of this research show an alternative forecast compared to the existing calculation of energy demand by the government.

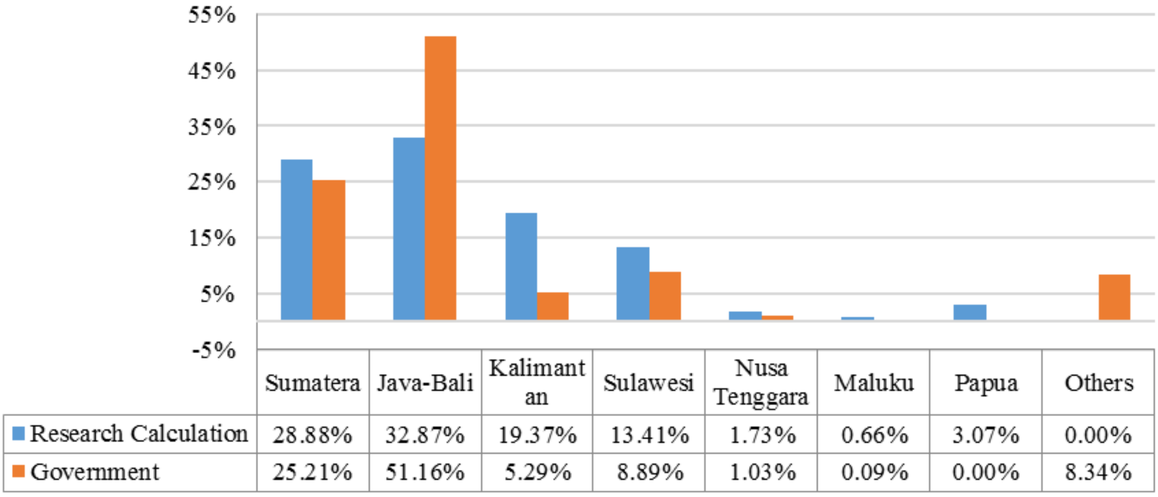

Figure 3 Comparison of energy demand calculate by the government and by this research for new power plants in the 35,000 MW project

For instance, the Java–Bali region accounts for only 32.87% of the energy demand while the government calculation shows a higher figure of about 51.16%. Other regions outside Java Island that tend to have higher energy demand compared to the government calculation are Sumatera, Kalimantan, Sulawesi and Nusa Tenggara. The comparison is presented in Figure 3.

The identified energy demand was then used to calculate investment cost. However, first, the required capacity of the power plant must be generated by multiplying the minimal plant reliability (30%) by the energy demand. The total capacity of required power plant is showing a higher level estimated compared to the government calculation for about 47,345 MW.

3.2. Scenario of Power Plant Development

Currently, Sumatera has the most energy capacity from non-renewable and renewable sources in Indonesia ranging from coal, geothermal, hydropower, and solar power plants. The Java–Bali region has similar energy resources but lower capacity compared to Sumatera, including coal, geothermal, hydropower, wind power, and solar power plants (PT. PLN, 2015a) (Table 4).

Table 4 Potential of resources in 6 regions in Indonesia

Region	Coal (MW)	Gas (MW)	Geothermal (MW)	Hydropower (MW)	Solar (Locations)
Sumatera	580,857.24	47,985.40	10,270.0	3.567.0	3
Java–Bali	1.62	5,116.71	8,089.0	4,659.5	7
Kalimantan	650,973.6	8,101.00	116.0	1,277.6	3
Sulawesi	1,725.19	1,455.00	2,522.0	2,691.0	2
Nusa Tenggara	-	-	1,214.4	8.9	2
Maluku–Papua	1,065.43	1,455.00	916.8	10,000.0	1

On the other hand, similar reference also argued that Kalimantan has the largest energy potential in Indonesia in terms of coal but fewer resources such as gas, geothermal, and hydropower. Sulawesi has a decent amount of energy resources from coal, gas, geothermal, and hydropower, ranging from 1,725.19 MW of coal power to the largest source producing 2,691 MW of hydropower. Nusa Tenggara has the lowest potential resources compared to other regions with only geothermal and hydropower. Furthermore, the Maluku–Papua region has the largest potential in hydropower in Indonesia with 10,000 MW but only a small contribution from of coal, gas, and geothermal.

The following scenario for developing power plants in Indonesia is divided into three operational areas, Sumatera, Java–Bali, and Eastern Indonesia (Sulawesi, Kalimantan, Nusa Tenggara, Maluku–Papua). The scenario is based on the previously identified natural resources potential. For instance, coal in Sumatera has the potential for about 580,857.24 MW and only 6,800 MW can be developed. Further identification of power plant forecast in Sumatera is shown in Table 5.

