Communicating Complexity in Indonesia's Electricity Economics and Market Development Using System Dynamics Based Game

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Abstracts

Fast growing electricity demand in Indonesia has threatened country's economic development pace. However, government owned Electricity Company cannot cope with this growing demand. As a result they rely on Independent Power Producer (IPP) which harm government budget. In the mean time, government realizes this growing issue and tries to do something by building more power plants. On the other hand, their plan on building new coal and oil based power plant is meeting a lot of resistance from NGO and parliament. On top of it, government cannot afford continue funding electricity from IPP. The situation is increasingly become worse if government does nothing about the issue. Therefore, understanding and smooth communication is needed to provide solution for the issue. A system dynamics based game is built to foster communication between stakeholders, in order to help them visualize dynamics and feedback loop inside Indonesia's electricity system. In the first development phase the game tested on group of students and showed good result on improving their understanding on current electricity issues.

Keywords: Communication, Electricity, System Dynamics, Game

Introduction

Known as one of the fastest growing economic nation in past 10 years, Indonesia final energy consumption has nearly touched 150% increase as the consequences of economic growth. With this growth rate Indonesia is having trouble to fulfill all energy needs. Specifically, electricity demand has become number the fastest growing energy form consumed in Indonesia; with more than 5% demand increase and less than 1% increasing supply every year the Indonesian government vision on providing electricity throughout Indonesia in 2020 is about threaten to happen[1]. The current condition is Indonesia supply and demand ratio is only 1.05, it means that Indonesia only has 5 % of extra capacity for its installed system. This number reflects instability in Indonesian electricity network. For example, if one power plant which contributes 8% of all electricity is doing maintenance work then there is lack of supply on the electricity which makes a blackout in some region. Nevertheless, this vast economic and industrial development happens after recovery of 1997 economic crisis requires swift rising of electricity supply. In which the fastest way to get enough electricity is by building more oil based power plant.

The building of new oil small and medium scale power plant initiated by private sectors successfully create a temporary energy supply solution, it quickly fulfill new industrial and commercial electricity demand flourishing all over Indonesia. The government follows the same path by converting some of its gas and coal power plant in Java to oil based power plant in order to create fast electricity supply. Especially after legislative pressure made in early 2008 as a result of occasional blackout in greater Jakarta region which potentially harm Indonesian economics by 14000 USD every hour of blackout in greater Jakarta region[2]. In fact, most of Indonesia electricity only concentrated in Java and Bali Island which counts for more than 55% all the country's demand, and having blackout in Java region also cost a lot of political capital[3]. However, this government decision face predictable problem. Indonesian government budget is bleeding after giving subsidy to buy oil to power the power plant. On the other hand government with National Electricity Corporation (PLN) which regulates and manage electricity business activity cannot increase electricity price. Since final electricity price to consumer is regulated and they need to have legislative approval to change the price, while to get that approval will take so much time and political effort[4]. Consequently, Indonesian government also has to deal with increasing oil price over time. On the contrary, Indonesia is also known as world main producer of coal and natural gas. But then, energy mix structure of Indonesian primary energy still dominated by fuel especially oil. Therefore, government tries to reduce oil dependency in electricity generation by also building gas and geothermal power plant.

Building gas and geothermal power plant not only will solve Indonesian problem over lack of electricity supply but also open up opportunity to new clean source of energy. However, these gas and geothermal power plant is expensive and also takes longer time to build. In the mean time, government proposed 10,000 mega Watt additional electricity supply and most of them is planned to be gas and coal powered plant[5]. Nonetheless, gas and coal powered plant has its downside due to supply constraint of its primary energy especially because Indonesia's electricity activities is centralized which prone to supply chain problems [6, 7]. Most of the primary energy excavated from Borneo Island while most of the new big power plants would be initiated in Java Island. Therefore, PLN will face a lot of technical risk constraints like seasonal condition of Java Sea to carry gas and coal from Borneo to Java[8]. Nevertheless, big plants other than gas and coal in Indonesia also pose major technical problems. Big plants like Cirata, Saguling and Jatiluhur which greatly contributes to Indonesia's overall electricity supply, is water powered and vulnerable to seasonal change. For example, in dry season these water powered plant generation reduce up to 1,300 MW[9]. These factors add up complicate situation in

