# Renewable Energy Potential for Sustainable Long-Term Electricity Energy Planning: A Bottom-up Model Application

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# Renewable Energy Potential for Sustainable Long-Term Electricity Energy Planning: A Bottom-up Model Application

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**Abstract-** This paper presents a preliminary assessment of renewable energy potential for long-term electricity energy planning. In order to implement a sustainable supply-demand framework, renewable energy resources consist of geothermal and solar energy based power plants are included in a bottom-up accounting based model along with energy efficient and energy conservation approach in the demand side. The developed model is applied to a region comprises of 5 cities or regencies in the eastern part of East Java province, Indonesia. The main purpose of the study is to compare several supply-demand scenarios with respect to the resources, costs, and environmental impacts over the study period. According to the analyses in this research, the 2025 total electricity consumption of the observed area would be 6,873.8 GWh for the case of "Business as Usual" scenario, or increase by 203% compared to year 2014 as the baseline. Meanwhile, applying "Energy Efficiency and Conservation" scenario, the growth is in a lower pace with 175% compared to the baseline or 6,222 GWh. Given the shortage of supply, more electricity should be imported from the interconnected system if the existing coal fired power plant is preserved throughout the simulation period compared to planning involving geothermal and solar energy based power plants.

**Keywords** Renewable energy, sustainable, geothermal, electricity planning.

## 1. Introduction

Renewable energy is one promising alternative to meet the ever growing electricity demand in developing countries. The decreasing costs of investment in terms of unit capital cost and comparatively lower operational and maintenance costs compared to fossil fuel based power plants have attracted more attention from policy makers and regulators. In addition, the appearance of either grid connected or isolated distributed generation based on renewable energy have shown positive impacts related to energy security improvement., particularly for those countries with few fossil fuel resources [1]. In the case of Indonesia, there is a huge opportunity and potential to increase the penetration of renewable energy based power plant using geothermal and solar energy. Geothermal energy, for example, is one form of renewable energy that is abundantly available across the country but with very low utilization. The total installed capacity of geothermal power plant until 2013 is still 1,343 MW from 28,900 MW potential resources and reserves [2]. Other potential renewable energy based power plant is photovoltaic, which is improved in its capacity, in either grid connected or isolated plant up to 1 MW for each plant.

Many papers in the field of electrical network expansion planning are recently published, particularly in the area of long-term energy planning model and its implications. For instance the feasibility identification of sustainable energy in

Crete, Greece, is presented by Giatrokos et. al [3] and application of LEAP in the electricity sector planning of Panama and its implications is studied by McPerson and Karney [4]. The earlier study reported the possible implementation of LNG and added pumped storgage into the scenario in addition to some renewables possibility. The second research considered up to three improved scenarios of renewables in addition to the Business as Usual but with assumption that energies could be transmitted without transmission losses.

In the technical point of view, firstly, this "zero constraint" assumption should not be made because it will affect the cost calculation and the real capability of the supply side in meeting the ever growing demand. Secondly, the role of renewables in the electricity planning should consider specific resources available within the region, especially if the observed area consist of many island. Here, transporting the energy generated even from renewables is one big issue. Other papers also discussed the nation wide electricity energy supply-demand and in the related sector [5-8]. On the other hand, lack reports or references on the role of renewable energy in the regional electricity supply-demand planning have been reported, particularly in Indonesia.

This paper presents the possible scenario of long-term electricity supply-demand planning model in five regencies in the eastern part of East Java Province, Indonesia, over 2015-2025. Renewable energy based power plants are included in the model by including geothermal and grid connected distributed generation in the form of photovoltaic power plant in order to meet the future demand and environmental protection to 2025. The simulation results based on research activity to assess the potential of locally available renewable energy into the long-term electricity supply-demand planning. The observed areas is selected in a way to provide example to other regions, particularly in Indonesia. In the demand projection, lower growth rate of electricity consumption is compared to the high level growth rate to observe its potential benefits. The supply-demand electricity model in this study is developed using the bottom-up accounting framework based energy model.

The paper is organized as follows: research methodology comprising general overview of the observed area, energy modeling using LEAP, scenarios and key parameters are discussed in the next section. Results and discussion are presented subsequently followed by conclusion.

