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Indonesia energy mix modelling using system dynamics

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ABSTRACT

Indonesia is facing tremendous challenges in bridging the broadening gap of demand and supply prior to developing a steady energy vision. This paper is to introduce system dynamics in solving the problematic national energy management, share an initial stage of the modelling and discuss the challenges. A literature review defines the preferred modelling, empirical data demonstrates the supply mix trends and used in developing the initial model to represent the past behaviour prior to be enhanced, upgraded and simulated towards the vision. The initial simulation runs succeed in imitating the historical trends and suggests that its engineering to the envisaged patterns may offer viable solution. The use of System Dynamics in Indonesia is unprecedented and the results are noteworthy in supporting the formulation of the national Energy Mix Vision.

Keywords:

Comparative overview;
Empirical data;
System dynamic modelling;
Initial model of indonesia today;
Modelling challenges;

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1. Introduction

Worldwide, a wide range of energy technologies exist, and each country has developed vastly different core competencies to generate their unique portfolios and sustainable energy vision. Many countries signed the Kyoto Protocol (1997), an international treaty whose critical features aim to prevent climate change, reduce greenhouse gas (GHG) emissions, and accelerate renewable energy use. The tradition of energy modelling had seemingly begun when the world was urged to develop energy system models for a sustainable supply and national energy security due to the 1970s energy crisis [1]. All countries have since been competing to develop their own unique energy portfolio to ensure their respective domestic energy supply. In the 1990s, the focus shifted toward the interactions between energy, the environment, and climate change issue, and various new features have then been developed as the existing models were updated and expanded.

Indonesia has depended heavily on fossil fuels to maintain sustainable growth, despite having considerable energy resources, worked hard to maintain its declining domestic oil supply and to increase the amount of renewable energy resources in its national energy mix. For those reasons, in the Presidential Regulation No.5/2006 [2], a different mix was promoted, and a much higher share would be coming from renewables, while coal uses would be suppressed due to environmental issues, as its share is projected to be multiplied to substitute the severe shortage of oil (Figure 1).

The U.S. Energy Information Administration's (EIA) short-term outlook [3] shows a broadening gap for petroleum and other liquid supplies versus consumption in Indonesia, after more than a decade of being a net oil importer (Figure 2). An energy shortage is forecasted by 2022, as Indonesia's crude production continues to fall as its domestic demand is climbing. Business Monitoring International Ltd. [4] projected that production will only

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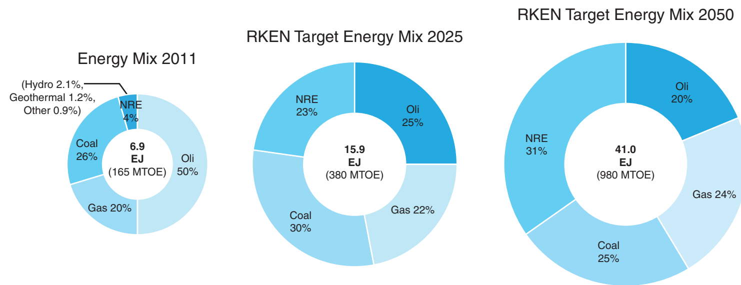

Figure 1: The past and targeted energy mix of Indonesia [5]

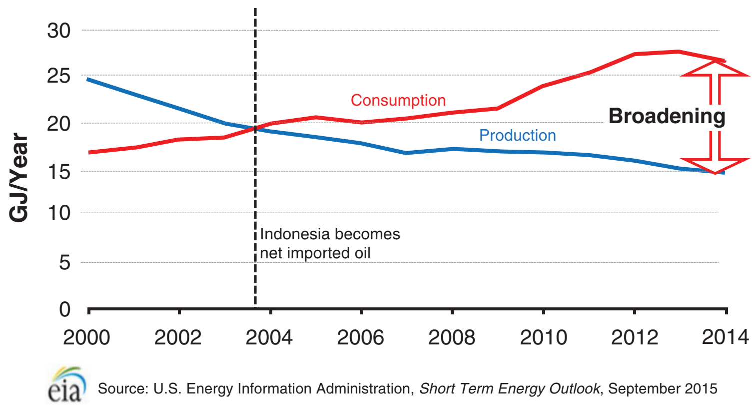

Figure 2: Petroleum and other liquids supply and consumption in Indonesia after more than a decade of being a net oil import [7]

be about half of domestic consumption in 2020, and most believe that with the current trend, Indonesia may only produce oil for another 10 years. According to the EIA, Indonesia's gas production will peak in 2018, after rising approximately 25 percent since 2005; production will then decline sharply [3].

Ramping up Indonesia's per capita GDP requires a sustainable energy supply to maintain growth, while the fossil fuels heavily dependent energy supply portfolio caused a rapid increase in emissions. Empirical data on the primary energy supply (Figure 3 and 4) suggest that the current trends will not lead the country to the desired optimum energy mix. The over produced coal is a strong negative indicator in the country's performance for the Kyoto Protocol's Clean Development Mechanism. Likewise, the under-performed oil and gas production suggests weak capital stewardship in the upstream ventures. So does the ironic story of the clean geothermal resources for the country that is the majority shareholder of the world's potential. Even though the new Presidential Regulation No.79/2014 [6] replaced the older one and regulated more ambitious energy mix goals for 2050, the trends remain opposite, and the country is facing tremendous challenges in energy management prior to developing a steady energy vision.

This paper aims to introduce System Dynamics modelling as a preferential approach to portrait the past behavior state of Indonesia's energy supply mix performance in the way to understand and develop a new model to support the formulation of the national Energy Mix Vision. It discusses the energy statistics in the background, an early stage of the modelling with a unique causal-loop diagram reflecting the country energy supply model today, an initial simulation run and the modelling associated challenges.

1.1. Scope and structure

This research is began with the finding of the most suitable modelling approach to be used in developing new model to portray the performance of the energy supply mix implication in the past. It is then expected to be able to simulate the behavior of the supply mix in the future under certain selected terms and conditions towards the desired destination. Empirical data solicited from the corresponding energy departments is used to examine the past behavior trends (2000–2016), whereas the energy mix vision will be determined and engineered in defining the envisioned behavior modelling (2017-2050). The modeling is to be focused on energy supply system, confronts the dominated fossil energies against the new and renewable energies (NRE), their impact to environment and so development as well as the regulatory instruments. The oil and gas sectors are separated, so are coal and biomass, while the renewable sector is simply represented by geothermal, biofuels, hydropower and solar photovoltaic energy. The simulation programs Vensim PLE 7.1 is used in the building of the qualitative and quantitative modelling.

The paper is structured as follows. Section 2 summarized the background literature which have been discussed in more detailed in the author's previous publication on this topic [1], whereas sub-section 2.1 highlights the advantages of using System Dynamics as research approach. Section 3 outlines the approaches used in this study: (a) analyses the background statistics, (b) energy supply preferred model and its uniqueness, and (c) regulatory instruments and the supply mix dynamics. Section 4 discusses the initial system dynamics model of Indonesia today: (a) causal loop model, (b) stock and flow model, and (c) results of the initial simulation run. Finally, discussion and conclusion are given in Section 5.