Indonesia’s electricity issues which compromise of the need of fast and vast capacity generation with low cost and few major operational risks. However, government seems losing its direction on where to go in order to solve the problem. Consequently, an instrument to increase understanding is needed to provide vivid image of the problem and how to deal with it.

Dynamic Hypothesis

At present condition, growing Indonesia’s electricity demand with lack of supply growth develops into major threat to support Indonesia’s economic and well being growth. With more and more factories and commercial area building throughout the country the rate of demand shows a foremost shape increase toward exponential growth. Moreover, Indonesia middle class number also rising causing growing of electrical appliances usage per household. This condition leads to increasing domestic usage of electricity which contributes for more than 30% of total electricity demand. With a prediction that Indonesia’s middle income would be the biggest in the world no wonder that population sector will always also be important variables to watch in electricity demand. Furthermore, increasing demand and lack of supply grow in Indonesia’s electricity is shown on Figure 1 as main reference mode of the problem.

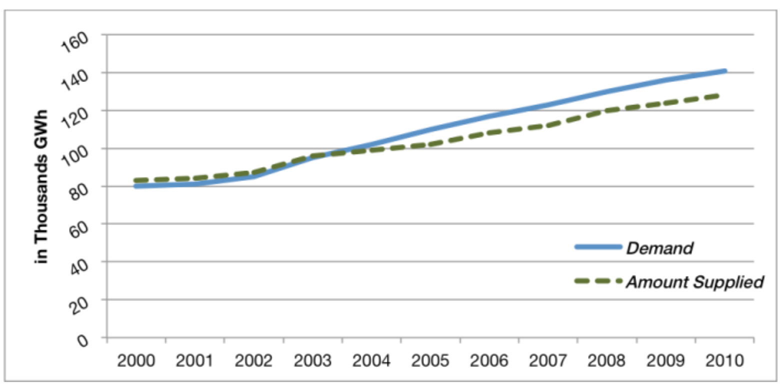

Figure 1 Reference mode of supply and demand in Indonesia's electricity market

As we can see in Figure 1the amount of electricity supplied by PLN is not even adequate to fulfill electricity demand since 2004. In reality capacity installed in PLN power plan is enough to fulfill current demand. However, several technical issues and unreliable maintenance scheduling make PLN power plant produced far less than its actual installed capacity. Therefore, in order to satisfy current demand PLN need to buy electricity from Independent Power Producer (IPP). This condition is troublesome for the government, because Indonesia’s electricity price is still heavily subsidized that means increasing electricity buying from other entities will make subsidy budget for electricity increasing. Moreover, IPP uses oil based power generator to supply PLN needs. Therefore, government must buy electricity that comes from world price based oil. This world price oil price is fluctuated consequently will make further risk develop for government budget. In addition, recent to increasing oil price trends the electricity price provided by IPP will also rising.

In 2008 Indonesian electricity subsidy was skyrocketing as a result of oil price spike, even the amount of electricity generated and oil needed to support is less than what it takes on 2010 the value of electricity is almost double like shown in figure. Therefore in Indonesian electricity planning world oil price is one major factor to be included. With oil price increasing trends government afraid in the near future cost of electricity subsidy will be more than 10% of governmental budget[10]. If this condition occur many public services will need to be sacrifice or budget deficit will grow larger. As Figure 2 shows how electricity subsidy is growing in the past 5 years.

