

Scenario Analysis of Indonesia's Energy Security by using a System-Dynamics Approach

Yudha Prambudia and Masaru Nakano

Abstract—Due to rapid economic growth, Indonesia's energy needs is rapidly increasing. Indonesia's primary energy consumption has doubled in 2007 compared to 2003. Indonesia's status change from oil net-exporter to oil net-importer country recently has increased Indonesia's concern over energy security. Due to this, oil import becomes center of attention in the dynamics of Indonesia's energy security. Conventional studies addressing Indonesia's energy security have focused on energy production sector. This study explores Indonesia's energy security considering energy import sector by modeling and simulating Indonesia's energy-related policies using system dynamics. Simulation result of Indonesia's energy security in 2020 in Business-As-Usual scenario shows that in term of supply demand ratio, energy security will be very high, but also it poses high dependence on energy import. The Alternative scenario result shows lower energy security in term of supply demand ratio and much lower dependence on energy import. It is also found that the Alternative scenario produce lower GDP growth.

Keywords—Energy Security, Modeling, Simulation, System Dynamics.

I. INTRODUCTION

INDONESIA is among the emerging Asian economies with rapid economic development. With year-on-year GDP growth of 4.2% of 2009, Indonesia outperformed other Southeast Asia economies [1]. Alongside the economic growth, Indonesia's energy needs are rapidly increasing as well. With total primary energy consumption growth average of 4.12 MTOE/year, Indonesia's primary energy consumption has doubled to 132.5 MTOE/year in 2007 compare to year 2003 consumption [5]. One important event which marked Indonesia's energy needs concern was its withdrawal from OPEC in 2008 due to its change from net exporter to net importer country [8]. It is very important for Indonesia to secure its energy supply at an adequate level to maintain its economy growth.

The term energy security in this study is based on the notion that energy security is a sufficient and uninterrupted supply of energy; this notion is closely related to energy security in term of 'availability of energy' [16]. This study used ratio between

supply and demand of energy to measure the energy security in term of availability. Other measures of energy security which may be used for this term of energy security can be found in [11] and [17]. In addition, to address the changing of Indonesia's OPEC status, energy import dependency with specific interest to oil is analyzed as well. There are several ways both from supply and demand side to indicate import dependency (for example see [4], however, since the interest is more on the supply side, for this study import dependency is measured by the amount of import of energy compared to total energy supply of the country.

Due to its relatively easy to understand concept, System dynamics is used to approach energy security issue in this study.

II. METHODOLOGY AND DATA

A. Methodology

The methodology for this study is consist of four steps namely; problem identification, model design, scenario development, implementation and simulation. It is presented in Fig 1. The first step is to clearly identify the problem. Literatures on energy security were reviewed to find the definition of energy security and the perspective from which this study will stand. Energy security definition is naturally polysemic [9]. Its definition depends on which dimension it stand. However recent definition of energy security considers a holistic approach that take into account many dimensions of energy security [21] which makes it a very complex issue to model.

The next step is designing a system dynamics model. System dynamics is selected for this study firstly because it has been successfully dealing with complex issues such as energy issues [15]. Secondly, it is based on simple concepts which allow relatively faster model development, and it's causal relationship feature makes it easier to be communicated to non-technical community, for instance; policy makers [3] [21].

The designing process in this step is categorized into three levels namely; system, sub-system and component. At system level, a conceptual model capturing the general structure of the model is constructed. At sub-system level, the conceptual model is decomposed into more detail modules. The modules consist of variables and relationships between them. At this point causal diagram is constructed. At the component level, identification of stocks-and-flows, auxiliaries and constant based on the variables taken into account at sub-system level is conducted.

Yudha Prambudia M.Sc. is with the Business Engineering Laboratory, Graduate School of System Design and Management – Keio University, 4-1-1 Hiyoshi, Kohoku-ku, Yokohama-shi 223-8526 Japan (e-mail: prambudia.yudha@a6.keio.jp).

Prof. Masaru Nakano, Ph.D. is the Head of Business Engineering Laboratory, Graduate School of System Design and Management – Keio University, 4-1-1 Hiyoshi, Kohoku-ku, Yokohama-shi 223-8526 Japan (e-mail: m.nakano@sdm.keio.jp)

In the third step, scenario development is conducted and variables selected as parameters are determined.

