Forecasting Indonesia’s electricity generation: an application of long-range energy alternatives planning

A Qolbi\(^1,2\) and A Utomo\(^1,2\)

\(^1\) Mechanical Engineering (Energy Systems) Department, The University of Melbourne, Australia
\(^2\) The Indonesia Endowment Fund for Education Republic of Indonesia (LPDP RI)

Abstract. The primary focus of this paper is to provide an energy forecast for electricity generation in Indonesia. The modelling method with Long-range Energy Alternatives Planning System (LEAP) software is implemented with the interpolation with growth, linear forecast, exponential forecast, and logistic forecast upon two projection scenarios of business as usual (BAU) and with current government policy (CGP). Input data used are including the past data of electricity generation from 2005 to 2017, the target electricity generation from 2019 to 2028 and its share based on Indonesia's policies and planning on electricity generation, and other electricity generation highlights based on the defining policy. The result analysis for the BAU data projects the total energy generation of 1,306.17 Terawatt-hour (TWh), comprising of 47.7% coal, 43.4% gas, 3.51% hydro, 2.32% oil, and 1.85% geothermal with the remaining percentage from other renewable energy resources. On the second scenarios with current government policy, the model predicts electricity generation to be 1,404 TWh, consisting of 54.4% coal, 22% gas, 10.93% hydro, 0.4% oil, 9.63% geothermal and the rest percentage from other renewable energy resources. The gap in the two results in the renewable energy mix shows the actual challenge that will require the government to take significant action to realize the plan.

Keywords. Electricity Generation; Forecast; Indonesia; LEAP

1. Introduction

Energy has a strong correlation with the nation's economy, specifically in all sectors advancement and growth. Knowing the past energy balance of one country will give an understanding of its economic journey. Having the energy balance forecasted to the future will help to determine the direction of the economy. As a vast country, Indonesia has caught the attention of the global community with its resilient economic growth, low government debt and prudent fiscal management, which has determined the scope of this forecasting [1]. The strong financial performance has been indicated by the real gross domestic product (GDP) that set to be stable, by 5.11% annually for the last five years [2]. High profile economists in Indonesian cabinet predict the country to be the world's fourth-largest economy by 2045 [3]. To achieve this, Indonesia needs to maintain economic growth beyond 5% on year to year level, which is currently on the track and possible by 2050, according to Nikkei Review [4]. However, the national focus is to secure this position by 2045 which is to commemorate the 100-year independence of Indonesia [5].

This paper will limit the scope of the energy forecast to the electricity generation in Indonesia that makes up around 11% of the total national energy consumption [6] and its generation mix by primary energy resources. There have been some electricity forecasting studies in Indonesia, such as [7], [8], and [9]. However, these studies focused on the demand side of the electricity forecasting and did not
consider the generation mix on the generation side. Another report in Indonesia’s 2018 Energy Outlook by Badan Pengkajian dan Penerapan Teknologi (BPPT) also performed electricity forecasting modelling. However, the model is built using Market Allocation (Markal) with the base year of 2016 [10]. In this paper, the forecasting model employs LEAP software with the updated base year of 2017. The Long-range Energy Alternatives Planning System (LEAP) software provides the modelling for the forecast. It implements the interpolation with growth, linear forecast, exponential forecast, and logistic forecast. This paper will employ two scenarios based on the World Bank projection and defining policies from national policies. Rencana Usaha Penyediaan Tenaga Listrik (Indonesia's policies and planning on electricity generation) provides the detailed national policies from 2019 – 2028. The generated forecast method will be able to be implemented in other countries or to be upscaled to a global level as long as the data required can be defined. These data are including economic (GDP and GDP growth), energy (past and projection growth), and relating policies. This forecast is considered valuable to provide the forecasted patterns of the electricity generation which can provide necessary information to the unit evaluated to observe its positioning and adjust its policies towards it, and also to the related investors to indicate opportunities to invest in the growing segment.

2. Methodology

LEAP, as an integrated and scenario-based modelling tool, tracks and forecast energy consumption and production [11]. As a forecasting tool, LEAP will process data and scenario given by users to generate the forecast of electricity generation in Indonesia by 2045. The following part will explain the details of these data and scenarios:

2.1. Electricity generation data and defining policies

Electricity generation data is required to define the current trend for electricity generation and consumption alongside the defining policies. It determines the direction for the prediction of each electricity generation in the future. Summary of the past electricity generation data for LEAP Modelling is presented in Table A2 on the appendix.