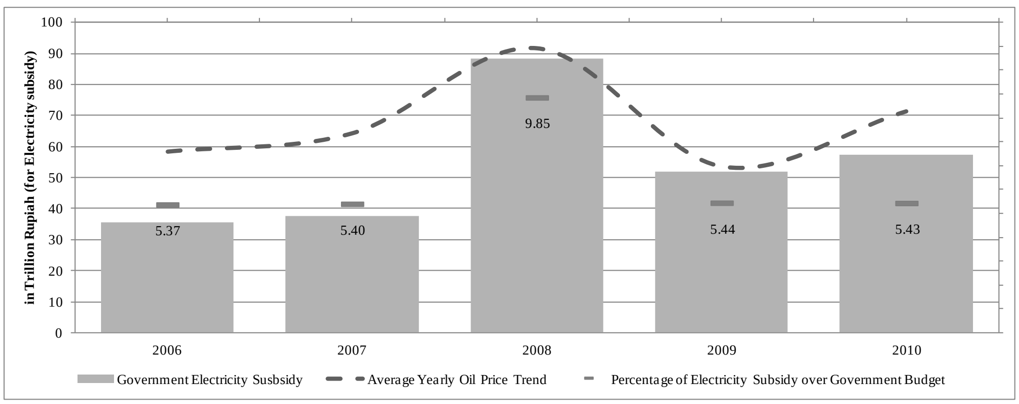

Figure 2 Government Subsidy over electricity and oil price

Government realizes that they should do something in order to solve price and lack of supply issue. But then, their current measure by increasing electricity price is rejected by national parliament. The parliament thought that root cause problem of this issue is not low electricity price but PLN as electricity provider is not efficient enough on providing electricity. Moreover, environmental NGO like *Wahana Lingkungan Hidup* (Indonesian Environment NGO (WALHI)) rally a public refusal to turn down government plan in building more coal power plant which is cheaper to build for government. More and more actors involved in this issue make it more complicated and consequently current condition is not improving nor getting anywhere.

Increasing understanding on electricity issues in Indonesia among stakeholders and actors hopefully will bring better communication that leads to smart solution so solve electricity concern. Therefore, in order to create better understanding this paper tried to propose usage of Electricity Dynamics Game to clarify and visualize dynamics of current electricity situation. Nevertheless, by using this game stakeholders will see different point of views and able to imagine other position to take account into their decision making process. Figure 3 shows complexity of current Indonesian electricity issues, it shows how government as problem owner has to deal with

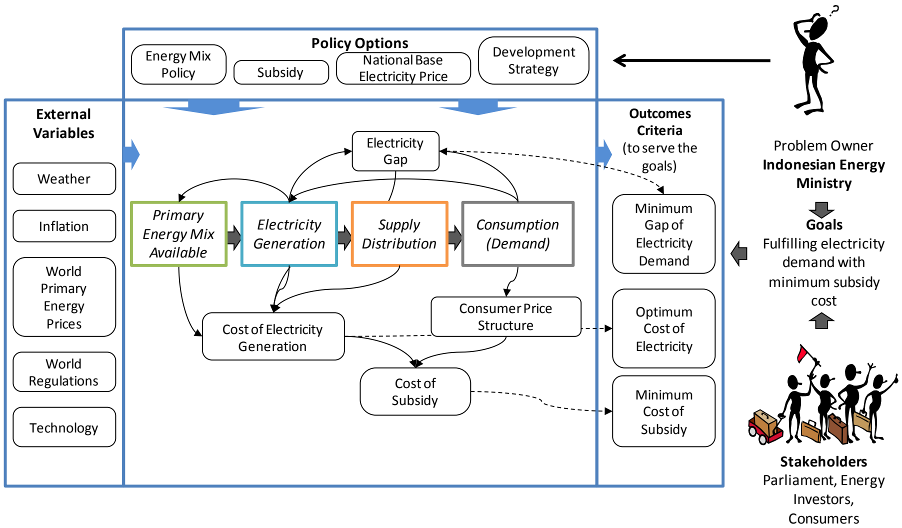

Figure 3 System and Actor Diagram of Current Electricity Issues

Model Development

The purpose of this model development is to communicate complexity for all actors and stakeholders involved in Indonesian electricity issues. Therefore, model focus is on how to visualize interaction of variables inside the system. Interaction in Indonesia electricity system can be narrowed down into three big aspects. Which are: Primary energy mix and electricity generation, Electricity consumption or demand and Electricity cost factor. Based on previous electricity dynamics model [11-15] we develop locally adapted model in which will serve the purpose and condition in Indonesia. A Causal Loop Diagram (CLD) is used to determine key framework of variables interaction inside the model.