## 2. Methodology

### *2.1. General Overview and Electricity Profile*

In this paper, five regencies located in the eastern part of East Java province, Indonesia, namely Jember, Bondowoso, Situbondo, Banyuwangi, and Lumajang are taken as the observed areas. This five regencies have similar characteristics in terms of electricity consumption trend and major sectors that consumed relatively large amount of electricity compared to other sector. In the employment activities, agriculture and trading affect the livelihood due to the wide area of farming, rice fields and plantation. To the North, the observed areas border with Probolinggo regency and the Java Sea, to the East with Bali Strait, to the West with Malang regency and to the South with the Indian Ocean. The location of the five observed regencies on the East Java province map is shown in Fig. 1 [9].


**Fig. 1.** The map of Jember-Situbondo-Bondowoso-Banyuwangi-Lumajang regencies.

Electricity provision and services in Indonesia are the responsibility of the state owned utility, namely PT. Perusahaan Listrik Negara, or hereafter called PLN. The PLN East Java Distribution Company is the branch of PT. PLN that is responsible for provisioning and servicing electricity all over East Java province. Electricity is bought from other PLN subsidiary and thus delivered to the customers depending to the customers tariff sector. There are five major customers tariff sector, namely household, social, business, industry, and government or public sectors. Other than this classification is the multipurpose customer who consume electricity for irregular activities within a short period of time. The number and amount of electricity consumed in this particular sector is very few and therefore can be neglected. The overall PLN customers per customer tariff sector and electrcity consumption in 2014 is shown in Table 1. Meanwhile, the average growth of PLN customer per customer sector and electricity consumption over 2008-2014 is shown in Table 2.

**Table 1.** Number of PLN customers and electricity consumption in 2014 over the observed five regencies [10]

| Customer sector | Number of customer | Electricity consumption (MWh) |
|---|---|---|
| Household | 1,661,824 | 1,662,898.53 |
| Social | 44,379 | 94,635.82 |
| Business | 49,121 | 251,533.67 |
| Industry | 1,362 | 421,637.45 |
| Government/Public | 7,036 | 128,172.36 |
| Total region's electricity consumption | | 2,558,877.83 |

The five regencies are served by three office area of PLN East Java Distribution Company. One office area is located in Jember for Jember and Lumajang, another one is located in Situbondo which is responsible for the services in Situbondo and Bondowoso, and the last one is located in Banyuwangi to handle Banyuwangi regency. The primary supply for the regencies is originated from Paiton coal fired power plant. A proven 110 MW geothermal energy is located in the Ijen-Belawan area, a border of Bondowoso and Banyuwangi. Meanwhile, Updated information regarding the electrification ratio in five observed regencies is given in Table 3.

**Table 2.** Average growth of PLN customer per customer sector and electricity consumption over 2008-2014 in the observed five regencies [10]

| Customer sector | Number of customer's average growth (%) | Electricity consumption's average growth (%) |
|---|---|---|
| Household | 10.06 | 9.41 |
| Social | 8.80 | 10.03 |
| Business | 4.85 | 9.78 |
| Industry | 8.75 | 15.29 |
| Government | 7.07 | 6.68 |

**Table 3.** Electrification ratio of five regency at the end of 2013 [10]

| Regency | Electrification ratio (%) |
|---|---|
| Jember | 80.21 |
| Lumajang | 61.98 |
| Bondowoso | 51.65 |
| Situbondo | 64.06 |
| Banyuwangi | 77.69 |

The historical and distribution losses over 2007-2013 for each office area can be seen in Table 4. The average losses for all areas is then taken as one value as the baseline losses for the simulation purpose.

**Table 4.** Historical and average distribution losses over 2007-2013 for three PLN's service area office covering all observed regencies (in percentage) [11]

| Service area office | Yearly Distribution Losses (%) | | | | |
|---|---|---|---|---|---|
| | 2007 | 2009 | 2011 | 2012 | 2013 |
| Jember (covering Jember and Lumajang) | 10.85 | 8.23 | 9.34 | 8.94 | 11.23 |
| Situbondo (covering Situbondo and Bondowoso) | 6.79 | 6.84 | 7.12 | 6.87 | 9.41 |
| Banyuwangi | 7.66 | 6.88 | 7.6 | 7.5 | 8.6 |
| Total average 2007-2013 | 8.37 | | | | |