As the national electricity company, PT. Perusahaan Listrik Negara defines the policies related to the electricity generation target in Indonesia with the authorization of the Ministry of Energy and Mineral Resources [12]. This policy is summarized and published under Rencana Usaha Penyediaan Tenaga Listrik or RUPTL (Indonesia's policies and planning on electricity generation), which is updated and reviewed yearly. The latest version of RUPTL is published in the last 20th February 2019, which including the most recent policies and plans for 2019 – 2028. Table 1 below represent the summarised policies in the RUPTL:

| Table 1. RUPTL 2019-2028 Electricity Generation Highlights [13] |
|---------------------------------------------------------------|
| Parameters               | Unit | Period 2019 – 2028 |
|--------------------------|------|---------------------|
| Electricity Demand       | %    | 6.42                |
| Growth                   | %    |                     |
| Energy Mix Target started by 2025                             |
| Coal                     | %    | 54,6                |
| Gas                      | %    | 22,0                |
| Oil                      | %    | 0,4                 |
| Renewables               | %    | 23                  |
| Additional of 35 GW generators is still on progress           |

2.2. Demographic and economic data

A typical linkage between national energy consumption with its population size, population growth rate, gross domestic product (GDP) or gross domestic product per capita (GDP per capita) is linear [14]. Typically, the larger the population and the higher population growth will result in higher energy
consumption. However, the GDP correlation towards energy consumption varies between countries as the energy consumption will differ in countries with comparable GDP per capita [14]. In this modelling, the economic data (GDP and GDP per capita), the demographic data (population and population growth), and the growth rate are presented on the appendix are provided from the World Bank. These data are not direct inputs for the modelling, rather to verify the trend to the correlation of the demographic and economic projection.

2.3. Long-range energy alternative planning (LEAP) Software Simulation
LEAP is a software developed by Stockholm Environment Institute that has been used widely in energy forecasting and energy modelling in national level, such as US, Mexico, China, Taiwan and India [15]. The time-series forecasting methods used in the LEAP simulation consist of the following:

2.3.1. Interpolation with growth. This method calculates a value (in any given year) by conducting linear interpolation of a time-series of year/value pairs. Another optional parameter for the growth rate input is applied after the last specified year. No growth rate means zero growth is assumed. Each intermediate year’s value is tabulated as:

\[
Value_{iy} = Value_{fy} + \left( Value_{ey} - Value_{fy} \right) \times \left( \frac{Year_{iy} - Year_{fy}}{Year_{ey} - Year_{fy}} \right)
\]

Where, iy is the intermediate period in which the value is to be interpolated fy is the first period that is used as the basis for the interpolation ey is the end period that is used as the basis for the interpolation

2.3.2. Linear forecasting. This method calculates new values to be forecasted by using linear regression, assuming a linear trend \( Y = mX + c \); where \( Y \) is a value in any given year to be forecasted and \( X \) is the years.

2.3.3. Exponential Forecasting. This method calculates new values to be forecasted by using linear regression to an exponential growth model of \( Y = m + X^c \); where \( Y \) is a value in any given year to be forecasted and \( X \) is the years. Exponential forecasting is most useful to predict certain values where constant growth rates are expected over the period in question.

2.3.4. Logistic Forecasting. This method calculates new values to be forecasted by using an approximate fit of a logistic function by linear regression. The general form of a logistic function is:

\[
Y = A + \frac{B - A}{1 + e^{-aX+b}}
\]

where \( Y \) is a value in any given year to be forecasted and \( X \) is the years. A, B, a, b are constants and e are the base of the natural logarithm (or 2.718 in value). Logistic forecasting is most useful to predict certain values where a variable is expected to show a “S” shaped curve over time.

2.4. Forecasting Scenario and Results
Two types of scenarios are utilized in this electricity generation forecasting in Indonesia to observe the different pattern in the forecasted result. The base year for each scenario is the year of 2017 with the process flow shown in figure 1 that represents the forecasting process flow:
Furthermore, the scenarios implemented in the modelling can be described as the following:

2.4.1. **Scenario One: Projection without Government Intervention (Business as Usual Scenario - BAU).** The first scenario implemented in the simulation is based on the condition that there is no intervention from governmental policies and target. Data inputs to the LEAP software is historical data of Indonesia’s total electricity generation data 2005 to 2017 referring to the International Energy Agency and RUPTL [16] as presented in Table A2 on the appendix.