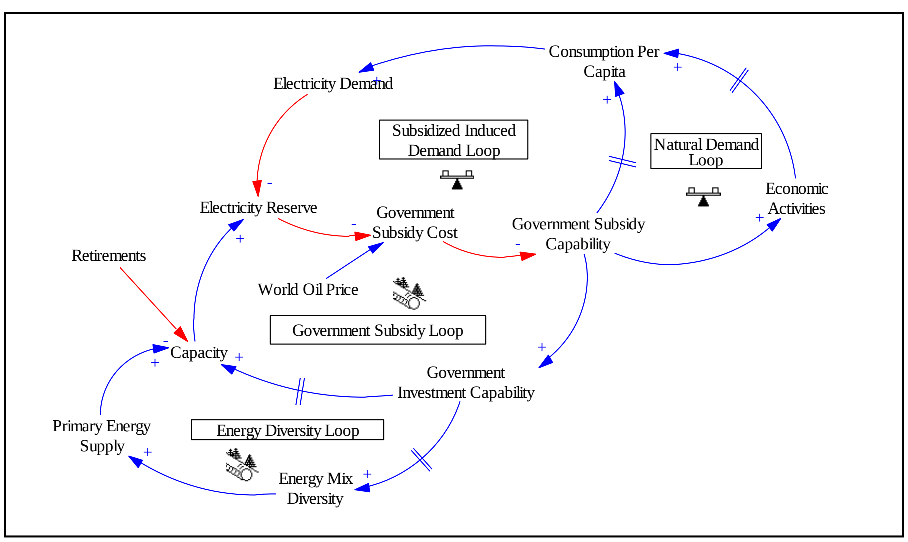

Figure 4 Causal Loop Diagram for Indonesian Electricity Issue

Figure 4 show that government subsidy capacity plays key role in the entire system. Represented as amount of money government can put for electricity subsidy per year affected both supply and demand aspects. As seen above, increasing government subsidy capacity will make consumption per capita of electricity increase due to low electricity price. Nevertheless, this condition is not favorable in long term as demand rose will cause shortage of electricity and end up in government loss as a result of increasing subsidy cost. On the other hand, reduces of government subsidy capacity will slowing down economic activities which is not a flattering condition for other actors, especially those in industrial and commercial sectors. Hence, that increasing energy mix diversity needs big government investment capability. Moreover, significant delay on creating new power plant will be foremost obstacles to increase capacity[16]. In addition, Figure 4 shows that world oil price does not have any direct impact toward economic activities; this assumption is made as simplification for the mode, in this model economic activities and consumer electricity demand solely affected by electricity price.

Next step of model development is to build model artefacts that consist of three main model aspects.

1. *Primary energy available and Electricity generation*

   This section tries to elaborate power producing capacity of average Indonesian power plant. The power plants itself consist of different kind of primary energy which has their own risk and specification. In this case five energy mix power plant is endorsed as these five power plants are: Water power plant, Gas power plant, Diesel Oil power plant, Geothermal power plant. In this first phase, the model aggregates each different energy mix power plant capacity. In addition, it elaborate 5 biggest water power plants; 48 coal power plants, 59 oil power plants, and 19 geothermal power plants based on existing Indonesia's condition.

   The model would also elaborate power plant average common technical specification for power producing and power distribution such as capacity factor, thermal efficiency and load factor.

