Indonesia’s Electricity Demand Dynamic Modelling

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Abstract. Electricity Systems modelling is one of the emerging area in the Global Energy policy studies recently. System Dynamics approach and Computer Simulation has become one the common methods used in energy systems planning and evaluation in many conditions. On the other hand, Indonesia experiencing several major issues in Electricity system such as fossil fuel domination, demand – supply imbalances, distribution inefficiency, and bio-devastation. This paper aims to explain the development of System Dynamics modelling approaches and computer simulation techniques in representing and predicting electricity demand in Indonesia. In addition, this paper also described the typical characteristics and relationship of commercial business sector, industrial sector, and family/ domestic sector as electricity subsystems in Indonesia. Moreover, it will be also present direct structure, behavioural, and statistical test as model validation approach and ended by conclusions.

1. Introduction
The energy consumption continued to increase up to 7\% each year, but in other hands, Indonesian fossil fuel resources and oil reserves experience a significant decline since the era of the 80s. Power shortage, fossil fuel dominated energy mix, environmental impact, electrification ratios, and energy loses in distribution channel, really are, the major issues of current Electricity system in Indonesia. Not to mention the electricity consumption of Indonesia was and still is showing a progressive increase over the years. This paper objective is to develop a dynamic model of electricity demand in Indonesia. Dynamic model suitable for complex system which is compliant with this case, it allow inclusion of external issues [1], contribute to question decision makers’ mental models [2].

2. Methodology
The main purpose of the research is to develop dynamic model of Indonesia’s electricity demand integrated with specific real system behaviour. Therefore, System Dynamics is fruitful in addressing such system. Data collected by observation as well as document and survey result from any related sources. Conceptual modelling based on causal loop and archetypes, cause and effect and influence diagram. Moreover, system analysis and design based on system dynamic based computer simulation, policy study framework, and multi-model ecologies perspective. On the other hand, structural, behavioural, and policy validation are the main approaches for model validity assessment. Nonetheless, due to the complexity of system, this research focus on developing model on demand side of the system.

Research stages are as follow. (1) Problem formulation. Comprehensive review of current condition of energy system in Indonesia, especially in electricity sector including Indonesian strategic policy for future energy. This review will also discuss the emerging sustainable modelling approach.
for energy system and analysis. (2) Conceptual Model Development. This part explained the Conceptual or Framework Modelling of Electricity System for Socio-Economic and Environmental impact. Combination of causal loop and its generic archetypes, influence diagram, and circular-economy perspectives will applied as development tools and carried out as main approaches in this part [3]. (3) System Dynamic Computer Model Development. In this phase, system dynamic model will be developed and verified for Sustainable Electricity System in Indonesia. (4) Model Testing and Validation. After all aspects and scope of the system transformed into a computer simulation model, a validation is required. In addition, computer simulation conducted in this step either to analyze the existing policy or designing recommended policy for future sustainable energy system in Indonesia. (5) Policy Design, Analysis, and Report Writing.

![Image of problem formulation and conceptual model](image1)

**Figure 1** Research methodology

#### 3. Dynamic modelling

The model consists of three sectors: (1) commercial business sector, (2) industrial sector, and (3) family/domestic sector. Commercial business sector and industrial sector shows simple relations among its variables. A more complex dynamics exhibits in family sector whereas its relation to population sub-model. Population represented by level variable, which added by population growth in-rate caused by birth rate and immigration. On the other side, population decreased by population decline out-rate caused by death ratio and emigration.

![Image of flow diagram of Indonesia's Electricity Demand](image2)

**Figure 2.** Flow diagram of Indonesia's Electricity Demand
3.1. Growth Rate
Population growth is the change in the number of residents in a certain area at a certain time compared with previous times, caused by fertility (births), mortality (deaths) and migration [4]. Indicators of population growth is very useful for predicting the population of a region or country in the future. By knowing the number of people, we also know the basic needs of this population, not only the social and economic fields but as well as the electrical energy needs in the future. Population grows geometrically and food items increased by arithmetically. The following equation calculate the rate of growth of customers using [5].

\[
\text{Growth} = \frac{\text{variable year}(t) - \text{variable previous year}}{\text{variable previous year}} \times 100\% \tag{1}
\]

Customer’s growth rate equation above also used to calculate the growth rate of electrification ratio, growth in demand for the business sector and the industrial sector demand growth but it is also used to find the level of emigration and immigration rates. In the family sector, also affect the amount of electrification ratio or families that use electricity.

3.2. Electrification Ratio
The largest electrical energy consumers are the family sector. On one certain regional, electrical energy influenced by the amount of electricity users (electrification ratio) [6]. Electrification ratio defined as the number of families that have been electrified divided by the number of all families in Indonesia [7]. So that the electrification ratio calculations used the following formula:

\[
\text{ER} = \frac{\text{number of families that have been electrified}}{\text{number of all families}} \tag{2}
\]

The government has made great efforts to increase the electrification ratio in the area, including: instructed all regents / mayors to implement the accelerated development of rural electricity in their respective areas; allocate funds to provide power for at least 5 thousand families per year and PLN 50 thousand families per year. Rural electricity program expected to develop electricity grid villages to use the potential of renewable energy locals like power plants micro hydro (MHP), power plants wind / wind (PLTB) and solar power plants (PLTS) [8]. By using the electrification ratio, can be used to determine the needs and growth of electric energy in the family sector which will increase the demand for electrical energy overall.

