Supply Security Improvement of Long Term Electricity Expansion Planning of Java-Madura-Bali System in Indonesia

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Abstract

Supply security can be defined as a system ability to provide a flow of energy to meet demand in an economy. The rapid increase of economic and population growth has resulted in increasing electricity demand and supply security in Indonesia. In 2005, the electrification ratio in Indonesia was 54 % and increased to 63% in 2006. According to the National Electricity Master plan 2006-2026, the electrification ratio is expected to be 93% in 2026. Despite the huge geothermal potential in Indonesia, it has been relatively little developed. Meanwhile, current Indonesian government policy concerning the power sector is to promote coal utilization. This paper analyzes Indonesian electricity supply security in the Java-Madura-Bali(Jamali) system from 2006 to 2025. The results show that using geothermal energy as an electricity source together with reducing transmission and distribution (T&D) losses, and implementing energy efficiency in the household sector would reduce installed capacity by 6.7 GW in 2025, mitigate 75 million tonnes of CO_2 equivalent emissions from the power sector, and reduce the total system cost.

Keywords: supply security, demand side management, electricity planning, emissions reduction.

1. Introduction

Supply security can be defined as a system ability to provide a flow of energy to meet demand in an economy. In relation to electricity, there are several threats to the security of an energy supply, including failure in primary fuel sources [1, 2], transmission network problems and generation capacity limitation due to under investment.

The rapid increase of economic and population growth has resulted in increasing electricity demand and supply security in Indonesia. Moreover, electricity as one of the final energy forms plays a very important role in supporting various economic activities to increase people's welfare. In other words, the electricity supply supports economic prosperity.

As one of the developing countries and also the fourth most densely populated country in the world, Indonesia is facing problems of electricity supply. The electrification ratio which is supplied by a state owned company and Independent Power Producer (IPP) in 2005 was 54% and increased to 63% in 2006 [3]. In 2000, Indonesian transmission and distribution (T&D) losses were 11.65% and increased to 16.88% in 2003. In 2006 the T&D losses reduced to 11.45%; however, Indonesia still relies on fuel oil for electricity generation. In 2006, the power sector consumed around 62.9 million barrels of oil. This is due to the fact that the Indonesian government subsidizes electricity and oil prices.

Meanwhile, Indonesian geothermal potential is estimated to be around 28 GW which is equivalent to 40% of world potential. Despite the huge geothermal potential in Indonesia, there has been relatively little development. In 2005, the total installed geothermal capacity was 797 GW or 2.2% of the total system installed capacity in the country. This increased to 3% in 2006.

This paper analyzes Indonesian electricity supply security improvement in the Java-Madura-Bali (Jamali) system from 2006 to 2025. The study is developed by using the Long–range Energy Alternatives Planning (LEAP) model.

2. Power Sector in Indonesia

In 2006, total installed capacity was 30 GW [4]. Nearly 70% of it was located in Java-Madura-Bali (Jamali) islands [5]. The Jamali areas consumed almost 79% of total electricity production. The Jamali generation capacity mix consists of 43% of coal, 39% of natural gas, 13% of hydro, 4% of geothermal and the rest is oil. The T&D losses in the Jamali system were slightly higher than national losses. In 2006, the T&D losses in the Jamali system were 15%, consisting of technical and non technical losses of 11% and 4%, respectively.

Based on Electricity Law no. 15/1985, the electricity supply activities in Indonesia include generation, transmission and distribution according to the geographical location. Electricity generation in Indonesia is under state authority and conducted by the electricity state-owned enterprise or PLN (*Perusahaan Listrik Negara*).

Currently, Indonesian government policy is to diversify the primary energy sources for electricity generation from oil to others before 2012, and mainly to promote coal utilization in the power sector. The total installed capacity of coal-fired power plants will be 10,000 MW with 6,650 MW in the Jamali system.