   Primary relation in this section shows that in power generation there are unique technical risks for each different energy options. Moreover, there is delay in order to generate new power capacity, and it cannot go to maximum power capacity. Risk variables created by coal supply constraint, oil supply constraint and dry season constraint increase complexity in electricity model.

   Moreover, the model also involved Independent Power Producer (IPP) as power source. Where these IPP is seen as single big private identities that can serve all power deficit. A main characteristic of this IPP is they produce electricity by using High Speed Diesel (HSD) oil. This is one of government concern that using HSD means that they should buy oil from foreign entities using world oil price which is fluctuate over time and adding government risk on increasing budget cost.

The IPP calculation only activate if there is government power generation deficit. However, as a result and implementation of previous investment on new power plant capacities the whole system capacity will increase over time. Therefore, IPP calculation would not be activating all the time during the model depends on electricity demand.

Equation 1 shows base calculation of power generation.

$$Power\ Generation = Risk * Technical\ Specification * \int Power\ Capacity\, dt + Technical\ Specification * Delay * \int New\ Power\ capacity\, dt \tag{1}$$

2. *Electricity consumption or demand*

Electricity consumption and demand in this model is triggered by two major forces. Firstly, is the natural electricity demand growth which came from increasing population and increasing natural economic growth and secondly, demand triggered by electricity price change which a natural demand multiplied by factor coefficient of electricity price change.

The main idea of electricity consumption is visualizing how low electricity price can be somewhat dangerous to long term planning and condition of electricity itself. As government will not have adequate resource to keep on racing with growing demand while having their budget on deep deficit after financing heavy electricity subsidy. Excessive, electricity usage will lead country to power deficit. In that case, an IPP is needed to fulfill all electricity demand. Buying electricity from IPP is burden of central government which needs to pay for all excessive power gap from their budget and sell it in the same price.

Electricity consumption also affected by electricity education campaign by the government. This option will activate education campaign inside the model which will reduce overall electricity usage.

3. Electricity cost factor and price

Cost factor inside the model intended to show how much government would pay. In this cost factor government will be single entity that pays electricity produced. Amount of money government paid is counted from how much electricity produced by every power plants. Each power plants also have different price structure, which differs from technical specification and primary energy used.

The calculation of oil power plant is special due to nature of Indonesian subsidized oil. Because, oil used in power plant come from other government entity which has subsidiary price.

Government also needs to pay PLN margin in order to keep company ability for keeping up of consumers demand. As an overview, Indonesian electricity cost and price work in equation 2

$$\text{Electricity base price} = \sum(\text{Electricity produced each plant} * \text{factor cost}) + \text{PLN Margin} + \text{Distribution Cost} - \text{Parliamentary Approved Subsidy} \tag{2}$$

Model Validation

The model is validated by using Barlas validation method[17]. As structure validation, we asked and confirmed relationship inside the model with several electricity experts from government as a structural validation.

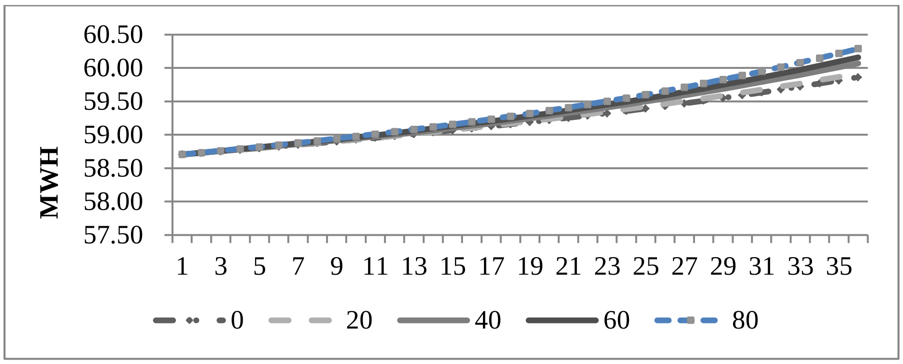

Figure 5 Sensitivity analysis of each 20 T Rupiah Subsidy over Industrial Electricity Demand

Experiment and Result

In order to serve purpose of this model on creating communication over different actors the model is equipped with user friendly interface. This interface allow user to try and tested different kind of parameters changing and also allow them to observe value changing as a result of risk and uncertainties inside the model. Figure 6 shows how the user interface looks like.