*2.2. Energy Modeling Using LEAP*

The Long Range Energy Alternatives Planning (LEAP) software is used in this study. LEAP is an accounting framework based bottom-up energy model which works under scenario-based energy supply-demand and environmental modeling. LEAP is developed and maintained by the Stockholm Environmental Institute [12]. The end-use driven scenario based analysis, the main concept of LEAP, is based on accounting relationship of how energy is produced, converted, and consumed in a certain economiy boundary. The wide use of LEAP in the area of energy planning is triggered by its flexibility of data, easiness of use, and its capability to analyse impacts resulted from certain scenario imposed into the model. LEAP is an integrated modeling tool which works on annual-time step calculation, useful to trace energy production, consumption, extraction, and transformation in predefined sectors within the system boundary. Important modules of LEAP are demand analysis, transformation analysis, resources analysis, and emission analysis.

There are many reports and journal articles that have been published on the topics that involve LEAP as the tool to analyse energy planning and its implication, energy modeling, supply-demand, emission mitigation and costing analysis of the energy planning. Analysis of potential energy demand reduction and emission in the China's transportation sector is presented by Yan and Crookes [13]. Li reported investigation of energy efficiency improvement in the China's building [14]. Long-term scenario analysis for renewable energy transition in the Korean power sector is presented by Park et. al [15]. Other updated publications documentation are provided and accessible in the LEAP website [16].

*2.3. Scenarios and Key Parameters*

In this study, three scenarios are considered to be applied in LEAP, in order to construct three supply-demand models. The first scenario is called Business as Usual, or "BAU". The BAU scenario reflects the utilization of existing fossil fuel based electricity supply, which is coal fired power plant without renewable energy contribution. On the demand side, projected number of PLN customers per sector is based on 2008-2014 average growth. In the same way, electricity consumption growth for 2015 onward is projected according to the 2008-2014 average growth, as seen on Table 2.

The second supply-demand scenario is named Sustainable Coal-Geothermal, or hereafter "SUS-1". On the supply side, a 110 MW Ijen-Belawan geothermal power plant is expected to begin its service in 2019. On the other hand, while keeping the number of customer growth over 2015-2025, the same as the first scenario, electricity demand growth is expected to be reduced by 1% for each sector compared to that projected for BAU scenario, or 8.41% for household, 9.03% for social, 8.78% for business, 14.29% for industry, and 5.68% for government or public sector.

The third supply-demand scenario is named Sustainable Coal-Geothermal-Solar, or hereafter "SUS-2". In this scenario, 20 MW grid connected photovoltaic power plant is potentially applicable within the observed regencies starting in 2018. If all regencies participated in the program, only 4 MW capacity should be installed per regency. The development of grid connected photovoltaic power plant is not that difficult as in 2014, 2 MW grid connected plant are already installed in Bali, with several off-grid capacity. In 2023, the installed capacity is expected to be totally increased up to 30 MW. The authors have thought evaluation of wind energy potential as another renewable resources. However, due to very low wind speed in the observed areas, the wind farms as well as individual wind turbine is not taken into account. On the demand side, the same projection as applied to the second scenario is also employed for this scenario. The main reason to keep the number of customer growth rate the same for all scenarios according to the average growth rate is the importance of achieving higher electrification ratio in the observed areas.

In all scenarios, the installed capacity of existing coal fired power plant is set fixed 600 MW over the simulation period in order to enable analysis of the impact of electricity consumption growth toward the supply requirement. Coal power plant efficiency is 31.21% [17] and is expected to increase up to 35% in 2025. In other words, if existing supply capacity is not sufficient to meet the projected demand growth, we can calculate the amount of that additional electricity should be supplied from the interconnected grid system. In addition, all power plants availability is set 100% to allow system receiving theoretically maximum amount of energy from the generation side. Meanwhile, transmission and distribution losses baseline as seen in Table 4 with 8.37% and is expected to be decreased until 6% in 2015.

This study assumes 5% inflation rate and 7% discount rate in order to calculate total generation costs ever the simulation period. Electricity generation costs is classified into three components. The values are varied according to the power plant type. They are unit capital cost for power plant, fuel cost, and operation and maintenance (O&M) costs. Costs components and respective values applied in this study is shown in Table 5.