Table 5 Sumatera power plant forecast (MW)

Type of Power Plant	2015	2016	2017	2018	2019	2021	2023	2025	TOTAL
Coal	1,000	800	2,000	1,200	300			1,500	6,800
Gas	400		290						690
Coal and Gas			140	600			1,000		1,740
Gas Engine									
Geothermal	440	330	990	75	860		550	110	3,355
Hydropower	304		173	1,012	638	300			2,427
Micro-hydro		173	30.95		10				214
Solar		4	2						6
TOTAL	2,144	1,307	3,625	2,887	1,808	300	1,550	1,610	15,232

Based on the table above, renewable energy (geothermal, hydropower and solar) makes up about 39.4% or an increase of 31% from the existing scenario, while non-renewable source power plants contribute about 60.6% of electricity needs. This figure was obtained by assuming the development of fossil power plants will be replaced by renewable energy.

Table 6 Java–Bali power plant forecast (MW)

Type of Power Plant	2015	2016	2017	2018	2019	2021	2023	2025	TOTAL
Coal	-	1,315	5,000	860	600	500	-	1,000	9,775
Gas	4	-	-	-	-	-	-	-	4
Coal and Gas	1,950	1,460	-	-	200	-	-	200	3,810
Gas Engine	-	-	-	-	-	-	-	-	
Geothermal	595	830	230	110	95	-	220	330	2,410
Hydropower	1,177	-	560	450	120	-	500	-	2,807
Micro – hydro	-	27	44	38	80	-	-	-	188
Solar	-	-	-	-	-	-	-	-	-
Wind	50	-	-	-	-				50
TOTAL	3,776	3,632	5,834	1,458	1,095	1,000	720	1,530	18,544

In the Java–Bali region, renewable energy (geothermal, hydropower, wind, and solar) is projected to supply about 29.4% of energy needs, an increase of 23% from the existing scenario, while non-renewable source power plants still contribute about 70.6% of energy needs. Additional power plant capacity from the projection is about 18.54 GW with average growth around 1.24 GW annually.

On the other hand, The Eastern Indonesia region is projected to increase its power plant capacity to 13,569 GW (Table 7). The composition of renewable and non-renewable energy sources is about 33.6% and 66.3%, respectively. Most power in this region is supplied by smaller power plants, such as gas engines, gas, micro-hydro, and solar power plants spread through the various islands

Table 7 Eastern Indonesia power plant forecast (MW)

Type of Power Plant	2015	2016	2017	2018	2019	2021	2023	2025	TOTAL
Coal	164	1,380	1,200	400	700	500	1,550	1,044	6,938
Gas	100	100	-	-	370	-	-	-	570
Coal and Gas	769	-	-	-	-	-	-	500	1,269
Gas Engine	80	50	-	-	-	-	40	70	240
Geothermal	65	120	300	24	158	110	220	260	1,257
Hydropower	344	371	1,040	410	713	-	100	-	2,978
Micro-hydro	100	112	55	14	22	-	-	-	303
Solar	-	-	-	6	9	-	-	-	15
TOTAL	1,622	2,132	2,595	854	1,972	610	1,910	1,874	13,569

The distribution of potential renewable power plants in Indonesia is supported by Table 5 up to Table 7 and visualized into Figure 4.