2. Literature review

Some tabulation structured using energy selection parameters developed on energy portfolio management [8] reveals that none of the articles reviewed discuss the energy supply mix vision is about Indonesia and discuss the energy supply mix quality [1]. The article review was subsequently focused on energy supply system modelling and concentrated on a theoretical justification of why system dynamics is needed to answer the main research questions. Of the 35 articles reviewed on energy system modelling, some papers are categorized as comparative overviews, while the rest discuss the applications of specific system dynamic models for certain energy case studies. They include Bottom-up Optimization/ Accounting Models, Hybrid Models, Electricity System Models, Causal-Descriptive (System Dynamics Models) or Correlation (Top-Down Econometric). There are also more comprehensive models that incorporate a larger number of economic components, and new models that include the interactions between energy, society, economy, and environment as a major innovation, e.g., GEM- E3, T21 and MCM. And only 12 of which discuss a causal loop diagram or a stock and flow diagram in the presentations [1].

In their two-step comparative overview of models covering energy systems, [9] concluded that "the bottom-up accounting type of framework appears to be more appropriate for developing country contexts for their flexibility and limited skill requirement, they can capture rural-urban differences, traditional and modern energies and can account for non-monetary transactions, the models do not look for an optimal solution, can take non-price policies prevailing in developing countries enhances their suitability, their inability to analyze price-induced effects is the main weakness though; however, given the regulated nature of prices in many developed countries and incompleteness of markets, this weakness is not a major concern for modelling". However we argue that this weakness would be fatalistic for developing countries because of their less regulated nature; thus, an alternative model is needed that can analyze the price- and many other exogenously-induced effects. Although the best non-simulation model can take non-price policies prevailing in developing countries and enhance their suitability, a good model should look for an optimal solution. Both weaknesses of the bottom-up accounting model can be covered by system dynamics modelling [1].

According to [9] the hybrid models come next and followed by the optimization and econometric models, the latest "use price-driver which play a limited role in developing countries and cannot capture informal sector or traditional energies adequately," besides having "difficulties in capturing the technological diversity that require high skill levels." So most of the essentially global models are not suitable for developing countries contexts and so inappropriate as the essential features are not explicitly covered, developed from different perspectives applying entirely those features common to developed countries and fail to capture specific needs of developing countries [1].

[10] argue "A simple distinction is often made between a bottom–up approach, which is more data intensive and more appropriate for detailed analysis of individual energy policies and a top–down approach, which has a more econometric approach and uses less

technology explicit data." [5] finally suggest "despite the distinction being widespread, both categories are not mutually exclusive, there also exists a 'hybrid' class where the two approaches are combined; one of the main contributions of the hybrid approach is the detection of missing information and dynamics that simple top–down or bottom-up models cannot detect on their own."

Based on the literature review, the discussion comes to a conclusion that non-simulation models are not suitable for this research since the models "inadequately capture the developing country characteristics, the level of data requirement and the theoretical underpinning of these models, as well as their inability to capture specific developing country features," [97] concluded. Subsequently [1] emphasize when the best model of these conventional approaches is applied to developing country like Indonesia, the problems are increased. Thus, it is certain that a very large, complex and dynamic energy portfolio management with feedback of many subsystems in a non-linear fashion cannot be simply represented or easily solved by known or extended mathematical optimization models.

Nevertheless [11] presents "two key questions should have been at the top of policy makers' agenda: (a) can the Government develop a national energy system that will provide security and jobs and also leave a heritage of clean air, clean water, and pristine wilderness areas for the children and grandchildren? (b) can the nation reduce carbon dioxide emissions, which threaten to destabilize the global climate, by developing a truly balanced portfolio of clean energy solutions that would allow to also having economic growth?" This is a very idealistic view that an energy supply system may be built and maintained at zero cost to the environment and is contradicted considering the arguments of [12] that "if the rest of energies are likely to come on-stream fast enough to offset conventional oil decline, what would be the new scenarios of greenhouse gases if this would happen." He continued "the results show that even strongly optimistic rhythms of substitution have a hard time to continue the growing demand of energy that characterizes today's pattern." And concludes that if the present relationship between energy and the economy is maintained these results lead to a long economic stagnation period in the most optimistic scenarios. [12]

Whereas ironically [13] emphasizes that International accounting standards do not differentiate between low and carbon intensive investment and do not take into account climate risks beforehand." This is a critical issue for the development of renewable energies and a sustainable economy in general, the environmental issue and its impact on the financial statements is no longer an ecological question. For those reasons, [14] "investment in renewables can be at risk, depending on the continued existence of financial incentives." Policy makers have to either prolong financial incentives to renewables (in spite of the recognized maturity), capacity payments to dispatchable power generation, or by any other design change to provide adequate signals for existing and new generation capacity.

2.1. System dynamics as a suitable energy modeling approach

System dynamics is generally understood as an approach to understanding the non-linear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays. It is a mathematical modeling technique to frame, understand, and discuss the complex issues and problems. In this methodology, a problem or a system is qualitatively represented as a causal loop diagram, a simple map of a system with all its constituent components and their interactions. Two types of feedback loops are the positive reinforcement labeled as R and the negative reinforcement (B or balancing). A causal loop diagram is then transformed to a stock and flow diagram to perform a more detailed quantitative analysis. A stock is the term for any entity that accumulates or depletes over time, a flow is the rate of change in a stock, while time delay is a shift in the effect of an input on an output dynamic response. Thus, System Dynamics modeling is most suitable for modeling in the energy realm because it is:

- *reliable for large, complex subsystems, nonlinear and dynamic problems.* [15,16,17,18,19] emphasize that such problems can only be properly represented or solved by a reliable model of the system dynamics approach. The present models have considered the factors that influence the oil and gas exploration/exploitation industry, along with their effects on the system. A system dynamics model with numerous interconnected variables forming loops is particularly suitable and can be used with relative ease and convenience by following the methodology without sacrificing the basic character of the problem.
- *can replicate world patterns.* [20] "A System Dynamics model that uses energy as the describing medium of all socioeconomic activity has been

possible to replicate the world patterns as the result of the interplay of the industries that extract and refine primary energy and compete to provide the driving force of socioeconomic society."

- *can lead to develop effective policies to achieve sustainability and be used to analyze possible threats and design optimal adaptation strategies.* [19] explain that from a policymaker perspective, a System Dynamics model of the automotive sector can lead to the development of effective policies, while from an energy company's such a model could be used for the analysis of a highly volatile and market that is always on the edge of starting a new major transition. "The model presented can serve both purposes, and the results obtained show how a similar instrument can really make the difference in highly dynamic sectors with ongoing major transitions." [19].
- *a good method for a holistic approach,* "since it enables the integration of several aspects and is designed to take into account all sorts of feedbacks among those aspects." [13]
- *a valuable tool to forecast supply and consumption.* [12] argue that the simulation results allow the model to forecast fuels supply and consumption that making it "a valid alternative to the most known and used forecasting techniques in the context of energy-economics." This model "can be used to investigate the factors influencing the long-term supply and demand of energy and to determine the nature of system behavior as well as examining the effectiveness of various policies in softening the transition from self-sufficiency to energy import-dependence in the long term." [12].
- *a sophisticated modelling method,* which is needed for the supply side. [21] state that "the wide array of current and proposed production technologies, each with different costs and benefits and different greenhouse gas emissions levels, makes electricity production the most complicated element of the supply-side." and so needs the sophisticated System Dynamics modeling.
- *useful for gaining insight into the underlying behavior* [16], "System Dynamics modeling is useful for understanding the underlying behavior of complex systems over time, taking into account time delays and feedback loops" and
- *widely used and has abundant achievements.* [17] "System Dynamics is widely used in the study of sustainable development and has plentiful research achievements from macro-perspective but few studies in the microcosmic project systems. Studies that take a look at the complete picture, paying attention both to the economical, the geological and the technological aspects are not frequent in the literature."