3. Methodology

3.1 The Long-range Energy Alternatives Planning (LEAP)

The Long-range Energy Alternatives Planning (LEAP) model used in this study is a scenario-based energy-environment modeling tool which was developed by the Stockholm Environment Institute. The main concept of LEAP is the end-use driven scenario based analysis. Its scenarios are based on comprehensive accounting of how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology and so on. The LEAP model contains the technology and environmental database (TED) that is used to estimate the environmental emissions of energy utilization.

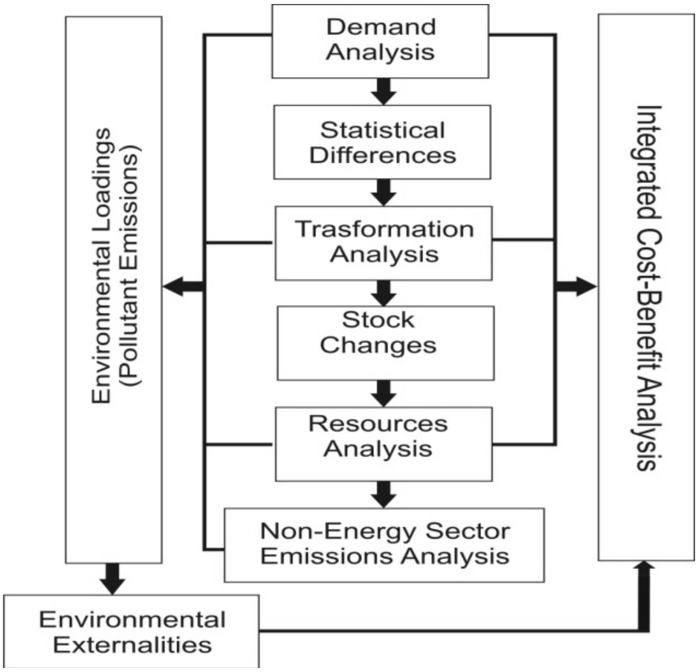

Figure1. LEAP model structure.

Unlike macroeconomic models, LEAP does not attempt to estimate the impact of energy policies on employment or Gross Domestic Product (GDP), although such models can be run in conjunction with LEAP. Similarly, LEAP does not automatically generate optimum or market-equilibrium scenarios, although it can be used to identify least-cost scenarios. Important advantages of LEAP are its flexibility and ease-of-use, which allow decision makers to move rapidly from policy ideas to policy analysis without having to resort to more complex models [6]. Fig. 1 shows the LEAP model structure.

3.2 Final Energy Demand Analysis

The LEAP energy demand analysis is calculated as the product of the total activity level and energy intensity at each given technology branch. Energy demand is calculated for the current accounts year and for each future year in each scenario.

$$D_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \quad (1)$$

where D is energy demand, TA is total activity, EI is energy intensity, b is the branch, s is scenario and t is year (ranging from the base year to the end year). Energy intensity is the annual average final energy consumption (EC) per unit activity, or in other words:

$$EI = \frac{EC}{activity\ level} \quad (2)$$

The total activity level for a technology is the product of the activity levels in all branches from the technology branch back up to the original demand branch.

$$TA_{b,s,t} = A_{b',s,t} \times A_{b'',s,t} \times A_{b''',s,t} .... \quad (3)$$

where A_b is the activity level in a particular branch b, b' is the parent of branch b, b'' is the grandparent, etc.

3.3 Electricity Transformation

The planning reserve margin is used by LEAP to decide automatically when to add additional endogenous capacity. LEAP will add sufficient additional capacity to maintain the planning reserve margin at or above the value that has been set. Planning reserve margin is defined as follows:

$$PRM = 100(MC - PL)/PL \quad (4)$$

where *PRM* is the planning reserve margin (%), *MC* is the module capacity in MW and *PL* is the peak load in MW.

Module capacity for all processes in the module is defined as:

$$MC = Sum(Capacity \times Capacity\ Value) \quad (5)$$

Exogenous capacity values are used to reflect existing capacity as well as planned/committed capacity additions and retirements, while endogenous capacity values are those which are internally calculated by LEAP in order to maintain a minimum planning reserve margin. Endogenous capacity additions occur in addition to the exogenous level of capacity specified on the exogenous capacity.