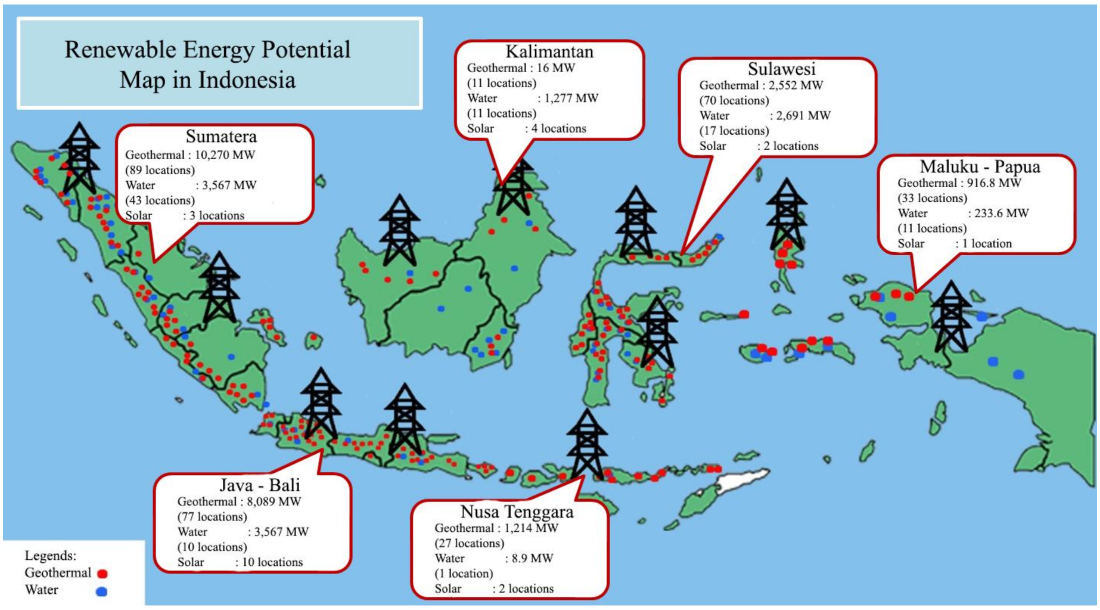

Figure 4 Renewable energy potential map in Indonesia

3.3. Life Cycle Cost

The analysis of investment cost conducted by firstly identify cost component of each type of power plants. It generated through a benchmarking process from the similar power plant in other projects abroad. Basic cost then converted using cost construction index to produce the current value of power plant cost. In a region, there are several types of power plants. All of them which has been identified then simulated to obtain investment cost a region.

The total of the project is estimated at about 1,813 trillion rupiahs. Sumatera contributes as the highest investment followed by Java–Bali region, Kalimantan, Sulawesi, Maluku, Nusa Tenggara and Papua respectively. Despite requiring lower capacity about 2,322 MW from Java–Bali region, Sumatera shows higher investment cost. This might occur due to topography and technical consideration where Sumatera has mountain and hills, meanwhile Java–Bali contour relatively flat. Details are given in Table 8.

Table 8 Investment cost considering location

No	Region	Investment Cost	Capacity (MW)
1	Sumatera	604,802,838,091,547	14,432
2	Java-Bali	602,554,250,168,235	16,754
3	Kalimantan	298,859,125,455,620	8,107
4	Sulawesi	238,581,714,747,414	6,121
5	Maluku	18,157,062,154,386	440
6	Nusa Tenggara	43,876,661,430,384	1,156
7	Papua	6,495,932,663,803	335
	Total	1,813,327,584,711,390	47,345

Furthermore, the government estimates of the investment cost in 35,000 MW project are 1,167 trillion rupiahs to generate 36,565 MW of electricity. The research presented here shows higher investment costs of about 1,813 trillion rupiahs to meet a higher demand of about 47,345 MW of electricity.

On the other hand, operation and maintenance cost consider fuel, maintenance, depreciation, personnel, and other related costs. Among the types of power plants, non-renewable source power plants require a higher operation and maintenance costs. Gas power plants have the highest operation and maintenance costs, about 3,248.72 rupiahs/kWh, followed by gas machine power plants (3,064.30 rupiahs/kWh), gas and coal power plants (1,500.08 rupiahs/kWh), and coal power plants (815.73 rupiahs/kWh). On contrary, renewable power plants require a lower operation and maintenance costs. Geothermal requires 612 rupiahs/kWh, hydropower costs 212.48 rupiahs/kWh, micro-hydro costs 48.64 rupiahs/kWh, and solar power plants require only 459.66 rupiahs/kWh (Loutatidou & Arafat, 2015; PT. PLN, 2015b; Kristianto, 2010; Wijaya et al., 2012). The total cost of all types of power plants spread across Indonesia was then calculated to produce operation and maintenance costs for every region.

The Java–Bali region requires 111.93 trillion rupiahs to produce a total energy capacity around 18,544 MW, while Sumatera needs 94.21 trillion rupiahs for 15,232 MW of energy, and the lowest is eastern Indonesia, requiring 82.99 trillion rupiahs for a total energy capacity around 13,569 MW. Details of operation and maintenance costs are given in Table 9.

Table 4 Operation and maintenance costs of all power plants in Indonesia

Region	Total Capacity (MW)	Energy Production (kWh)	O&M Cost (Rp.)
Sumatera	15,232	111,686,644,200	94,212,576,643,317
Java-Bali	18,544	135,073,111,200	111,930,972,687,922
Eastern Indonesia	13,569	98,223,884,400	82,986,551,761,639
TOTAL	47,345	344,983,639,800	289,130,101,092,878

4. CONCLUSION

The demand for electricity in Indonesia is increasing progressively by about 6% per year. This research produces the total required power plant development by 2030 is about 47,345 MW. Of that demand, power plants providing 30.48% of the total capacity will be built in Sumatera, 35.39% in the Java–Bali region, 17.12% in Kalimantan, 12.93% in Sulawesi, 0.93% in Maluku, 2.44% in Nusa Tenggara, and 0.71% in Papua. The cost to support the construction of those power plants is estimated at about 1,813 trillion rupiahs. This is a higher cost compared to the existing government calculation, which estimates a cost of around 1,167 trillion rupiahs. However, the research here shows higher needs, with a total power plant capacity of 47,345 MW compared to the 36.565 MW estimated by the government.

This research is based on an increase in the use of renewable energy from 27% to 34% of total capacity associated with the existing calculation. The results also identified the operation and maintenance costs for the projected power plants in Indonesia in 2030, totaling 289.13 trillion rupiahs per year.

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