The fourth step is to implement the model in a computer modeling tool and simulate the model. In this case, due to author's familiarity to Vensim, it was selected as the implementation tool.

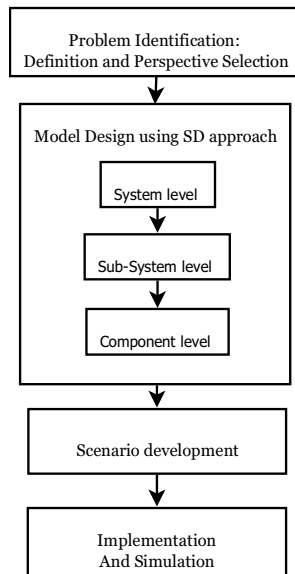


Fig 1. Modeling Methodology

B. Data

The main data for the model is the energy data, other data are appropriately selected to follow the available energy data. There are some sources for data; however, to maintain consistency as much as possible, only a few sources of data are selected. Data for each energy sub-systems are come from ADB Energy Statistics in Asia and the Pacific [2]. The data provided from this source is between the years of 1990 to 2006. Biomass data from 1990 to 2003, however, is estimated due to unavailability of biomass data before year 2004. Other data such as GDP components, technology advance, and national productivity are respectively come from the United Nation Statistics (UN Stats). United Nations Industrial Development Organization [19] and Asian Productivity Organization [6].

III. THE MODEL

The model consists of one main sub-model namely Energy System, and two smaller sub-models of Economic System and Technology System as depicted in Fig.1.

The Energy System is further elaborated by sub-systems according to the types of energy carrier namely Oil Sector, Gas Sector, Coal Sector and Other Energy Sector, and one sub-system namely; Energy Balance to capture the supply-demand behavior of energy. The Other Energy Sector is a collection of energy carrier of Hydro, Biomass, and Geothermal energy. Each type of energy carrier sector is further detailed into their Production, Consumption and Balance sub-sectors.

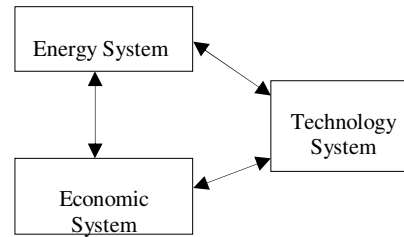


Fig. 2 Conceptual Model Structure

The Economic System consists of Gross Domestic Product (GDP) sub-system which is modeled as a summation of Household Consumption, Capital Formation, Government Spending, Export and Import variables. The Technology System consists of four variables of Technology Advance, Technology Adoption, Energy Efficiency and Productivity. Fig 2 present an overview of the model. Due to the size of the model, only key variables and sub-systems are presented.

A. Feedback loop

There are three groups of feedback loop characterized the model. In the following sections, the loops and the regression underlying the key assumptions of the loop will be presented.

Energy-Economy Loop

This is the main loop that connects to other parts of the model. A key assumption applied in this loop is that the amount of energy consumed is depending on energy availability in term of ratio of supply over demand. Ratio value of 1 or above means that energy is sufficient and consumption will perform as usual. If the ratio value declines to below 1, it means energy is insufficient and the energy consumption will be reduced parallel to the ratio. The loop is represented in Fig.2.

Following [13] and [14] that show developing countries economic development is driven by energy consumption, the model assumes causal relationship from energy consumption to GDP. For this assumption, regression technique was performed on GDP data and Total Energy Consumption. Since GDP data behavior is sensitive to 1998 Asian economy crises, the data is divided into two periods because the data shows two opposite trends for the period of 1990 until 1998 and 1999 until 2003. The regression produces as following; for period of 1990 to 1998,