Peak system power requirements on the module are calculated as a function of the total energy requirements and the system load factor.

$$PR = \frac{ER}{LF \times 8760} \quad (6)$$

where *PR* is peak requirement in MW, *ER* is energy requirement in MWh, and *LF* is the load factor.

The reserve margin before the addition of endogenously calculated additions is calculated as follows:

$$RM_{BA} = \left[\frac{CA_{BA} - PR}{PR}\right] \quad (7)$$

where RM_{BA} is the reserve margin before additions and CA_{BA} is capacity before additions. The amount of endogenous capacity additions required (EC_{AR}) is calculated as follows:

$$EC_{AR} = (PRM - RM_{BA}) \times PR \quad (8)$$

3.4 Emission from Electricity Production

The LEAP uses the most up-to-date global warming potential (GWP) factors recommended by the IPCC (Intergovernmental Panel on Climate Change). The emission is calculated as:

$$Emissions_{t,y,p} = EC_{t,y} \times EF_{t,y,p} \quad (9)$$

where *EF* is the emission factor, *t* is type of technology (fuel), *y* is year, and *p* is pollutant. The LEAP contains data on the GWPs for carbon dioxide, methane, nitrous oxide and the most common non-energy sector gases with high GWPs (SF6, CFCs, HCFCs and HFCs).

3.5 Cost Analysis

The LEAP performs cost-benefit calculations from a societal perspective by counting up all of the costs in the energy system. LEAP can include all of the following cost elements: demand costs (expressed as total costs, costs per activity, or costs of saving energy relative to some scenario), transformation costs (capital and operating and maintenance costs), primary resource costs, and environmental externality costs.

Capital costs are annualized (spread-out over the plant lifetime) using a standard mortgage formula as follows:

$$Annualized\ cost = Total\ cost \times CRF \quad (10)$$

where

$$CRF = \frac{i \cdot k}{k-1} \quad (11)$$

and

$$k = (1+i)^n \quad (12)$$

where *i* is the interest rate, *n* is the plant lifetime and *CRF* is the capital recovery factor.

4. Development of Scenario

4.1 Business as Usual (BAU) Scenario

In this study, the BAU scenario starts from 2006 as the base year. The data on existing, committed and candidate power plants and electricity demand profile used in this study are based on [4, 5]. The population growth rate is assumed to be 1% per year and the electrification ratio is expected to be 93% in 2026. The demand sector was divided into four categories: household, commercial, public and industry. Their electricity demands in 2006 were 32 GWh, 14 GWh, 4 GWh and 39 GWh, respectively. The expected growth rates of electricity demand are given in Table 1 [5].

Table 1. Expected electricity growth rates in the Jamali system

Sector	Growth rate/year (%)			
	2006 - 2010	2011 - 2015	2015 - 2020	2021 - 2025
Household	8.9	8.2	7.1	6.2
Commercial	9.6	8.5	7.8	7.2
Public	10.7	11.1	10.7	10.7
Industry	4.0	3.5	3.6	3.8

The efficiency of transformation and distribution branches was calculated by using losses. In 2006 the losses were 15% and assumed to be reduced by 1% per five years. Table 2 shows expected transmission and distribution losses from 2006 to 2025.

Table 2. Expected T&D losses

Year	Losses (%)
2006 – 2010	15
2011 – 2015	14
2016 – 2020	13
2021 – 2025	12

In the Jamali system, in 2006, the total installed capacity was 19,615 MW. Due to lack of data, the total installed capacity in this study is approximated to be only 19,531 MW. The difference is due to unavailable data of small power plants. All power plants are dispatched based on their ascending merit order[1]. Table 3 shows dispatch of power plant based on merit order. Merit order 1 indicates power plants for base load, merit order 2 indicates power plants for middle load, and merit order 3 indicates power plants for peak load.