**Table 5.** Major electricity generation costs components

| Power Plant Type | Unit Capital Cost (US$/MW) | *Fuel Cost (US$/MWh) | *O&M Cost (US$/MWh) |
|---|---|---|---|
| Coal Fired Plant | 1,126,000 [18] | 42.73 | 6 |
| Geothermal Plant | 1,800,000 [19] | 65.66 | 10 |
| Photovoltaic Plant | 2,000,000 [20] | - | 30 |

*PLN Statistic 2013 (The price is subject to current exchange rate: US$ 1 = Rp. 13,000)

O&M costs comprise fixed and variable cost component. The availability of generation station is set at 100% for the purpose of analysis in the simulation. Hence, both cost component plus the fuel cost are used as single cost structure in the simulation.

## 3. Results and Discussion

Baseline and projection of electricity consumption of the BAU and SUS-1/SUS-2 scenario for all sectors and regencies during the simulation period is shown in Figure 2 and Figure 3, respectively. In the case of BAU scenario, the household sector is expected to consume up to 3,919 MWh in 2025, followed by industry, business, social, and government or public sector with 1,862 MWh, 633.2 MWh, 238.8 MWh, and 220 MWh, respectively. In total, electricity demand is projected to 6,873.8 MWh, or an increase of 203% compared to year 2014 as the baseline.

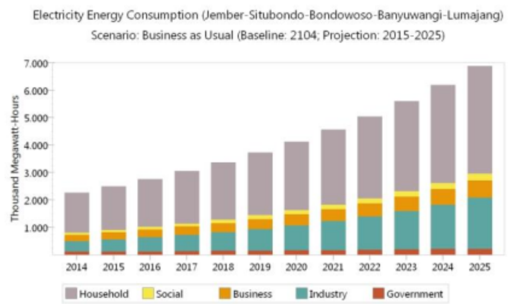


**Figure 2.** Electricity demand for each customer sector in 2014 as baseline and projection over 2015-2025 under BAU scenario.


**Figure 3.** Electricity demand for each customer sector in 2014 as baseline and projection over 2015-2025 under SUS-1 or SUS-2 scenario

In SUS-1 and SUS-2 scenarios, the consumption growth increases in a lower pace with 175% compared to the baseline or 6,222 GWh. This is possible by applying energy efficiency and conservation approach. One interesting point is the increasing consumption of industrial sector, particularly on fisheries and plantation based product. Electricity supplied for BAU scenario is shown in Fig. 4 based on the key parameters and scenarios conditions as described in earlier section.

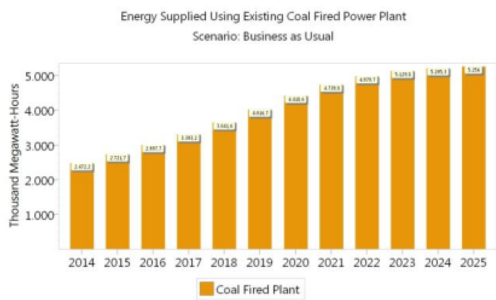


**Figure 4.** Electricity supplied for baseline year and projection years under BAU scenario.

In this scenario, the amount of energy supplied by the existing coal fired power plant into the transmission and distribution lines would be 5,256 MWh, in the last year of simulation. In general, amount of energy delivered by the power plants have already consider transmission and distribution losses throughout the simulation years. Results for the case of SUS-1 and SUS-2 scenarios are given in Fig. 5 and Fig. 6, respectively. As seen in Fig. 5, a 110 MW geothermal power plant would begin its operation in 2019 with 594.7 MWh energy supply. The output of energy would increase up to 923.7 MWh in 2025.