$$\ln(GDP) = 1.3626\ln(\text{Total Energy Consumption}) + 6.5039 \quad (1)$$

$$R^2 = 0.94 \quad RSS = 0.01$$

And for period of 1999 to 2003,

$$\ln(GDP) = 2.5462\ln(\text{Total Energy Consumption}) + 0.4425 \quad (2)$$

$$R^2 = 0.88 \quad RSS = 0.02$$

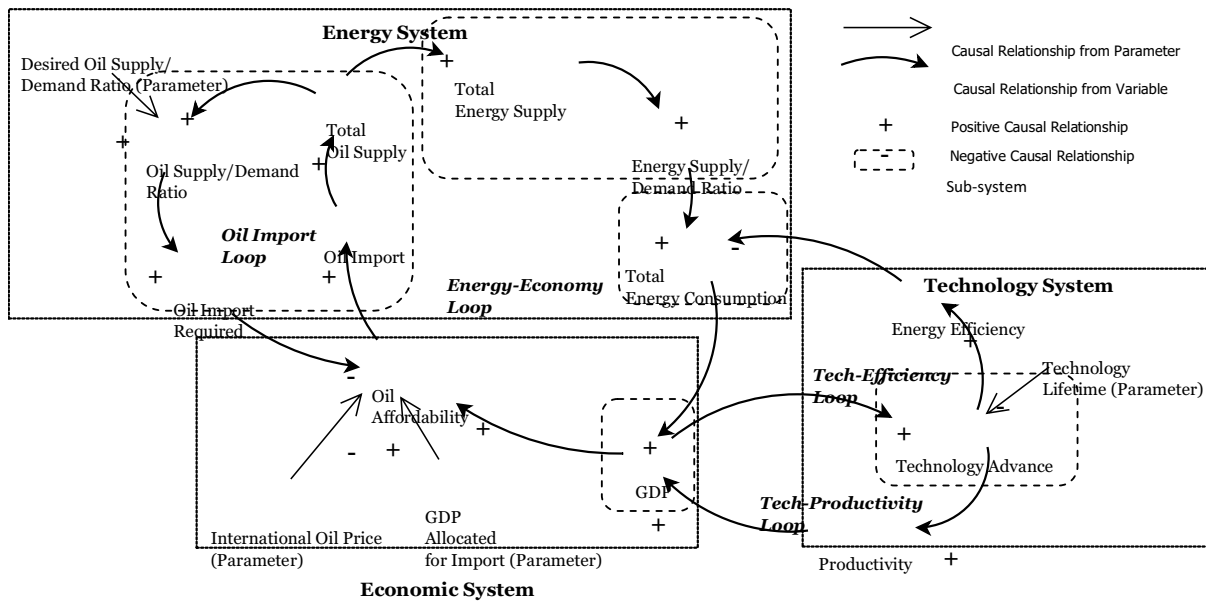


Fig 3. Key feedback loops of the model

In turn, the economic development will influence the energy system. Based on [12], the model assumes that increase of energy price will retard the economy by slowing down energy imports if the nations GDP can not afford it. Affordability variable is introduced in the model to address the assumption. The idea of affordability is that the capability to import energy is depend on the relationship between prices of energy and level of GDP. It will be explained in the next section.

The total energy supply is a summation of total supply of oil, gas, coal and other energy. Since oil is the main interest, the total supply of gas, coal and other energy types are not elaborated in further detail in Fig 2. The same condition applies for total energy consumption and members of economy sub-system that constitute GDP. These sub-systems are depicted in the figures as bracketed variables with small arrows.

Oil Import Loop

Based on [12], that high energy prices will retard the economy, the model assumes it will happen through the decrease of energy import, thus decrease in energy supply. It is depicted in the Fig.2.

This loop illustrates the influence of affordability towards the fulfillment of oil supply needs. The amount of oil import required is depending on the desired oil supply demand ratio level. Thus,

$$\text{Oil Import} = \text{Oil Import Required} \times \text{Oil Affordability} \quad (3)$$

$$\text{Oil Import Affordability} = \frac{\text{GDP Allocation for Oil Import} \times \text{GDP}}{\text{International Oil Price} \times \text{Oil Import Required}} \quad (4)$$

$$\begin{aligned} \text{Oil Import Required} &= (\text{Desired Oil SD Ratio} - \text{Oil SD Ratio}) \\ &\quad \times \text{Total Oil Demand} \end{aligned} \quad (5)$$

Definition of terms used in equations above is provided in the appendix.