In addition, [22] concluded that "the challenge of doing business in development of biofuel in developing countries, such as Indonesia, is that the market suffers from a lack of information, infrastructure and institutions. With inadequate assessment and a poorly equipped infrastructure (local scale policy, market, science and technology and public acceptance), any initiative for a large-scale introduction of biofuel will be premature. Assessing the present governmental policy may help to identify the barriers and at a later stage to find the solutions to ease the penetration of biofuel into existing energy systems." While [23] highlight the problems associated with public policy using traditional non-simulation approaches, which have several characteristics that impede resolution.

Further from most recent publications [24] concludes that "Large shares of renewable energy sources are decreasing energy prices in spot markets due to the merit order effect. This is good news for the consumer welfare," Meanwhile in crowdfunding platforms for renewable energy investments [25] argues that renewable energy-crowdfunding activity thrives on stable long-term policy support schemes for small and medium scale projects, as well as on comprehensive financial regulation that exempts crowdfunding from traditional financial service regulatory obligations." Interestingly, comparing the evolution of financial regulation of crowdfunding, it is concluded that "a loose financial regulatory framework leads to a range of business models and financial instruments, while a more specific framework tends to reduce RES-crowdfunding to one business model/one instrument," [25]. However, back to the merit-order effect, it is argued that in fact the value estimated for the financial incentives is often lower than the merit-order effect.

3. Research approaches

To conduct this research, at the initial phase, a model is built to delineate the existing system as baseline to demonstrate the strengths and weaknesses of the existing system based on the system behavior today, the trends and the potential pitfalls to which it is heading toward, its impacts to sustainability of the national energy supply and its capability in leading the country to a securer energy supply system. Along with the statistics in the background, the System Dynamics modelling are structured and assembled based on the past constrains and situations. The developed simulation model is then processed and run sequentially to obtain the outcomes that a) closely represent the past realities or statistics and b) would have represented the past if all the variables representing best practices were well implemented.

So the objective of this initial modelling is to delineate the past situation that led to the current problematic behavior, and take lessons learned to be used in developing new model that can lead to the desired behavior. This is with respect to the research question how system dynamic modelling will be able to simplify the complex and dynamic realm and be reliable as an alternative model in the development of the Energy Mix Vision. In the next phase of this research, the model will be upgraded and engineered to accommodate more key variables or feedback loops that potentially constrain the future and be directed to the desired energy journey and destination. The following proposition may eventually be developed: through studying the structure, statistics and policies of the past energy supply system, it is expected that the historical barriers may be identified, mapped and subsequently used in developing alternative models. The model is in turn will be used as basis in the formulation of a new energy mix vision and policy frameworks of resolution, formulation of which will subsequently be examined and fine-tuned through Focused Group Discussions. Under this scenario, the concerned parties will have a better understanding of the concept and so a higher sense of belonging and will therefore buy in and be interested to participate with a stronger sense of urgency to implement the envisioned energy mix goals. The model may subsequently be improved to obtain the ultimate energy mix vision through further feedback from energy industry practitioners [1].

In those regards, the following discusses the background statistics, the regulatory instruments, and the energy supply preferred system dynamics models for this study as well as the uniqueness of the new model.

3.1. Background statistics

This empirical data [5] is presented as comparison to the modelling outcomes of the past behavior and used as baseline in engineering the model to the envisaged future. The total of supply of primary energy in barrel oil equivalent (BOE) shown on figure 3 appears to have a steady increase from approximately one billion BOE in 2000 to approximately 1.6 billion BOE in 2015. When the Presidential regulation No.5/2006 was issued [2], the total was still less than 1.2 billion BOE. In terms of volume, the graphs also indicate that each energy technology shows significant increases, except in the case of biomass, which appears to remain flat. This apparently corresponds to the steady ramping up of Indonesia's population, per capita GDP, as well as the intensity of the final energy consumption per capita.

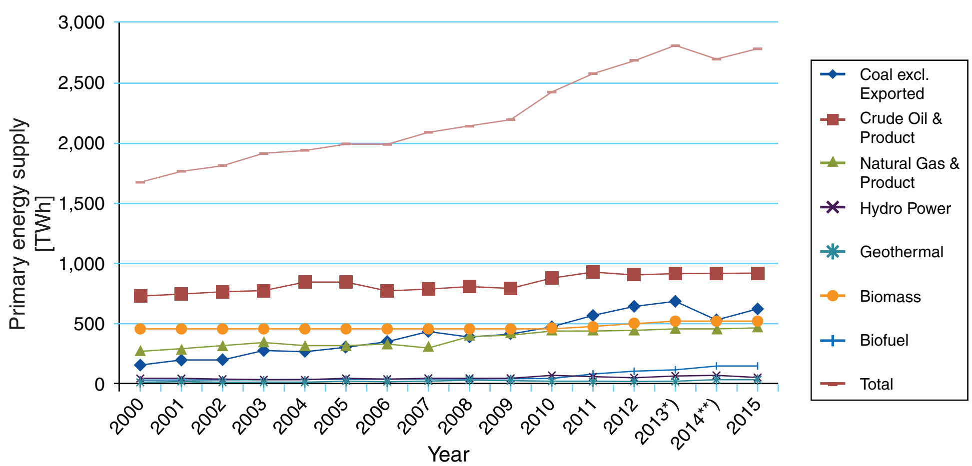

Figure 3: Indonesia supply of all primary energy in barrel oil equivalent [5]

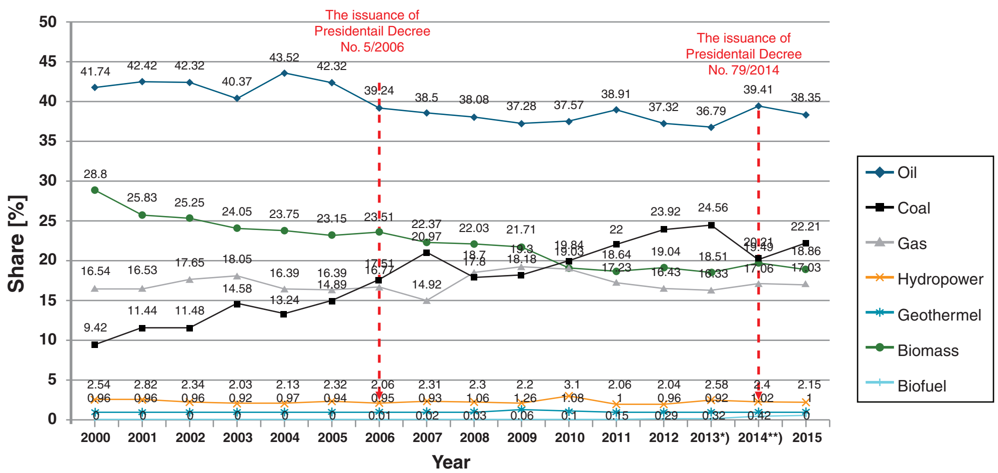

Figure 4: Indonesia supply of all primary energy in percentage [5]

Those assumptions will soon be changed when the graphs are presented in terms of share percentages of each technology (Figue 4). At the time that the Presidential Regulation No. 5/2006 was issued, the national energy mix was oil 39.24%, gas 17.51%, coal 16.72%, biomass 23.51%, while all renewables contributed only 3.02% (hydropower 2.06%, geothermal 0.95% and biofuel only 0.01%). The question is, what have been happening since the issuance of the presidential regulation and the national energy mix goals were regulated? The shares of oil and biomass have continuously been declining, gas remains relatively stable, while coal has agressively been ramping up, maintaining the previous robust trends, whereas renewables remain at a crawl. It is probably for those reasons that the Presidential Regulation No. 79/2014 [6] has subsequently been issued. The gaps between those envisaged by the energy mix vision 2025 (oil 25%, gas 22%, coal 30% and New and Renewables 23%) and reality remained unbridged after almost a decade, as the role of oil remained dominant at 38.35%, gas is unchanged at 17.03%, coal increased to 22.21% and biomass remained high at 18.86%, while New and Renewables were stagnant at only 3.56%.