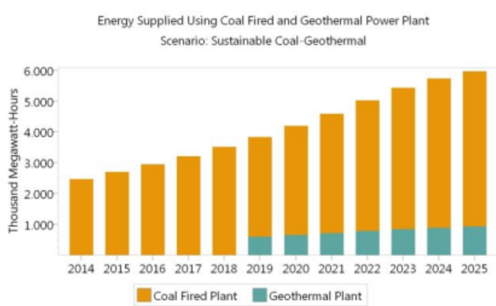


**Figure 5.** Electricity supplied for baseline year and projection years under SUS-1 scenario.

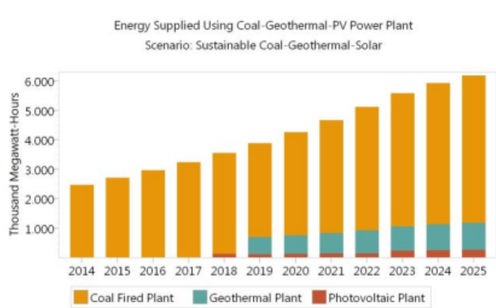


**Figure 6.** Electricity supplied for baseline year and projection years under SUS-2 scenario.

In Fig. 6, the photovoltaic grid connected power plant would join the supply side earlier than geothermal plant, or in 2018, under the SUS-2 scenario. The 20 MW plant would produce 114.3-140.3 MWh energy, or about 18% energy compared to that resulted by geothermal plant during its first three years, Meanwhile, increasing penetration of photovoltaic plant in 2023 onwards would result in a better supply mix.

The summary of energy supply mix is presented in Table 6. We can see that under the SUS-1 scenario, penetration of geothermal energy is maintained stable on 15.49% from 2019 to 2025. In the case of SUS-2 scenario, additional capacity of photovoltaic plant would reduce the share of coal fired power plant larger than the share of geothermal, and would become the lowest at the end of analysis period.

**Table 6.** Energy supply mix without additional capacity of coal fired power plant

| Scenario | Year | Coal (%) | Geothermal (%) | Solar (%) |
|---|---|---|---|---|
| BAU | 2015-2025 | 100 | - | - |
| SUS-1 | 2019 | 84.51 | 15.49 | - |
| | 2022 | 84.51 | 15.49 | - |
| | 2025 | 84.51 | 15.49 | - |
| SUS-2 | 2018 | 96.77 | - | 3.23 |
| | 2021 | 82.19 | 15.07 | 2.74 |
| | 2025 | 81.08 | 14.86 | 4.06 |

From the transformation analysis, it is revealed that all installed capacity of power plants in all scenarios would not meet overall electricity demand. Preserving the existing capacity of coal fired power plant, the BAU scenario would only meet the total demand until 2019 whereas in 2020, there may be a shortage of 14 MWh energy. The unmet energy demand for BAU scenario is given in Fig. 7.

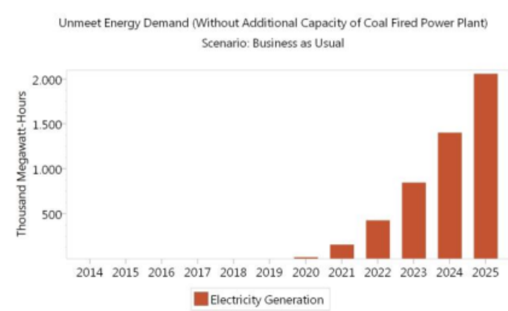


**Figure 7.** Unmet electricity demand without any additional capacity of coal fired power plant under BAU scenario.

In the final year of projection, it is expected that the total unmet energy demand for all areas would be around 2,057 MWh. In this sense, additional capacity is required to cover the shortage in the remaining years after 2019 or the supply should be delivered from the Java-Madura-Bali grid interconnection system. If the observed area is focus with adding new-renewable energy based power plant, the most suitable candidate for new-renewable energy based power plant would be Ijen-Belawan geothermal power plant with 110 MW capacity. Other alternative is to develop and utilize grid connected photovoltaic plant that can be built in every regency.

The summary of scenarios impact on unmet energy demand per year is presented in Table 7. As we can see, the SUS-1 and SUS-2 scenarios offer significant improvement to cover the unmet energy demand in the final years. By adding only geothermal power plant, there would be no energy shortage during 2020-2022. Moreover, a significant improvement could be achieved from 845.9 MW unserved demand down to only 78.8 MWh. If we observe the total unmet energy over the study period, the BAU scenario would give aorund 4,900 MWh unserved energy demand. Those value could be potentially reduced by 80% or become only 910-1,031 MWh if the SUS-1 or SUS-2 scenario is taken into account.