Table 3. Dispatch of power plant

Type of power plant	Merit order
Steam	1
Geothermal	1
Combined cycle	1
Hydro	2
Gas turbine	2
Diesel	3

Table 4. Committed power plants in Jamali system from 2006-2011

Type	Capacity (MW)
Gas turbine	790
Geothermal	470
Steam	9,810
Total	11,070

Table 4 shows committed power plants in the Jamali system from 2006 to 2011. The supply planning was based on required reserve margin. For Jamali, the projected reserve margin is 35% until 2019, and then from 2020 onwards the reserve margin is reduced to 30%.

The only committed power plants after 2011 are nuclear power plants. It is expected that nuclear power plants will be commissioned in 2016, 2017, 2023 and 2024 with additional capacity of 1,000 MW for each year. Since there is no more data for committed power plants, the other additional power plants would be calculated as the input in the endogenous capacity variable. The power plant operation follows the government intention to promote using coal resources. The additional power plants after 2011 are given in Table 5.

[1] The merit order of a process indicates the order in which it will be dispatched. Plants will be dispatched according to their specified merit orders as defined in the merit order variables. Each plant will be run (if necessary) up to the limit of its maximum capacity factor in each dispatch period [6].

Table 5. Additional power plants during 2011-2025

Additional order[2]	Type	Size (MW)	Fuel type
1	Steam	150	Coal
2	Combined cycle	100	NG
3	Gas turbine	100	NG

Note: NG stands for natural gas

4.2 Geothermal (GEO) Scenario

In the GEO scenario, the geothermal energy resources will be used optimally to reduce coal utilization in the power sector and also in order to fulfill the electricity demand, to maintain planning reserve margin and to develop clean power generation. In addition to the geothermal power plants, other power plant types are also included as additional capacity; namely, 1) combined cycle, 2) gas turbine and 3) oil-steam power plants. Details of the additional capacity are given in Table 6.

Table 6. Additional capacity of geothermal scenario

Additional order	Type	Additional size (MW)
1	Geothermal	100
2	Combined cycle	150
3	Gas turbine	100
4	Oil steam	100

4.3 Transmission and Distribution Loss (TDL) Scenario

The electricity sector in developing countries is generally facing high losses in T&D. In 2006, in the Jamali system, T&D losses were 15%, which is quite high. The developed countries such as Japan (JP), Australia (AU), Singapore (SG), the United States (US), and the United Kingdom (UK) have losses less than 10% [7]. The aim of the TDL scenario is to reduce T&D losses in the Jamali system.

Theoretically, the T&D losses can be divided into two different groups: [8, 9]

1. Technical losses (E_{TL}): losses caused by current flowing through the network. These losses include resistive losses of the primary feeders, the distribution transformer losses (resistive losses in the windings and core losses), resistive losses in secondary networks, resistive losses in service drops, and the losses in kWh meters.

2. Non-technical losses (E_{NT}): losses caused by theft, fraud and administrative errors.

Two scenarios of T&D losses reduction are considered: the low loss reduction (TDL1) scenario and the high loss reduction (TDL2) scenario. By using TDL1 scenario, T&D losses will be reduced by 1% per five-year period from the BAU scenario and by using the TDL2 scenario, T&D losses will be reduced by 2% per five-year period starting from the base year. Table 7 shows T&D loss reduction in the TDL1 and TDL2 scenarios.

Table 7. T&D loss reduction scenarios

Scenario	Loss reduction (%)			
	2006 - 2010	2011 - 2015	2016 - 2020	2021 - 2025
TDL1	14	13	12	11
TDL2	13	11	9	7

The loss reduction scenarios consist of technical and non-technical losses. Generally, the technical loss has the dominant share in total system losses. Gustafon and Baylor [10] and Marpaung *et*

[2] The LEAP calculates the additional power plants based on the additional order entered by the user. Should further additions be required in any given year to maintain the reserve margin, then an additional 150 MW of new steam power plants will be built, followed by an additional 100 MW of combined cycle power plants and so on [6].

al. [11] reported the share of technical and non-technical losses in a power system to be 80% and 20%, respectively. Details of reduction scenarios are presented in Table 8.