There appears no clue with the current trends that the energy journey is heading to the desired destination.

3.2. System dynamics model of preference

The new model will be focused on the energy supply system dynamics that take the unique factors of the developing archipelagic country and the common characteristic impediments of public policy development when using traditional non-simulation approaches into account. And marking the uniqueness of the new model, new variables are developed from the common characteristic impediments [19] as new criteria as shown in Table 1.

In this case, the Ghaffarzadegan's factors will affect the delay of policy designing and communication and the delay of policy implementation which are along with Government ability & capability will in turn cause delay in power development for additional capacity of NRE (Figures 5 and 6). The delay in policy designing and communication is contributed by under estimated policy maker (gf1), scapegoat-minded perspective (gf2) and political link & lobbying (gf3), while the delay in policy implementation is composed by policy acceptance (gf4) and rate of trials and errors (gf5). See Appendices A and B. The new approach focuses not on discrete decisions but on the potential impediments and the policy structure underlying the decisions, and emphasizes a continuous view that strives to look beyond events to see the dynamic patterns underlying them as partly represented by the additional criteria [1]. So it would be a combination of the different energy supply models, with all those endogenous and exogenous variables to be selectively integrated into the model.

Some novelties of the new model may be claimed by the following: 1) the complex realm of energy supply system is modelled using system dynamics, an unprecedented modelling effort for Indonesia to help policymakers to gain insight the system and subsequently use it in policy making consideration, 2) the new modelling includes new variables developed from the common characteristic impediments in public policy

Table 1: New variables developed from the five characteristics that impede resolution in public policy development and their relations to the policy making process (Modified after Sani, K. et al, 2017)

Tradition Non-Simulation Approach	System Dynamics (Simulation Approach)		Policy Making Process		
Characteristic Impedences to resolution in public policy development (Ghaffarzadegan et al, 2007)	**Proposed New Criteria**	**New Variables**	**Designing**	**Commu-nication**	**Implementation**
Over-confident policymakers	Under-Estimate Policymaker	Confidence level of policy makers	✓		
		Complexity & difficulty of the policy challenges	✓		
		Potential delay & degree of uncertainty of policy making	✓		
		Policymakers' assumptions, model of thinking & strategies	✓		
Need to have an endogenous perspective	Scapegoat Minded	Potential of undesirable events to occur from the policy	✓		
		Potential self-serving bias	✓		
		Ability to learn from the environment	✓		
		The tendency to looking for scapegoat	✓		
Need to persuade different stakeholders	Political Link and Lobbying	General agreement among diverse stakeholders	✓		
		Potential merits of policy to	✓		
		Broader public consensus behind the policy	✓		
		Effective means to inform & persuade stakeholders	✓		
Policy resistance from the environment	Policy Acceptance	Public resistance against the policy		✓	
		Delay between policy action & result		✓	
		Immediate impact of policy to the industry		✓	
		Immediate benefits brought by the policy		✓	
Need to experiment & the cost of experimenting	Rate of Traols and Errors	Cost of the policy experimentation			✓
		Attempt to improve future performance			✓
		Implement, observe and adjust policy			✓
		Experimentation attitude			✓

development when using traditional non-simulation approaches as shown on Table 1.

3.3. Regulatory instruments and the energy supply mix dynamics

An overview to the corresponding ministerial regulatory instruments that were issued during the same period as governmental efforts to manage the energy mix performance nationally and to influence the ongoing trends is performed and finds that at least 76 relevant ministry regulations have been enacted since the issuance of the Presidential Regulation No.5/2006. Interestingly, with the many ministerial policies and regulations have since been prevailing, it does not seem obvious that the legal instruments have succeeded in influencing the past trends of any technology or energy resource. The most distinctive is the case of renewable technologies, although in volume (Figure 3) they have shown significant increases, their shares in percentage are almost flat or even decrease (Figure 4). Only coal's supply demonstrates a progressive increase and has seemingly substituted the steady drop of oil supply and the stagnant growth of the gas share. Biomass continuously declined from 23.5% in 2006 to 18.86% in 2015, possibly suggesting more urbanization as people from the villages crowded the major cities and metropolises, or the aggressive expansion of cities in Indonesia.

4. Results - Initial system dynamics model of Indonesia today

According to the Handbook of Energy and Economic Statistics of Indonesia 2016, from 2000 to 2015, the population of Indonesia has increased from 205,843,000 to 255,462,000. This was followed by GDP growth from 1,390 to 3,042 trillion rupiah, the Primary Energy Supply increases from 726,687,000 to 1,332,242,000 BOE, and Primary Energy Supply per Capita from 3.53 to 5.22 BOE/capita. This will be used as the basis in developing the system dynamics model of the past.

In this model, the core is surrounded by at least six major Causal Loop Feedbacks that are tapped into it, i.e., the Oil sector, Gas sector, Coal sector, Biomass, New & Renewable sector, and the Regulator. The oil and gas sectors are usually treated as one sector in the upstream during the exploration, drilling and exploitation, and separated as they are transported and enter the mid-downstream industry. The coal sector is usually divided into two subsectors, the strip-mined coals and underground-mined coals from which the national coal productions are derived. In a much smaller scale, the renewable sector is traditionally supported by the subsectors of geothermal, biofuels, hydropower and solar photovoltaic energy.

4.1. Causal-loop model

As shown on figure 5, the following three major causal loops were demonstrated in this qualitative model of the past that resulted in the behavior:

1. Reinforcing Loop A (Government Policy - Fossil Energy Dominated System Economics - Power Demand).
2. Balancing Loop B (Government Policy - Supply and Demand Gap - Fossil Dependence System).
3. Balancing Loop C (the Energy Vicious Circle or Supply and Demand Gap Oil Gas Coal Biomass - NRE).

Reinforcing Loop A, in which all relationships are positive, is typical of the past system characterized by the fossil energies dominated regime in which various incentives for fossil energies development were regulated and maintained. Therefore, the Government had since been growing a fossil energy-based economic system for economic growth with the impact on greenhouse effects, besides GDP and then power consumption/demands and dependence of fossil power system.