**Table 7.** Unmet energy demand of the observed regencies given no additional installed capacity of existing coal fired power plant

| Scenario | Unmet Energy Demand (should be imported form the interconnection system, MWh) | | | | Total unmet demand |
|---|---|---|---|---|---|
| | 2020 to 2022 | 2023 | 2024 | 2025 | |
| BAU | 595 | 845.9 | 1,403.3 | 2,057 | 4,900.8 |
| SUS-1 | - | 78.8 | 295.8 | 657.1 | 1,031.7 |
| SUS-2 | - | 47.7 | 251.9 | 610.4 | 910 |

It should be noted that the unmet energy demand is based on existing capacity of Paiton coal fired power plant, which is set to be fixed 600 MW. In this case, the 2020 unmet demand would be 14 MWh, followed by 154.2 MWh and 426.8 MWh in 2021 and 2022, respectively. On the other hand, the power generation capacity would cover total regions demand if some coal power plant capacity is added and begins its service in 2020. The total generation costs is given in Table 8. It can be seen from the table that the SUS-2 scenario would certainly require the most cost of generation over the study period because of relatively expensive unit capital and maintenance costs.

**Table 8.** Scenarios comparison in terms of total generation costs given no additional installed capacity of coal fired power plant (Million US$)

| Scenario | 2018 | 2019 | 2022 | 2023 | 2025 |
|---|---|---|---|---|---|
| BAU | 540.2 | 593.8 | 731.4 | 752.9 | 770.9 |
| SUS-1 | 521.6 | 684.5 | 890.5 | 959.9 | 1,052.3 |
| SUS-2 | 493.6 | 634.6 | 801 | 852.6 | 921.2 |

If we consider this circumstance, then the SUS-2 scenario seems to be not attractive because its added value in terms of the capability to generate energy is comparatively lower than other remaining power plant. However, the utilization of photovoltaic power plant would bring another advantage. Photovoltaic power plant life time is the longest and practically no fuel is required for electricity generation. Hence, the contribution of solar energy to preserve fossil fuel is an important point here, and of course its benefit to mitigate the greenhouse gases emission. On the other hand, option with SUS-1 scenario is attractive in terms of costs and additional amount of energy supplied to the system.

As seen in Table 8, the total generation costs for BAU scenario in 2025 would seem to be the lowest compared to other senarios because the unmet demand of 2,057 MWh is not taken into account. Moreover, if the externality costs such as environment impact cost is taken into account, then the SUS-1 and SUS-2 scenarios would be surely competitive to the BAU scenario.

Meanwhile, the total generation costs for all scenarios in the case all scenarios are successful in meeting the demand is shown in Table 9. We can see that the costs of BAU scenario would be the highest among others.

**Table 9.** Scenarios comparison in terms of total generation costs in case all scenarios are successful in meeting the demand (Million US$)

| Scenario | 2018 | 2019 | 2022 | 2023 | 2025 |
|---|---|---|---|---|---|
| BAU | 576.5 | 630.1 | 828.7 | 910 | 1,099.4 |
| SUS-1 | 521.6 | 684.5 | 890.5 | 959.9 | 1,052.3 |
| SUS-2 | 493.6 | 634.6 | 801 | 852.6 | 921.2 |

From Table 7 and Table 9, it is obvious that geothermal and photovoltaic would play significant role to support long-term electricity demand in the observed area. The projected demand itself, may not be meet if the system only rely on the coal fired power plant without adding its capacity. On the other hand, if the decision maker go with the SUS-2 scenario, there would be significant saving in terms of the total generation costs compared with the BAU scenario, as currently practiced.

## 4. Conclusion

This paper presents the role of renewable energy in the regional long-term supply-demand model analyses. Although the ideal condition of supply can be simulated to meet the energy demand for all observed areas, the authors prefer to show the realistic model along with its impacts and improvement using renewable energy resources that are locally available within the observed areas. Therefore, this study is intended to describe the relationship between supply and demand condition for the five observed regencies in East Java province, Indonesia, by emphasizing on the benefits over immediate utilization of locally available geothermal and solar energy. In the next study, the externality costs of environment, other associated costs of the system, and more detailed ecomomic analysis will be investigated. In addition, the potential of isolated energy system will also be analysed to improve the electrification ratio in the observed regencies.

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