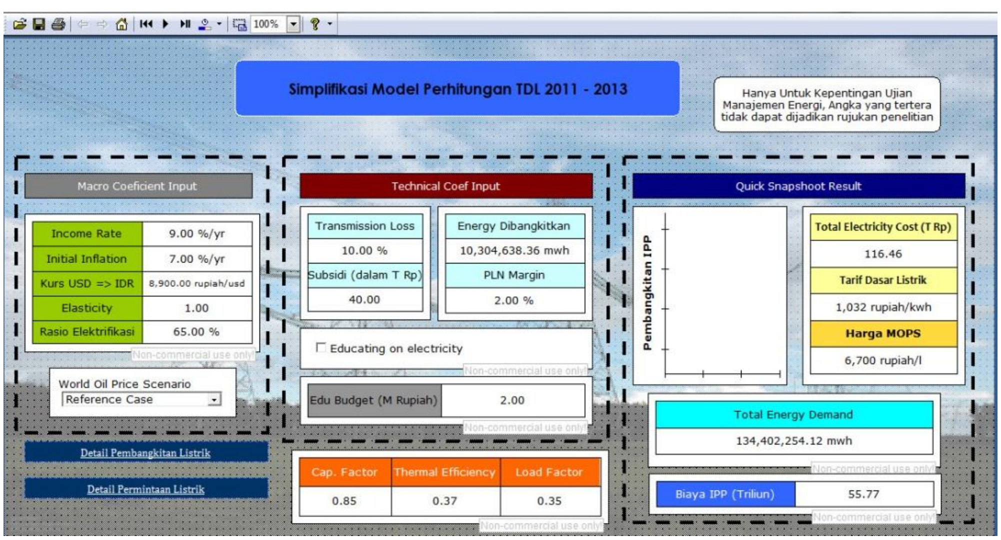

Figure 6 Model user interface

The model provides users with key performance indicators of each primary energy used for electricity generation. Key performance indicators including amount of energy produced over time and financial indicators. Detailed indicators were imported into a spreadsheet file so users could export the result into other file and create their own visualization conveniently if necessary.

This model then is as a tool on increasing student understanding over electricity issues in Indonesia. 83 students participate in the class for energy management held in the university, none of these students has background of energy or electricity related education or training before. The experiment is conducted by giving two one and half hour lectures. The first lecture is to give brief description on energy problem in Indonesia and the second lecture is to give brief detail about electricity condition in Indonesia and how to use the model. After that, the model is given to all students to have look at and try on. The students have one day to take a look on the model and having their own research on electricity issues in Indonesia. On the next day, a series of question regarding the use of each parameter in the model is given to the students. In addition, student also asked to create CLD based of their own perception and experience after using this model.

The experiment result is quite satisfactory as 80 out of 83 students participating are able to draw main relations and links like shown in Figure 4. Moreover, they also able to explain and answer question related to parameters inside the model and describe its usefulness and effect in the real electricity issues. The students also give comments and short paragraph about current Indonesian electricity issues and what should government do to overcome such situation. In fact, their comments and suggestion reflects that they have capture important message of complexity and multi actor dynamic inside Indonesian electricity issues.

Conclusion

The model and user interface used has proved to be one of valuable resource for communicating Indonesian. It serves the main purpose to boost up understanding of issues. The model adequately is able to picture interrelationship and interdependencies inside complex electricity system. Portrayed complexity of electricity price and subsidy as main driving force that leads to electricity supply and demand changes, by using this model user will have seen how it suppose to be if they are in the government position with such issue. The option by reducing electricity subsidy will have significant impact on economic activities as much as impact on electricity demand and the same thing goes to increasing electricity subsidy.