Loop A was supported by or resulted in Balancing Loop B in which, besides the positive relationships, some are negative, by which the Government policies primarily encouraged and were dependent upon imported refined oil in countering the supply and demand gap that in turn increased the country's dependence on fossil energies. Next at the very core of the system dynamics model is Balancing Loop C, or the Energy Vicious

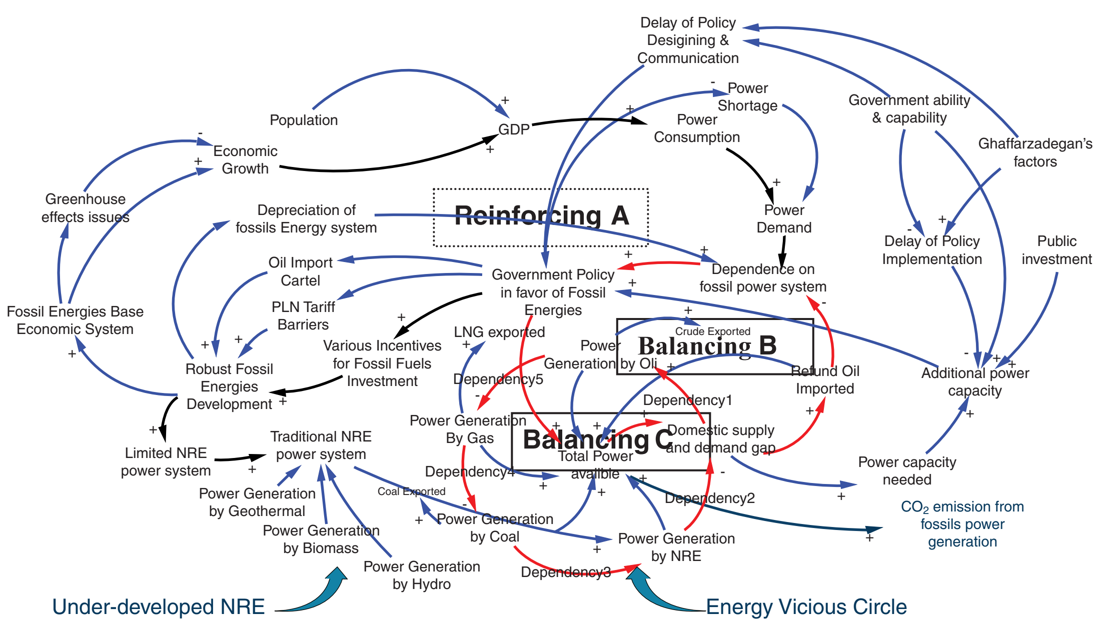

Figure 5: Causal loop diagram for energy portfolio management in indonesia today

Circle, as introduced by [1], who developed this initial model based on early observations "of the way the government has since been handling the energy supply portfolio management to cope with the continuously increasing energy demand in supporting sustainable economic growth, while the energy resources of preference, the top-priority oils are not always sufficient to meet the vital requirements." Except for several or a couple of developed countries who have made breakthrough policies, like Germany and France [1], national energy management has been dragged down by the classical global energy practices, so that its characteristics, trends, and patterns are very similar in many countries and may be described as follows:

- The system treats the oil sector as a top priority in meeting the national energy demand regardless of the localities of the resources, its impact on environment, and the volatility of its prices. "This is seemingly due to the well-established oil-based energy utility systems in most sectors throughout the world."
- Therefore, the gas sector resides in the second level despite being more environmentally friendly and more stable, having longer-term pricing, and recently having more discoveries made and new reserves booked.
- The coal sector, whose reserves are abundant and easy to explore and extract is in the next level. It holds a larger portion in the supply system to meet the electricity demand, and substitutes the shortage of oil despite its environmentally unfriendly technology characteristics.
- Last is the New and Renewables sector, which has indeed been treated as the last resort in energy supply portfolio management. This sector has been left behind in terms of exploration, exploitation and utilities despite their abundance and environmental friendliness, "This position is seemingly due to the old premise that the technologies are expensive, for the long-term externalities costs of their competitors are not taken into account, and thus their ability to be a primary energy supply is deteriorated by their intermittence and scattered characteristics."
- "The current national energy policy and strategy have not taking into account the externality costs of the energy technologies, the localities of the energy resources concerning modes of transport and market optimization, energy production efficiency, and energy diversity."

Thus, given the present conditions of the energy portfolio management formulated above, the key variables deriving the current system are identified, and their possible relations and interconnections are analyzed, the initial principal causal-loop diagram is subsequently generated to represent the system's view of the present conditions. After the model structure is determined, assessed, and defined at the very core of the system's thinking, the potential feedback loops of various subsystems with the many variables that potentially influence and shape the system's behavior will then be progressively expanded and included. Various incentive for fossil fuels investment, PLN tariff barriers, oil import cartel of Reinforcing Loop A are less relevant, whereas expansion of the power generations by various renewables is a must to get rid of the energy vicious circle. As more renewables can substitute the fossil energies the Balancing Loop B will be weakening while a new Balancing Loop associated with the growing renewable energies to grow, on which a new energy system are relied on.

4.2. Stock and flow model

In this quantitative model, six major and five minor stocks are developed, the major levels consist of Population, Power Generation by Oil, Gas, Coal, Biomass and Oil Generation by Imported, while the minor ones are composed of Power Generations by biofuel, hydro, geothermal and conceptually solar photo-voltage and nuclear. GWh is used as the unit of power (electric or non-electric) produced and Gw is used for the unit of power capacity. While Government ability and capability is set at approximately 0.4 to fulfill the additional power plant capacity needed, this is based on the Government budget readiness in building new power plants that according to [7], required an investment of US 2 million/GW. Subsequently, power electric growth per capita and non-electricity growth per capita are defined as RAMP to represent the demand growth of electricity per capita of 930 KWh/person, and a growth of electricity of 8.6% per year. The power capacity needed is derived from the domestic supply and demand gap multiplied by factor 1.3, first used by PLN to cope with the demand, as the power capacity has to be maintained higher than the growing demand.

Appendix A describes all the key variables, units and equations used in the quantitative modelling resulted in the behavior of Indonesia Today, while Appendix B shows the initial value of the variables for the initial simulation. The delay time is usually delaying time for construction of a power plant, in this case, because PLN needs to plan, design and budget approximately 2 years before obtaining permits from the government. In this modelling, the delay time is separated into delay time1, which is associated with the delay of power development, whereas delay time2 is associated with policy implementation. Delay time1 and delay time2 both correspond to common characteristic impediment in public policy designing, communication and implementation [23].

Next is the capacity factor (cf), which is the ability of the power plant to supply energy in a year, the ratio of an actual electrical energy output over a given period of time to the maximum possible electrical energy output over the same amount of time. Their values are very dependent upon the technology and thus differs for different kinds of power plants. [23] uses the average values from PLN 2016, but an average of various sources is used here. All the initial value of stocks (for the year of 2000) are quoted from [5]. Meanwhile, it is important to note that the Energy Mix Policy here is prefixed with the adjective "poor" and is defined as IF THEN ELSE (energy mix <0.25, 0.12, 0.12) to suggest that in the past, although the policy had already been issued early with the Government Regulation No.5/2006, in practice the derivatives regulations are still in favor of fossil fuels. Similarly, the Green Energy Policy has the adjective "uncommitted," as it defined at a higher threshold of CO_2 emissions under the function of IF THEN ELSE (CO_2 emission of fossil power generation >50, 0, 0), which is still in favor of fossil fuels.

4.3. Initial simulation run

In this initial experimentation, two scenarios were developed, the simulation period is set for 15 years, i.e., from 2000 to 2015, in accordance with the data available to delineate the past. Figure 6 shows the flow and stock diagram, and the scenarios are summarized in table 2 as follows:

The first scenario represents the past behaviour, although the energy mix policy and green energy policy were regulated earlier, following the Government Regulation No.5/2006 commitment to implement the policies were still low, dependency on imported oil was robust and ruled by the oil import cartel, the government's ability and capacity to grow energy capacity was low, while public investment in NRE was almost zero, and significant time delays occurred as the government struggled to overcome the bureaucracy.