Table 8. Type of loss reduction

Scenario	Loss reduction by		Total loss reduction (per 5-year period)
	E_{TL} (%)	E_{NT} (%)	
TDL1	0.8	0.2	1%
TDL2	1.6	0.4	2%

Note: E_{TL} *is electricity loss caused by technical factors.*
E_{NT} *is electricity loss caused by non-technical factors.*

4.4 Energy Efficiency Improvement (EEI) Scenario

The EEI scenario is the energy efficiency improvement in the household sector through lighting efficiency improvement. In Indonesia, approximately 59% of lamps used in the household sector are incandescent while the rest are fluorescent tubes [11].

In incandescent lamps, electricity heats up a filament causing it to glow and give light. About 90% of the energy consumed by incandescent lamps becomes heat, not light. Therefore incandescent lamps are inefficient light sources and they have a short lifetime of 750 hours. [12]

Table 9. Penetration rates in the lighting efficiency improvement scenarios

Period	Measure	Penetration
2006 - 2010	Replace incandescent 40W by CFL 8W Replace incandescent 60W by CFL 12W Replace incandescent 100W by CFL 20W	20%

Table 9. Penetration rates in the lighting efficiency improvement scenarios (Continued)

Period	Measure	Penetration
2011 - 2020	Replace incandescent 40W by CFL 8W Replace incandescent 60W by CFL 12W Replace incandescent 100W by CFL 20W	60%
2021 - 2025	Replace incandescent 40W by CFL 8W Replace incandescent 60W by CFL 12W Replace incandescent 100W by CFL 20W	80%

In the EEI scenario, penetration rates of the lighting efficiency improvement during 2006-2025 are assumed to be linear. Table 9 presents the lighting efficiency improvement scenarios and penetration rates.

Table 10. Lighting efficiency improvement in the household sector

Period	Energy intensity (kWh/household)	
	BAU	EEI
2006-2010	1369	1274
2011-2020	1369	1088
2021-2025	1369	996

The replacement of incandescent lamps with compact fluorescent lamps (CFLs) decreases lighting energy intensity. The energy intensity of the household sector in 2006 was 1,367 kWh/household. In the period of 2006-2010, replacing incandescent lamps by CFLs with penetration rates of 20% would reduce energy intensity by 93 kWh/household; in the period of 2011-2020, it would reduce energy intensity by 280 kWh/household; while in the last period of 2021-2025, it would reduce energy intensity by 373 kWh/household. The final energy intensities in both BAU and EEI scenarios are presented in Table 10.

4.5 Comprehensive Improvement (COM) Scenario

The COM scenario is the combination of the GEO, TDL, and EEI scenarios. Two scenarios are considered based on the low and high T&D losses: the low comprehensive (COM1) scenario and the high comprehensive (COM2) scenario. The COM1 scenario is the combination of GEO, EEI and TDL1 scenarios. The COM2 scenario is the combination of GEO, EEI and TDL2 scenarios.

5. Results and Discussion

5.1 Business as usual (BAU) scenario

Fig. 2 shows the electricity demand in the BAU scenario. At the end of the period the demand has increased over three times, compared to the base year. The household sector takes the largest share of electricity consumption by consuming 131.6 TWh or about 42% of total electricity consumption. The industrial sector takes the next place by consuming about 79.4 TWh. The change of the demand composition is an indication that there is a good opportunity to put effort on energy efficiency improvement in the household sector.

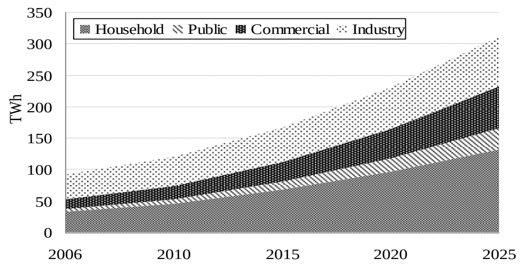

Figure 2. Electricity demand in the Jamali system in the BAU scenario.