3.3. Number of Family
Today, almost all classes of customers enjoy electricity subsidy, including the classes of customers that are highest economically. The subsidy recipient class is a class of small family 450 VA and 900 VA amounting to approximately 32.85% of the total subsidies in 2011. Another group that received subsidies are small family 1300 VA and 2200 VA, VA 3500-5500 medium families, medium industries > 200 kVA, the industry is 14-200 kVA, large industrial > 30 MVA, 6.6 to 200 kVA medium-sized businesses and public street lighting [8].

**Table 1. Number of family growth [8]**

| Year | Number of family |
|------|------------------|
| 2000 | 52,008           |
| 2002 | 55,041           |
| 2003 | 56,623           |
| 2004 | 58,253           |
| 2005 | 55,119           |
| 2006 | 55,942           |
| 2007 | 57,006           |
| 2008 | 57,716           |
| 2009 | 58,422           |
| 2010 | 61,390           |
| 2013 | 64,041           |
| 2014 | 64,772           |
Seeing these data, the number of families would greatly affect the number of customers in the family sector that will determine the amount of the electricity demand in the family sector and the overall. The number of families estimated by the following formula [5].

\[ \text{P}_{\text{Ht}} = \frac{\text{P}_{\text{t}}}{\text{R}_{\text{t}}} \]  \hspace{1cm} (3)

Where:
- \( \text{RT}_t \) : The number of families in year \( t \)
- \( \text{Pt} \) : The number of population in year \( t \)
- \( \text{Pht} \) : The number of family occupants (assuming four person)

3.4. Growing electricity demand

Electrification ratio used to estimate the increase in electricity demand of family sector by the following formula [5].

\[ \text{Pel Rt} = \text{Ht} \times \text{Ret} \times \text{electricity consumption/customer} \]  \hspace{1cm} (4)

The improvement in the electrification ratio increased sales and the impact on national electricity consumption, especially in the family. Sales of electricity in the family sector in 2011 increased by 8.9% growth, followed by sales for social customer 8.1%, commercial business and 7.7%, industry 7.3% and sales of electricity for street lighting 3.3%. Overall the total sales of the electricity in 2011 increased by 7.3% from 147.3 thousand GWh in 2010 to 157.9 thousand GWh in 2011. In addition to increase the electrification ratio, the improved reliability of electricity supply, especially in the Java-Bali electricity system also plays a role the increase in electricity sales during [8].

3.5. Number of Population

Number of population affected by changes in fertility (births), mortality (deaths) and migration [8]. The accumulation of the population of this will affect the number of families in Indonesia. Fertility influenced by many factors. Among the factors that affect the high and low fertility of the population is non-demographic factors and demographic factors. Factors that support and hinder the birth-rate in Indonesia are as follows:

a) Supporting birth (Pro birth-rate) (marry a young age, a view many children a lot of sustenance, a child of hope for parents as breadwinners, the child is a determinant of social status, the child is offspring especially boys) and

b) Factors inhibiting the birth (Anti birth-rate) (Implementation of the family planning program, delay the age of marriage because of completing education, a growing number of career women).

Discussing about various things regarding the cause of fertility and the impact on various aspects of life are more multi-disciplinary who studies the impact of the fertility rates of the various aspects of life, one of which is the growing demand for electricity from year to year. Mortality or death is one of the three components of demographic processes that affect the population. Factors that support the death (Pro mortality) is the lack of public awareness of the importance of health, inadequate health facilities, poor nutritional state of the population, the occurrence of natural disasters such as volcanic eruptions, earthquakes, floods, wars, disease and murder. While the death inhibiting factor (Anti mortality) is the increasing awareness of the population about the importance of health, inadequate health facilities, increasing the nutritional state of the population, multiply the medical personnel such as doctors and midwives as well as advances in medicine. Migration is one of the basic factors that influence the growth of population factors besides birth and death. Migration in question in this case is the migration permanently, that is to stay a lifetime in Indonesia or out leaving Indonesia lifetime. In developing countries, migration is regionally very important to study. Given the increase in population density rapidly in certain areas due to population distribution is uneven which of course it will affect other aspects of life that involves social and economic aspects is no exception will increase the
demand for electrical energy [8]. The population may be decline due to emigration permanently affected and the crude death rate (CDR). CDR is a number that indicates the number of deaths per 1000 population within one year so depopulation calculated by the formula:

\[ \text{Depopulation} = (\text{CDR} \times \text{Total population}/1000) + (\text{Total population} \times \text{Lifetime emigration}) \] (5)