The oil affordability is determined by the share of GDP allocated to buy certain amount of oil required to balance the energy supply demand ratio to a desirable level at the certain international price of oil.

B. Technology Influenced Loop

Also presented in Fig 3, Technology Efficiency loop and Technology Productivity loop represent relationship between improvement of technology with energy consumption and economic growth.

A technology advance indicator from UNIDO (UNIDO, 2006) is adopted to determine the level of Technology Advance. This indicator provides an index of the degree of new technologies adopted by society and industry of a country. Energy efficiency growth is assumed to progress concurrently with the advance of technology which then influences energy consumption.

The technology advance is also affecting the GDP via productivity. It is assumed that productivity is increasing along with technological advance. In order to calculate the influence of technology advance to productivity, regression is performed to productivity data from Asian Productivity Organization [6] and the technology advance indicator. The regression produce,

$$\begin{aligned} \text{Productivity} &= 1.1094 \ln(\text{Technology Advance}) \\ &\quad + 2.8632 \end{aligned} \quad (6)$$

$$R^2 = 0.70 \text{ RSS} = 0.12$$

In order to calculate productivity influence over GDP, a multiplier is introduced. The multiplier is produced by regression technique using productivity as independent variable and GDP growth as dependent variable. It is expressed as follow,

$$GDPM = 1.0116e^{0.270717 \times \text{Technology Advance}} \quad (7)$$

$$GDP = GDPI \times GDPM \quad (8)$$

Where, GDPI is the initial value of GDP and GDPM is the GDP Multiplier.

IV. PARAMETER AND SCENARIO

A. Parameter

Interactions between economy and oil price over energy security can be simulated by modifying parameters namely the International Oil Price, Desired Supply Demand Ratio and Percentage of GDP Allocated for Oil Import. International Oil Price can be arranged to follow certain increasing or declining trend or at certain level of price. The default value for this parameter is set to the increasing trend price of the corresponding period of the data available. Desired Oil Supply Demand Ratio is the ratio of amount of oil necessary to fulfill consumption need. This parameter can also be viewed as the amount of oil inventory as protection from disruption (i.e sudden decrease of supply). Percentage of GDP Allocated for Oil Import is functioning as a constraint to the amount of oil that can be imported to the country at a certain oil price.

The role of technology parameter is mainly to the consumption sector. The influence of technology over energy consumption is represented by efficiency. Efficiency level is depending on the replacement of older technology by newer technology that is assumed to bring more advance technology. The period of replacement is assumed as the life time of the older technology. The longer the life time of old technology, the slower efficiency will increase.

B. Scenario

Two scenarios are simulated for this paper to explore the energy security of Indonesia from 2007 up to 2020. The first scenario is the Business As Usual (BAU), in this scenario the Desired Oil Supply Demand Ratio parameter is set to follow the trend curve assuming that there will not be any change in energy supply-demand policy. Oil import burden on GDP is not limited assuming that GDP will always accommodate oil import needs, therefore the Percentage of GDP Allocated for Oil Import parameter is set to 100%. The Technology Life Time is set to 50 years assuming that newer technologies are adopted by Indonesia at current rate. In both scenarios, this parameter values is based on expert estimation on lifetime of industrial machinery and vehicle in Indonesia.

The alternative scenario (ALT) is a scenario that developed from a combination of parameters value assumed to be the most probable scenario given the parameter provided and a review of recent Indonesia's policy composed from [7], [18], and [5]. In this alternative scenario, the Desired Oil Supply Demand Ratio is set to the 1.25 assuming that Indonesia will follow EU

standard to have a reserve of oil for 90 days from normal oil demand [10]. Percentage of GDP Allocated for Oil Import is maintained at 1.6% level assuming that high increase of oil price can only be absorb up to this level without disrupting the oil import. The level is the average of oil import spending share in Indonesia's GDP calculated from 1990-2006 data. The technology life time is set to 10 years assuming that more advance technologies are adopted by Indonesia at high rate.

In both scenario, the Oil Price is assumed to continue its increasing trend and the value is estimated by calculating the trend curve from oil price data of 1990 to 2006.