2.4.2. **Scenario Two: RUPTL 2019 – 2028 Policies (Current Government Policy Scenario – CGP).** The second scenario correlates electricity generation planning based on the policies from Table 1. Since the current policies are only defining the projection of the next ten years from 2019 to 2028, the remaining forecasted years are projected with an interpolation method. It uses historical data, electrical generation planning and the demand growth of 6.42% as a baseline [13].

The forecast results will give electrical generation value per primary energy resources both in Terawatt Hour (TWh) and the fraction in percentage. It is worth to note that the primary energy shares from the RUPTL have a less category compared to past electricity generation data provided by the International Energy Agency and Perusahaan Listrik Negara.

3. Results

3.1. **Forecasted electricity generation results on business as usual scenario (BAU).** Figure 2 and 3 represents the electricity generation according to the estimated LEAP simulation for the BAU scenario. As observed on the results, the simulation projects coal will serve as the major sources of energy from 2025 until 2045. However, the shares of coal will be reduced to 47% in 2045 and are replaced by gas shares, that will increase significantly to 43% in 2045. Oil shares will decrease slightly, while renewable energy shares will be insignificant compared to the total electricity generated.
In summary, the total energy generation on BAU in 2045 is 1,306.17 TWh, comprising 47.7% coal, 43.4% gas, 3.51% hydro, 2.32% oil, 1.85% geothermal and the remaining percentage will come from biofuels, solar PV, wind, and other renewable energy resources.

3.2. Forecasted electricity generation results on current government policy scenario (CGP)

Figure 4 and 5 represents the electricity generation according to the estimated LEAP simulation for CGP scenario. As observed, the simulation projects coal as the major sources of energy from 2025 until 2045. The shares of each primary energy sources, however, will stay the same as the year of 2025. The simulation result is heavily affected by the current policy that dictates the shares of primary energy sources will not change from 2025-2028. These shares consist of 54% coal, 23% renewables, 22% gas, and 0.4% oil, referring to Table 1. In this case, gas will be the second-largest sources of energy for electricity generation. While renewable energy shares will come from hydro and geothermal power.

In summary, the total energy generation on CGP Scenario in 2045 is 1,404 TWh, comprising 54.4% coal, 22% gas, 10.93% hydro, 0.4% oil, 9.63% geothermal and the remaining percentage will come from biofuels, solar PV, wind, and other renewable energy resources.

4. Discussion and Analysis

The difference between the total electricity generated on the simulation result of the two scenarios is the results of different assumption used for each scenario, as explained in the methodology section. However, the difference in the electricity generation results is not significant, accounting for less than 7% difference between the business as usual and current policy scenario.
The gap results in the renewable energy mix from the forecast of BAU and ECP scenario provides evidence for the necessity for the government to take significant action in realizing the plan. Furthermore, the fact that the current realization of all renewable shares is only 12% [13] put more challenge for achieving renewable energy shares to be 23% in 2025 where the possible action is to increase the portion of hydro and geothermal as dictated by the present pattern.

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## Appendices

### Table A1. Indonesian demographic and economic data [2]

| Parameters                  | Year   | 2005   | 2007   | 2009   | 2011   | 2013   | 2015   | 2017   |
|-----------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Population (head)           |        | 229,838,202 | 236,159,276 | 242,524,123 | 248,883,232 | 255,131,116 | 261,115,456 | 229,838,202 |
| Population Growth (%)       |        | 1.37   | 1.35   | 1.32   | 1.28   | 1.22   | 1.14   | 1.37   |
| GDP per capita ($/person)   |        | 1,260.93 | 1,855.09 | 2,254.45 | 3,634.28 | 3,620.66 | 3,334.55 | 3,846.42 |
| GDP ($ in million)           |        | 285,868.62 | 432,216.74 | 539,580.09 | 892,969.11 | 912,524.14 | 860,854.24 | 1,015,420.59 |
| Growth GDP ($)              |        | 5.69   | 6.35   | 4.63   | 6.17   | 5.56   | 4.88   | 5.07   |
| Average Population Growth   |        | 0.71% projected from 2018 to 2050 |
| Average GDP Growth          |        | 6.04% projected from 2018 to 2050 |