Increasing the number of people affected by the birth rate and immigration are still so used the formula:

\[ \text{Pop growth} = (\text{Birth rate} \times \text{Total population}) + (\text{Total population} \times \text{Lifetime immigration}) \] (6)

3.6. Model credibility
Validation is the latest stage in the development of a model to check the model by reviewing whether the model output in accordance with the real system, with a view of internal consistency, correspondence and representations [9]. Dynamic systems model validation assessed in several ways. Firstly, test structures directly (direct structure test) without operate (running) model. Secondly, the structural test model of behavior (structure-oriented behavior test) to operate the model. Lastly, comparing the behavior of the model with real systems (quantitative behavior pattern comparison) [10]. Model validation exercise by comparing the behavior of the model with which to test the real system MAPE (Mean Absolute Percentage Error). MAPE (median absolute percentage error) is one measure of the relative involving percentage error. This test used to determine the suitability of the data resulting estimates with actual data.

\[ \text{MAPE} = \frac{1}{n} \sum \frac{|X_m - X_d|}{X_d} \times 100\% \] (7)

Where,
\[ X_m \quad \text{: simulation data} \]
\[ X_d \quad \text{: actual data} \]
\[ n \quad \text{: period} \]
\[ \text{MAPE < 5\%} \quad \text{: symmetric} \]
\[ 5\% < \text{MAPE} < 10\% \quad \text{: symmetric} \]
\[ \text{MAPE} > 10\% \quad \text{: asymmetric} \]

Validation based on the model outlined in the flow chart and the variables used in the simulation. Validation results as shown by the graph and four tables above. From the table, the use of the business sector indicates that the accuracy of the model was not right with MAPE value amounted to 13.85916%. The public sector electricity consumption is very high degree of accuracy (very appropriate) with MAPE value of 0.53839%. The family sector and the use of the industrial sector has a level of accuracy of the model is very high as well (very appropriate), with a value of 2.0493505% MAPE and 3.0144276%. Based on this, it is safe to say that the model can describe the real condition.

Based on the MAPE test, known to no one model that is not appropriate (not describe the actual condition), so we need another test, for example by using a direct test structure, namely using direct extreme condition. Direct extreme condition done by changing the initial amount of electricity consumption in the business sector to zero. If there is no electricity consumption in business sector it is expected that, the stock usage in the business sector remain zero all the time, as well as the use of the public sector, families and industry. This is the same as that of the while researching the needs of antiretroviral drugs, i.e. by changing the initial number of HIV-positive population to 0 so that if there are no people who are HIV-positive, it is expected the stock HIV-positive population remains 0 all the time, as well with a population of AIDS [11].
4. Discussion

The simulation exhibits an exponential growth in national electricity demand because of cumulative growth in all existing sectors.

Figure 3. Simulation results of total Indonesia's Electricity Demand

Figure 4. Simulation results of sectors effecting total electricity demand

Efforts on developing high degree accuracy models have been exercise. Correlation and regression analysis practiced to determine dominant variables effecting electricity demand in Indonesia. Average tariff and rate of capacity using per customers has given positive impact, and install capacity has given negative impact. Rate of capacity using per customer variable has significant influence to electricity demand of social sector but install capacity and average tariff has not significant influence to electricity demand of social sector [12]. Advance model such as Neural Network (NN) and Support Vector Machine (SVM) applied to predict the needs of electricity demand. Genetic Algorithm (GA) recommend as a method to optimize the value of NN and SVM parameters in predicting the demand of electrical energy [13]. Nonetheless, those models incapable to describe the dynamics and complexity of variables.

Similar to this research, a dynamics modelling approach employed in attempt to capture the complexity of electricity demand [14]. The research study the dynamics of electricity on both demand and supply side in East Java. The existing model shows that East Java will face energy crisis in 2025. In addition, the results of all design of experiment (pessimistic, optimistic, and most likely) are consistent. It concludes that no power plan supplying east java are adequate to meet future electricity demand in East Java.

The model’s credibility will improve if at least two methods of validation applied. Those methods are (1) Structural validation, and (2) Behaviour validation. This research share the same method to validate initial model. Mean comparison and Error variance are applied to validate initial model. Mean comparison test objective is to assess the mean difference between two sets of data. The test’s result, exclusively imply that there is no different between two sets of data.

5. Concluding remarks

From the description above, it can be concluded that the problem of policy planning and analysis of electricity systems is a significant issue in sustainable energy management in Indonesia. Furthermore, it can also be summarized, although still require various development, System Dynamics and computer simulations have contributed significantly in designing and modelling the demand side of Indonesia’s Electricity System.

Next, throughout this work, it has been described that The Indonesia’s Electricity System behaviour notably influenced by interdependency relation among commercial business, industrial, and domestic characteristic. Finally, from the description, it can be indicated that the research still has a sufficient opportunity to be developed specially to construct the integrated dynamics model of electricity system in Indonesia.
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