V. ANALYSIS OF SIMULATION RESULT

The simulation goal is to examine policies that may affect the development of Indonesia's energy security over the period of 2007 to 2020. This is done by comparing the simulation result of BAU scenario and ALT scenario. In the graphics, the simulation year starts at 2007 abbreviated as 07 and ends at 2020 abbreviated as 20.

A. Energy Supply Demand Ratio

The simulation result of BAU showed a significant increase of energy security, in term of Total Energy Supply Demand Ratio. It is mainly influenced by the import sector, and since the only type of energy source imported is oil, its influence over Energy Supply Demand ratio is very high.

The Desired Oil Supply Demand ratio in BAU is set to follow its trend curve as showed in Fig 4 due to lack of policy in determining the target of oil supply demand. Therefore, if there is not any decrease in demand side, this allows Energy Import Re

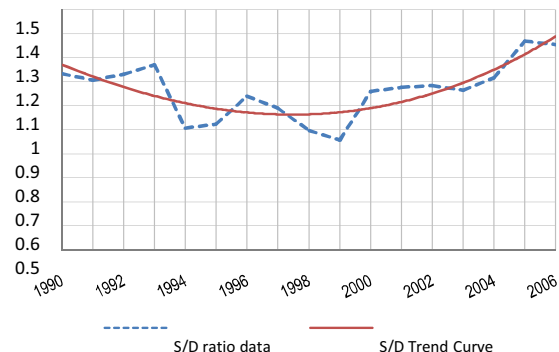


Fig 4. Oil Supply Demand Ratio

Thus, Total Energy Supply is also increasing because the GDP is always able to fulfill the Oil Import Required. A policy that targets the desired energy supply demand ratio is important to keep the energy in balance and not to oversupply. Fig. 5 shows the simulation result on energy supply demand ratio.

In ALT scenario, the growth of supply demand ratio is only slightly increased; this is due to the policy of maintaining the Desired Oil Supply Demand ratio at 1.25. It prevents the oversupply of oil, even as the Energy Consumption is decrease due to higher energy efficiency. As depicted in Technology Influenced loops, the energy consumption is affected by

efficiency. Policy measures that support faster technology advance are likely to be a significant demand-side factor in improving energy security. The simulation result of energy consumption is in the Fig. 6.

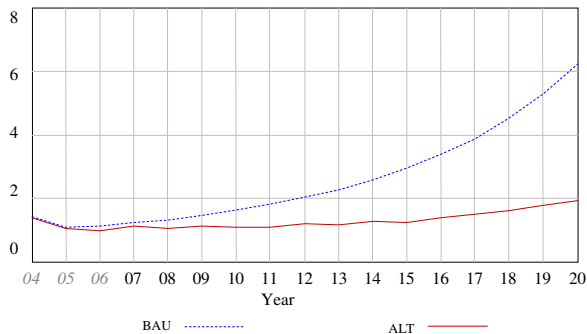


Fig. 5 Total Energy Supply Demand Ratio

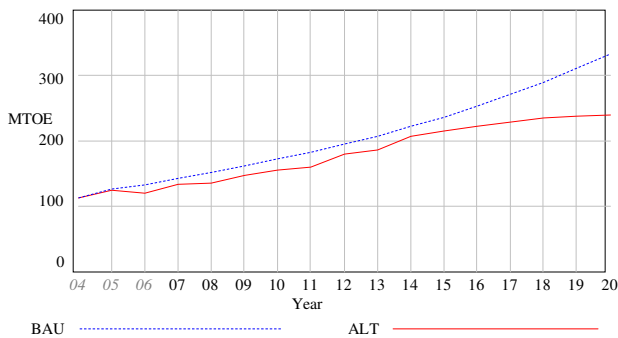


Fig. 6 Total Energy Consumption

B. Oil Import

The policy to reach the oil supply demand ratio at 1.25 in ALT scenario has a balancing effect on the overall Oil Import as when the Oil Import is sufficient to fulfill the ratio, and then there will not be any import. This policy, combined with the effort to limit oil import by constraining the percentage of GDP to oil import at 1.6% has resulted a lower amount of Oil Import, thus lower amount of Total Energy Import compared to BAU Scenario. Fig. 7 shows the Energy Import share in Total Energy Supply.