Table 11. Power installed capacity in the BAU scenario based on fuel types in selected years

Fuel type	Installed capacity (GW)				
	2006	2010	2015	2020	2025
Coal	8.5	15.5	21.6	25.6	31.9
Gas	7.6	9.4	12.2	17.6	26.1
Oil	0.1	0.1	0.1	0.1	0.1
Hydro	2.5	2.5	2.5	2.5	2.5
Geothermal	0.8	1.1	1.3	1.3	1.3
Nuclear	0.0	0.0	0.0	2.0	4.0
Total	19.5	28.6	37.7	49.1	65.9

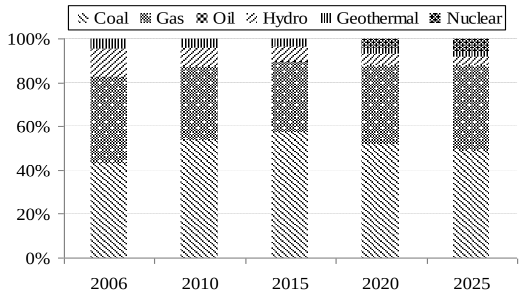

Figure 3. Capacity mix in the BAU scenario.

Table 11 presents the power installed capacity in the BAU scenario by fuel types in selected years. At the end of period, the capacity has increased over three times compared to that in the base year. Total electricity generation in the BAU scenario is nearly 66 GW in 2025, increasing from 19.5 GW in 2006. The rapid growth of installed capacity is due to the high growth rate of demand. The coal utilization is rapidly growing from the base year with a 43% share until the middle of the period with nearly a 60% share in total capacity generation. However, at the end of period, coal utilization is going down but still has the largest capacity. The capacity mix in the BAU scenario is illustrated in Fig. 3. In 2025, natural gas utilization takes second largest place after coal, about 26 GW or a 40% share in total capacity. Nuclear power plants take third place with a 6% share, while the geothermal power plant is the last with only 1.3 GW or a 2 % share in total capacity.

5.2 Geothermal (GEO) scenario

In the GEO scenario, the capacity of geothermal power plants in 2025 has increased over seven times compared to the base year (see Fig. 4). It increases to 8.2 GW from 830 MW in the base year. Moreover, at the end of the period, the geothermal capacity has increased by about six times, compared to the BAU scenario.

The share of coal power plants is not going to be the largest at the end of period. The natural gas power plant takes the largest share of electricity capacity by supplying about 25.7 GW or 39% of total capacity generation. It is slightly higher than the coal power plant capacity. The difference is around 300 MW.

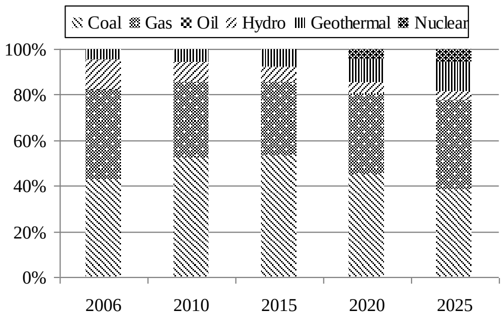

Figure 4. Capacity mix in the geothermal scenario

5.3 Transmission and Distribution Loss (TDL) Scenario

Table 12 presents the electricity generation capacity of each scenario. The T&D loss reduction gives effect on less generation capacity requirement. In the TDL1 scenario, the generation capacity would save 700 MW or account for a reduction of 1.1% compared to the BAU scenario in 2025, while the TDL2 scenario would save 5.6% or 3.5 GW by the end of the period.

Table 12. Electricity generation capacity of T&D loss reduction scenarios

Scenario	Electricity generation capacity (GW)				
	2006	2010	2015	2020	2025
BAU	19.5	28.6	37.7	49.2	65.9
TDL1	19.5	28.5	37.1	48.5	65.2
TDL2	19.5	28.1	36.3	47.1	62.4

5.4 Energy Efficiency Improvement (EEI) Scenario

The energy efficiency improvement reduces electricity demand in the household sector, in 2025, from 131.6 TWh in the BAU scenario to 116 TWh in the EEI scenario. Total electricity demand reduction in the EEI scenario is about 5.2% of total electricity demand in the BAU scenario in 2025. Fig. 5 shows electricity demand projection in the EEI scenario.