The second scenario still occurs during the past time frame (2000–2015) but considers if the energy mix policy and green energy policy were fully committed, dependency on imported oil was minimized, although government ability and capacity remained the same, public investment in NRE was very high as the government improved the business process resulting in insignificant time delays, which attracted investors. The energy portfolio performance would have been totally different.

In the quantitative model (Figure 6), at the very core is the total domestic power available, in which the Balancing Loop C is controlled by many stocks (power generation by oil, gas, coal, biomass and most importantly the renewable energies) and including the various energy exported as well as imported, each of which possess internal feedback loop that behaves independently in non-linear fashions over time. The difference between the energy supply mix targets and the total domestic power available result in the domestic supply and demand gap.

Under the current system, the gap is short-termly solved by the variable of additional of imported oil and energy strategy and policies in favor of the fossil energies, that is combined poor energy mix and uncommitted green energy policies. Resistance on the Balancing Loop B leads to the problem of system dependent on fossil energies. The domestic supply-demand gap should be managed through committing the various energy strategy and policies in long terms, by which the shares or additional capacities of NRE and fossil energies are regulated to produce an increasingly improving environmentally friendly energy supply balances. Besides the variables of government ability and public investment that determine the additional power capacity, the Reinforcing Loop A involves time delays that lead to the delay of policy implementation and delay of power development. Both delays are accumulation of the Ghaffarzadegan's factors or variables. This positive reinforcement feedback loop is to determine the balance of additional capacity of NRE against additional capacity of fossil producers, the energy mix that in turn dictates the CO_2 emissions and defines independency of the energy supply system.

The simulation results are quite encouraging. Compared to the past statistics (black, dotted line), the old model during the past time (scenario 1 old past, blue) obviously shows similar trends, both graphs resemble one another, and the model simulation moderately succeeded in delineating the historical data. Meanwhile,

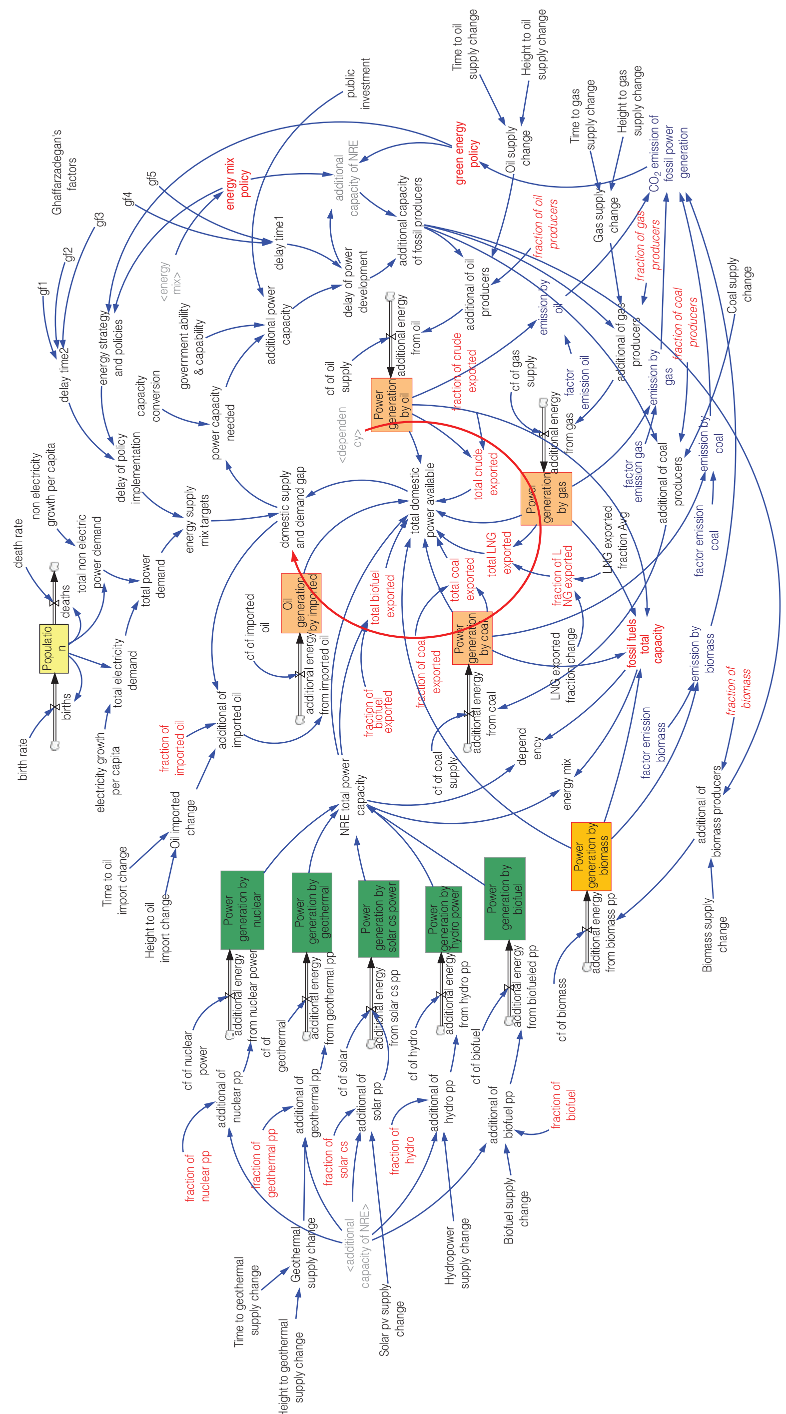

Figure 6: Stock and flow diagram for the study

Table 2: Initial scenarios of the simulation (2000–2015)

Scenario	Energy Mix Policy	Green Energy Policy	Fraction of Oil Imported	Government ability & capacity	Public Investment on NRE	Delay time1	Delay time2
Scenario 1 Old Past	(energy mix <0.25, 0.12, 0.12)	(CO_2 emissions >50, 0, 0)	35%	40%	10%	2	2
Scenario 2 New Past	(energy mix <0.75, 0.3, 0.3)	(CO_2 emissions >10, 0, 0)	15%	40%	60%	0.5	0.5

if the two scenarios are compared, it is obvious that under the second scenario (Scenario 2 new past, green, bold line) great improvement could have been achieved in all sectors of the national energy realm if the second scenario was well implemented. Figure 7 demonstrates that under the Scenario 2, although the total capacity of fossil fuels still increase significantly, the total power capacity of NRE increased drastically (green) from the previously almost flat curve (blue) under the old energy regime (Figure 8). These changes can be also seen in the oil sector (Figure 9–11), whereby imported oil (Figure 11) was drastically forced to decline as the domestic crude production (Figure 9) and crude exported (Figure 10) naturally declined under both scenarios. The presence of the Banyu Urip oil field in 2008 is moderately delineated.

An integration error tests that held by means of repetitiously cutting the time step in half and running the model from original time step of one year to only 0.03125 year when the results are no longer sensitive to the choice of time step. [26] argues "The integration error test should be the first simulation test you carry out, since failure here renders all model results meaningless."

Subsequently each decision rule on Table 2 in the model are examined for extreme condition tests by simulation and asked whether the output of the rules are feasible and reasonable even when each input to the equation takes on their maximum and minimum values (Table 3).