### Table A2. Indonesia’s Electricity Generation

| Parameters                  | Year   | 2005[16] | 2006[16] | 2007[16] | 2008[16] | 2009[16] | 2010[15] | 2011[15] | 2012[15] | 2013[15] | 2014[15] | 2015[15] | 2016[15] | 2017[15] |
|-----------------------------|--------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Electricity Generation      |        |          |          |          |          |          |          |          |          |          |          |          |          |          |
| Coal (TWh)                  |        | 51.793   | 58.630   | 63.817   | 61.392   | 65.890   | 68.445   | 77.737   | 100.710  | 110.421  | 119.605  | 129.807  | 134.069  | 147.825  |
| Oil (TWh)                   |        | 39.299   | 36.681   | 37.619   | 42.843   | 35.334   | 34.150   | 42.186   | 29.870   | 26.691   | 25.909   | 19.213   | 16.057   | 14.271   |
| Gas (TWh)                   |        | 19.086   | 19.448   | 22.372   | 25.207   | 34.804   | 40.247   | 36.551   | 45.278   | 50.257   | 54.465   | 57.649   | 65.316   | 59.376   |
| Biofuels (TWh)              |        | 0.022    | 0.032    | 0.036    | 0.047    | 0.063    | 0.095    | 0        | 0        | 0.148    | 0.718    | 0.653    | 1.211    | 1.007    |
| Hydro (TWh)                 |        | 10.725   | 9.623    | 11.286   | 11.528   | 11.384   | 17.456   | 12.419   | 12.801   | 16.923   | 15.156   | 13.741   | 19.370   | 18.632   |
| Geothermal (TWh)            |        | 6.604    | 6.658    | 7.021    | 8.309    | 9.295    | 9.357    | 9.371    | 9.417    | 9.414    | 10.036   | 10.048   | 10.656   | 12.672   |
| Solar PV (TWh)              |        | 0        | 0        | 0        | 0        | 0        | 0.001    | 0        | 0        | 0        | 0.038    | 0.019    | 0.021    | 0.029    |
| Wind (TWh)                  |        | 0        | 0        | 0        | 0        | 0.004    | 0.004    | 0        | 0        | 0        | 0        | 0        | 0.006    | 0        |
| Other Sources (TWh)         |        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0.208    | 0.441    | 0.584    | 0.590    |
| Total (TWh)                 |        | 127.529  | 131.072  | 142.151  | 149.326  | 156.774  | 169.755  | 178.264  | 198.076  | 213.850  | 226.135  | 231.570  | 247.290  | 254.402  |

### Table A3. Targeted Indonesia’s Electricity Generation Based on RUPTL 2019-2028 [15]

| Electricity Generation | Year   | 2019   | 2020   | 2021   | 2022   | 2023   | 2024   | 2025   | 2026   | 2027   | 2028   |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Coal (TWh)             |        | 177    | 197.6  | 219.2  | 232.7  | 243.4  | 247.3  | 225.4  | 239    | 256.9  | 272.4  |
| Oil (TWh)              |        | 8.8    | 8.8    | 4.8    | 1.9    | 1.9    | 1.5    | 1.7    | 1.8    | 1.9    | 2      |
| Gas (TWh)              |        | 59.9   | 58.3   | 58     | 63.3   | 71.7   | 76.9   | 90.8   | 96.7   | 103.9  | 110.2  |
| Hydro (TWh)            |        | 17.2   | 18.3   | 20.5   | 20.3   | 21.2   | 30.6   | 42.9   | 46.7   | 50.3   | 54.7   |
| Geothermal (TWh)       |        | 14.1   | 15.8   | 16.6   | 19.3   | 20.7   | 24.7   | 44     | 47.2   | 47.6   | 48.2   |
| Other Renewables (TWh) |        | 2.6    | 3      | 2.4    | 5.7    | 6.6    | 7      | 8.1    | 8.1    | 11.7   | 13.2   |
| Total (TWh)            |        | 282.1  | 301.8  | 321.4  | 343.2  | 365.4  | 387.9  | 412.9  | 439.3  | 472.3  | 500.7  |