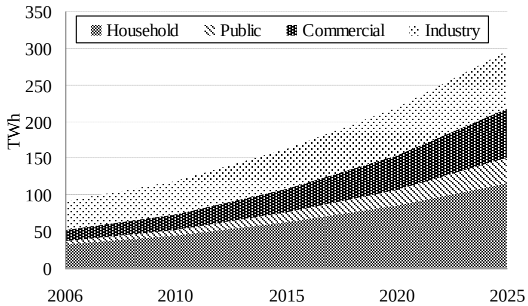

Figure 5. Electricity demand in the energy efficiency scenario

Table 13. Power plant capacity projection of the Jamali system in energy efficiency scenario

Scenario	Total capacity (GW)				
	2006	2010	2015	2020	2025
BAU	19.5	28.6	37.7	49.2	65.9
EEI	19.5	28.4	36.5	46.9	62.7

In the BAU scenario, to meet the demand in 2025, the Jamali system needs installed capacity of 65.9 GW, while in the EEI scenario it only needs installed capacity of 62.7 GW or it saves about 5% from the BAU scenario. Details of electricity generation capacity in each scenario are presented in Table 13.

5.5 Comprehensive Improvement (COM) Scenario

In the COM scenarios, the installed capacity is reduced significantly (see Table 14). At the end of period, in the COM1 scenario, the reduction in generation capacity is 4 GW. In the COM2 scenario, the reduction in generation capacity is 6.7 GW compared to the BAU scenario. In other words, the saving of electricity generation capacity in the comprehensive scenario is equal to capacity saving in the T&D loss reduction scenario and in the EEI scenario.

Table 14. Generation capacity in the comprehensive scenarios

Scenario	Generation capacity (GW)				
	2006	2010	2015	2020	2025
BAU	19.5	28.6	37.7	49.2	65.9
COM1	19.5	28.1	36.1	46.3	61.9
COM2	19.5	27.9	35.3	44.9	59.2

5.6 Supply Security Improvement

In terms of supply security, by comparing the BAU, GEO, TDL1, TDL2, COM1, and COM2, it can be seen that the COM2 is the best scenario for ensuring the electricity supply in the future. In 2025, the installed capacity is only 59.2 GW. The COM2 scenario uses geothermal energy, reduces transmission and distribution losses, and increases energy efficiency in the household sector. Those make the COM2 scenario more secure than the other scenarios.

The COM 1 scenario is in second place with 61.9 GW of installed capacity. The TDL2, EEI, and TDL1 scenarios are in third, fourth and fifth place respectively. Meanwhile, in 2025, the installed capacity of the GEO scenario is similar to the BAU scenario with 65.9.

However, the GEO scenario is better in supply security than the BAU scenario. The geothermal energy is a local energy resource. It will improve Jamali's electricity supply security since it is better than using coal, which is imported from outside of the Jamali area and it has a high risk on supply.

5.7 Environmental Emissions

The major global warming potentials (GWPs) in power generation are carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), sulfur dioxide (SO_2) and nitrous oxide (N_2O). In addition, GWPs are always expressed relative to level of CO_2. Recently, emissions from the power sector have become a main focus, since the sector is the main contributor of global warming.

Table 15 shows total emissions in all scenarios. The highest emission reduction scenario at the end of the period is the COM2 scenario with 71.7 million tonnes of CO_2 equivalent or accounting for a reduction of 33.1% compared to the BAU scenario. The reduction occurs since 8 GW of geothermal power generation is developed and 3.5 GW of electricity generation is saved by T&D loss reduction. Meanwhile, the lowest emission reduction is the TDL1 scenario with 3.6 million tonnes of CO_2 equivalent.