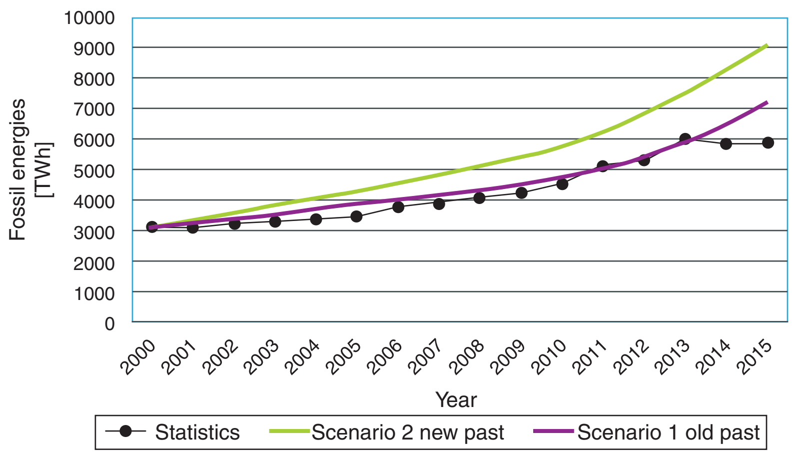

Figure 7: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total capacity of fossil energies by means of exporting table time down data from the simulation run into the same excel spreadsheet with the empirical data

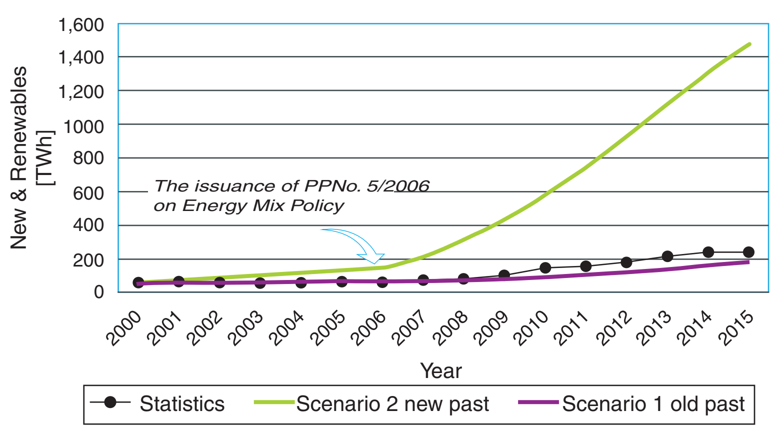

Figure 8: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total capacity of new & renewable energies by means of the same as in Figure 7

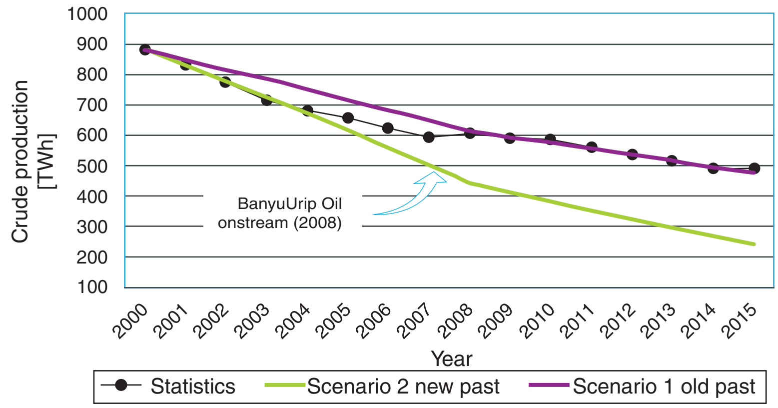

Figure 9: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total capacity of crude production by means of the same as in Figure 7

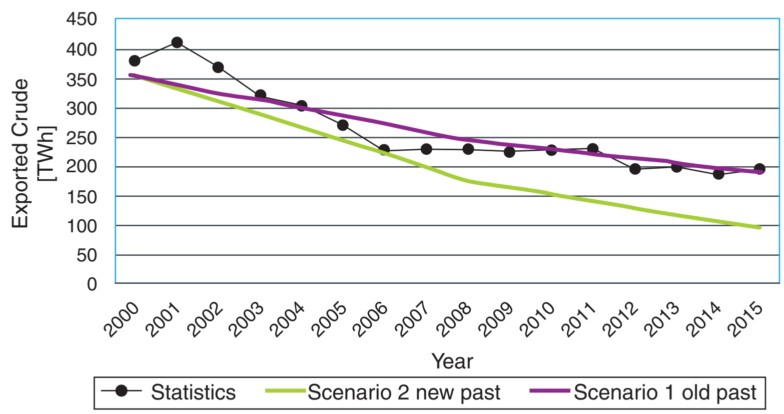

Figure 10: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total exported crude by means of the same as in Figure 7

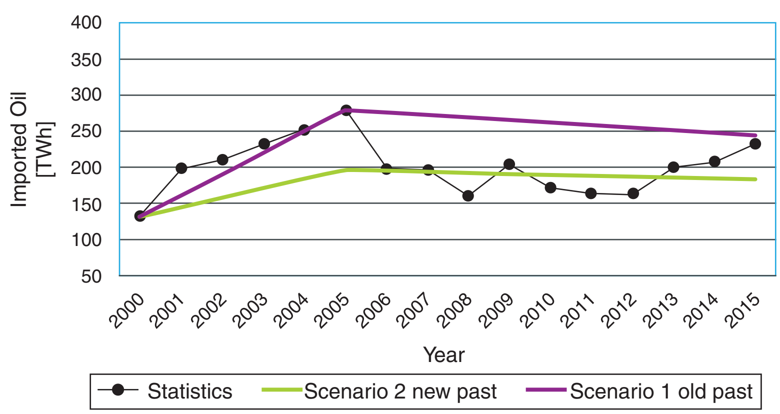

Figure 11: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total imported oil by means of the same as in Figure 7

In the extreme high case production of NRE goes to maximum capacity (includes biofuel, geothermal, hydro and solar powers), total domestic of power available also maximum, but not power generation by coal and its export that approach zero. Under this scenario, only oil imported drop to almost zero, oil and gas production and biomass go flat at their initial values. Meanwhile in the extreme low case, production of NRE immediately drop to zero, total domestic of power available also go to zero, so does power generation by coal and its export. Under this scenario, only oil imported steady high, while oil, gas and biomass remains flat at their initial values. The extreme condition tests suggest that the model is fine, no implausible behavior generated and no flaws uncovered.

Back to the simulation, the same trends occur in the gas sector (Figure 12–13), the performance of power generation by gas shows slightly decline under both scenarios, which is in turn also affect the total of LNG exported, despite more LNG exported under Scenario 2. Nevertheless, for the time period, this simple initial simulation poorly reveals the incoming of Tangguh gas field (Figure 12) with the associated Tangguh LNG

Table 3: Extreme condition scenarios of the simulation (2000–2015)

Scenario	Energy Mix Policy	Green Energy Policy	Fraction of Oil Imported	Government ability & capacity	Public Investment on NRE	Delay time1	Delay time2
Scenario Extreme High	(energy mix <1, 1, 1)	(CO_2 emissions >0, 0, 0)	0%	100%	100%	0.01	0.01
Scenario Extreme Low	(energy mix <0, 0, 0)	(CO_2 emissions >100, 100, 100)	100%	0%	0%	100	100