C. Economy

The result of ALT scenario produces a lower GDP growth than that of BAU. The result shows resemblance of GDP curve to Total Energy Consumption, as showed by Fig. 8. This is due to two factors, the limitation of Oil Import at 1.6% of GDP that limit the Total Energy Supply and the increase of Energy Efficiency by Technology Advance; both eventually restrain Total Energy Consumption.

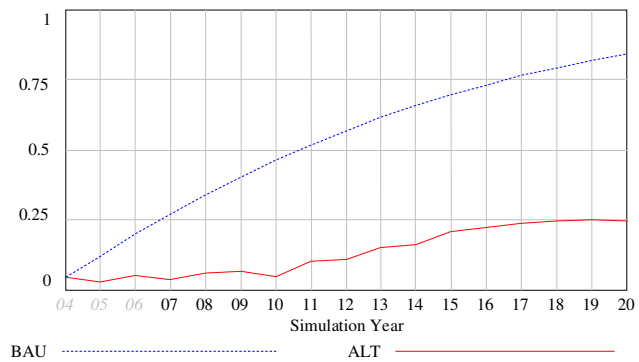


Fig. 7 Energy Import share in Total Energy Supply

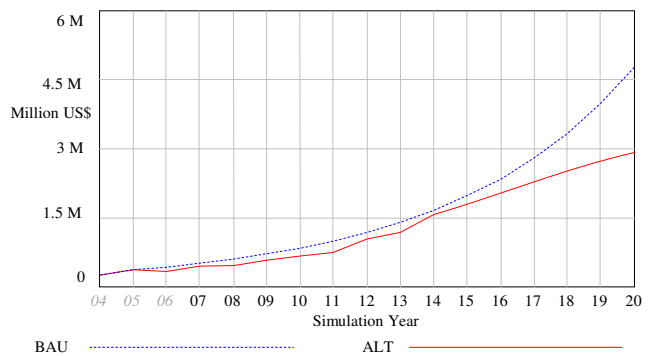


Fig. 8 Gross Domestic Production

VI. CONCLUSION

A modeling and simulation of future Indonesia's energy security in term of availability has been presented.

The methodology used in this paper provides in-depth model design process for system dynamics by divides it into three levels of details. The division helped modeler to decompose energy security issue systematically, thus helped to develop the model in a top-down manner. The model offers a useful experimental tool for determining how various assumptions related to economic, physical, and technological factors affecting the level of energy security.

The simulation result of BAU scenario shows that Indonesia will be able to achieve a very high level of energy security in term of availability. However, this is followed by a high growth of energy import resulting high energy import dependence, therefore in another sense; it suggests a low level of energy security. The ALT scenario result shows lower energy security than the BAU, however, this is mainly due to the goal of the policy in ALT scenario to maintain 1.25 energy supply demand ratio. The GDP growth in this scenario is also lower this is mainly due to the lower energy consumption which is the result of goal to limit 1.6% of GDP spend for oil import. More over, energy consumption is also influenced by the expected increase of energy efficiency by faster technology advance. Therefore, the level of energy security in ALT scenario can be concluded as sufficient, at the expense of lower economic growth.

The aspects of energy security considered in this paper provide only limited insight in understanding Indonesia's energy security. Further development of the model to include different aspects of energy security (i.e, environmental acceptability) is needed.

APPENDIX

TABLE I
DEFINITIONS

Term	Definition
Oil Supply Demand Ratio	A ratio between supply and demand of oil. Value between $\sim = < 1$ and $1 > \sim$
Oil Import Required	The amount of oil import required to fulfill demand of oil, in Million Ton of Oil Equivalent (MTOE).
Desired Oil SD Ratio	A predetermined ratio between supply and demand of oil. Value is ≥ 1 .
Oil Import Affordability	The ability of the country GDP to import oil at certain international price, between 0 and 1
GDP Allocation for Oil Import	Percentage of GDP allowed for importing oil. Value between 0% and 100%.

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