However, this result is not conclusive enough to make this model as solely tool to visualize Indonesian electricity dynamics. Therefore, more experiment from broader audiences is needed to confirm this. On the other hand, the model provides good starting point to help policy planner communicate with other stakeholders and actors. Which will make policy planning process more efficient and effective.

In the future, this model not only should be brought to different audiences but also it deserve chances to b used as tool to educate citizen. In bigger picture, by educating citizen that there are consequences for government if they have to burden big number of electricity subsidy. Moreover, in term of modeling activities, linkage between wider economic activities and direct environmental impact over electricity usage and development will provide better visualization for government and stakeholders.

References

1. Center for Data and Information and Mineral Resources, Handbook of Energy & Economic Statistics of Indonesia, in Handbook of Energy & Economic Statistics of Indonesia, Sutijastoto, Editor 2010, Ministry of Energy and Mineral Resources: Jakarta.
2. Santoso, C.S. Listrik Padam, Pengusaha dalam Sehari Bisa Rugi Miliaran. 2009.
3. Perusahaan Listrik Negara, Laporan Tahunan 2010, in Annual Report2010, Perusahaan Listrik Negara: Jakarta.
4. Purwantono, I. DPR Tolak Penaikan Tarif Dasar Listrik. 2012.
5. Kementerian Koordinator Bidang Perekonomian, Masterplan Percepatan dan Perluasan Pembangunan Indonesia: 2011 - 2025, 2011, Kementerian Koordinator Bidang Perekonomian: Jakarta.
6. Bouffard, F. and D.S. Kirschen, Centralised and distributed electricity systems. Energy Policy, 2008. 36(12): p. 4504-4508.
7. Fielden, D. and J.K. Jacques, Changing the management perspective on energy systems: how small clusters—and islands—can achieve greater cost and energy efficiencies. International Journal of Energy Research, 1997. 21(9): p. 767-786.
8. Nugroho, H. Apakah program percepatan pembangunan PLTU menjadi momentum perbaikan infrastruktur transportasi batubara di Tanah Air? . in The 1st International Trade Exhibition on Coal Mining Technology & Equipment. 2006. Jakarta: Bappenas.
9. Nurismarsyah, A. Musim Kering, PLTA Saguling Cirata Hanya Beroperasi Malam Hari 2011.
10. Direktorat FiskalKementerian Keuangan Republik Indonesia, Data Pokok APBN 2005 - 2010, Kementerian Keuangan Rpublik Indonesia, Editor 2011, Kementerian Keuangan Rpublik Indonesia: Jakarta.

11. Olsina, F., F. Garcés, and H.J. Haubrich, Modeling long-term dynamics of electricity markets. Energy Policy, 2006. 34(12): p. 1411-1433.
12. Pasaoglu Kilanc, G. and I. Or, A decision support tool for the analysis of pricing, investment and regulatory processes in a decentralized electricity market. Energy Policy, 2008. 36(8): p. 3036-3044.
13. Tobias Jäger, Susanne Schmidt, and Ute Karl. A system dynamics model for the German electricity market – model development and application in International Conference of the System Dynamics Society. 2009. Albuquerque: System Dynamics Society
14. Bunn, D.W., I. Dyner, and E.R. Larsen, Modelling latent market power across gas and electricity markets. System Dynamics Review, 1997. 13(4): p. 271-288.
15. Ochoa, P. and A. van Ackere, Policy changes and the dynamics of capacity expansion in the Swiss electricity market. Energy Policy, 2009. 37(5): p. 1983-1998.
16. Ford, A., System Dynamics and the Electric Power Industry. System Dynamics Review, 1997. 13(1): p. 57-85.
17. Barlas, Y., Formal aspects of model validity and validation in system dynamics. System Dynamics Review, 1996. 12(3): p. 183-210.