Table 15. Total emissions in all scenarios

Scenario	Total emissions (million tonnes of CO_2 equivalent)				
	2006	2010	2015	2020	2025
BAU	82.6	117.2	168.7	219.4	288.5
GEO	82.6	114.5	158	192.4	237.3 (21.6%)
TDL1	82.6	115.9	166.5	216.5	284.9 (1.3%)
TDL2	82.6	114.5	162.8	209	271.4 (6.3%)
EEI	82.6	116.2	163.5	208.3	272.7 (5.8%)
COM1	82.6	112.4	153.1	183.7	225.2 (28.1%)
COM2	82.6	111.3	150.7	178.7	216.8 (33.1%)

5.8 Total system cost perspective

The cost is important and should be carefully analyzed in the electricity planning. Table 16 presents components of cost in all scenarios. For capital cost, the geothermal power plant has the highest cost, which is US$ 1.8 million. Meanwhile, capital cost of the nuclear power plant is about US$ 1.7 million.

In terms of fuel cost, the gas turbine power plant is the most expensive generator at US$ 86/MWh, while the nuclear power plant is the cheapest generator, at US$ 4/MWh. In the case of O&M cost, the gas turbine power plant is the most expensive generator at about US$ 11.69/MWh, while the cheapest generator is the steam power plant.

At the end of period, the GEO scenario is the most expensive scenario compared to the other scenarios. The TDL2 scenario is the cheapest scenario since it uses more coal power plants and reduces the T&D losses. Table 17 presents the total cost of each scenario. In terms of geothermal utilization for electricity supply, the COM2 scenario is the cheapest total system cost, at about US$ 5.9 billion. It is cheaper than the total system cost in the BAU scenario.

Table 16. Components of cost in all scenarios

Type of power plant	Capital cost (10^3 US$/MW)	Fuel cost (US$/MWh)	O&M cost (US$/MWh)
Steam	1,226[a)]	26.76[b)]	2.15[b)]
Gas turbine	550[b)]	86.47 [b)]	11.69 [b)]
Combined cycle	600[c)]	52.34 [b)]	5.37 [b)]
Geothermal	1,800[d)]	48.19[b)]	3[b)]
Nuclear	1,728[e)]	4.4[e)]	8.3[e)]

Source: a) BATAN, 2002[13]
b) PLN, 2005 [16]
c) IEA, 2005 [14]
d) Sanyal, 2005 [15]
e) BATAN, 2006 [17]

Total cost mentioned is only to analysis cost of power generation. Furthermore, due to limitations of data, the total cost scenario in this projection does not include the cost of replacing incandescent with CFL, replacing transformers with more efficient ones and other miscellaneous expenses.

Table 17. Total cost in all scenarios

Scenario	Total Cost (US$ million)				
	2006	2010	2015	2020	2025
BAU	359	1,494	2,641	4,169	6,256
GEO	359	1,532	2,756	4,468	6,793
TDL1	359	1,476	2,583	4,102	6,176
TDL2	359	1,438	2,491	3,935	5,865
EEI	359	1,477	2,508	3,915	5,901

Table 17. Total cost in all scenarios (Continued)

Scenario	Total Cost (US$ million)				
	2006	2010	2015	2020	2025
COM1	359	1,460	2,564	4,088	6,286
COM2	359	1,438	2,457	3,905	5,940

6. Conclusion

This paper analyzes Indonesian electricity supply security in the Java-Madura-Bali (Jamali) system from 2006 to 2025. The results show that using geothermal energy as an electricity supply source, together with reducing T&D loss and implementing energy efficiency in the household sector, would save more generation capacity as well as mitigate CO_2 emission from the power sector.

However, in terms of total system cost, the COM2 scenario is not going to be the lowest total system cost since it uses geothermal energy. This is due to the fact that geothermal energy investment is more expensive compared to other energy sources. Moreover, an important issue that should be addressed by government is reducing oil subsidies to promote energy diversification and geothermal energy.

The COM2 scenario not only ensures that the electricity supply is secured to meet future demand, but it also develops a clean electricity supply and promotes renewable energy utilization in Indonesia, particularly in geothermal energy resources.

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