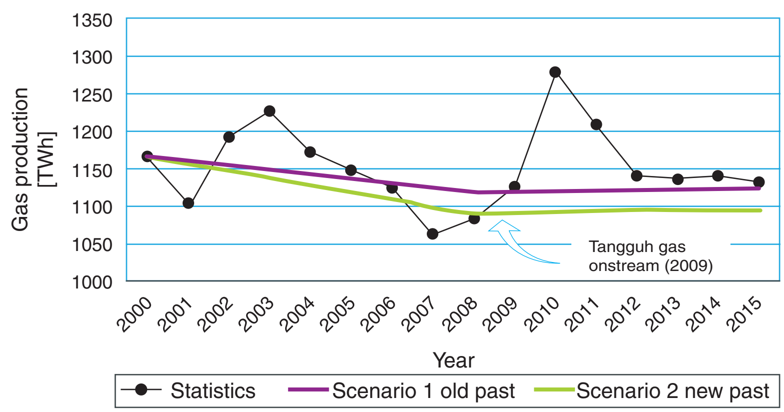

Figure 12: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total gas production by means of the same as in Figure 7

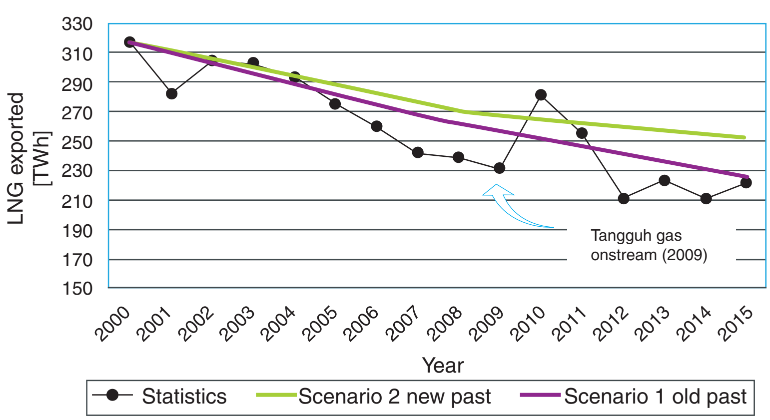

Figure 13: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total LNG exported by means of the same in Figure 7

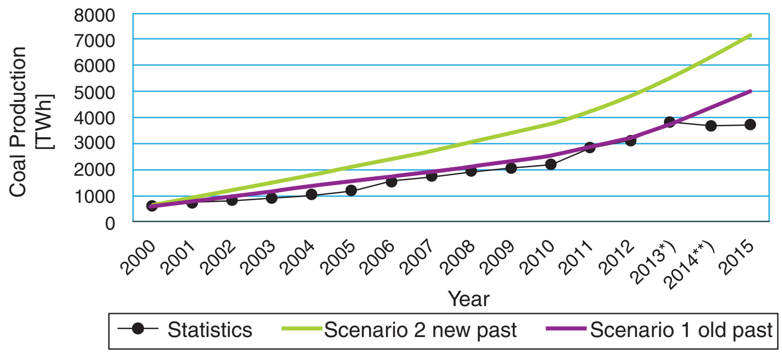

Figure 14: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total coal productionby means of the same as in Figure 7

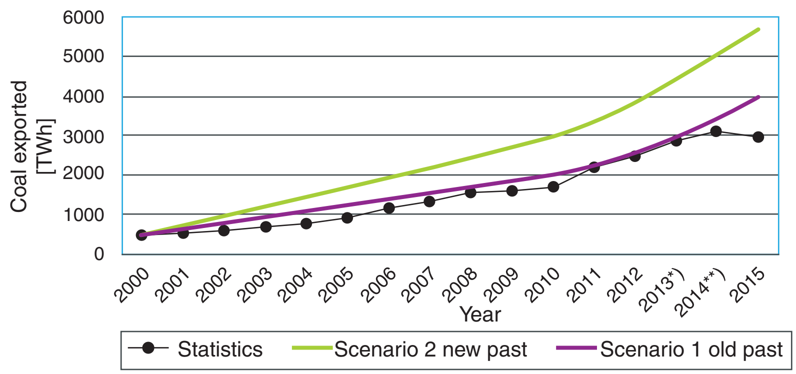

Figure 15: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total coal exported by means of the same as in Figure 7

exported on stream in 2009 (Figure 13), as the stock fluctuates cannot be captured by the curves of both scenarios. This can be understood as the onstream of new oil and gas fields or green fields and the shutdown of brown fields as separated feedback loops have not been included in the quantitative model.

Similarly, this initial simulation model has also missed the complexity of Indonesia's annual imported refined oil (Figure 11), as it is believed that more non-linear feedback loops are involved in its system dynamics. This may include oil and gas prices fluctuates, available supply from spot markets, domestic oil demands as well as the oil production.

In the coal sector (Figures 14 –15), the power generation by coal keeps increasing under both scenarios in line with the existing energy mix goal to manage the share of coal to ramping up from 26% in 2011 to 30% in 2025 while the contribution of oil and gas decreases, and this is followed by the total coal exported which demonstrates the same trends. The simulation however missed some deflections on the statistics of both graphs that mark the beginning of global coal prices drop in 2012 since feedback loops for coal prices fluctuates as well as the global market have not been taken into account.

The biomass, the power generation by this old, traditional and rural fueling system shows an obvious drop in Scenario 2 from previously inclined to increase under scenario 1 and statistically (Figure 16). Otherwise, during the same period of time, the NRE, including power generation by biofuel (Figure 17), power generation by geothermal (Figure 18) and power generation by hydro (Figure 19), are strongly leveraged and demonstrate drastic increases under Scenario 2 (after being suppressed under Scenario 1) thanks to the government policies that regulated various incentives in

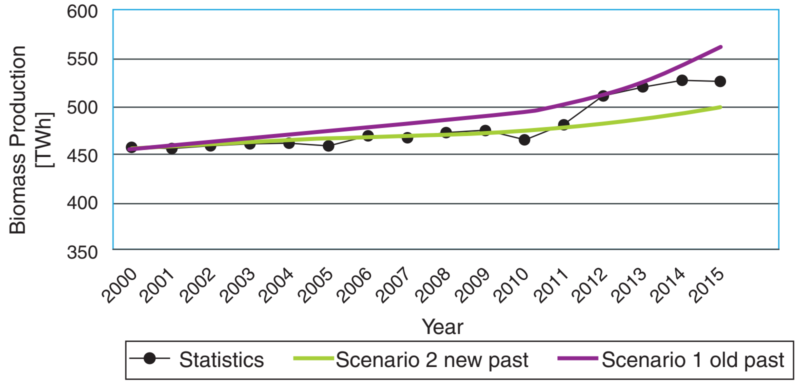

Figure 16: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total biomass power production by means of the same as in Figure 7

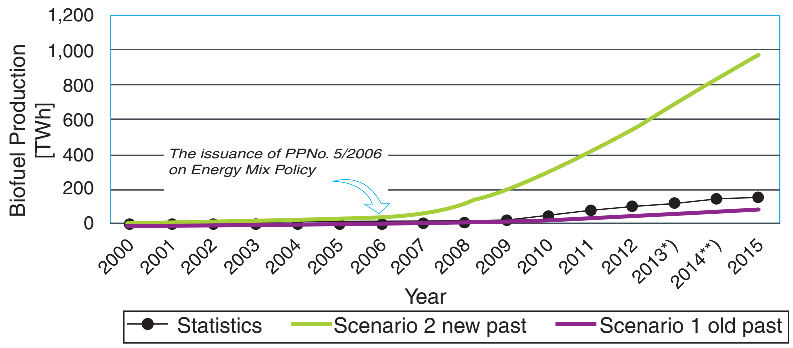

Figure 17: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total biofuel power production by means of the same as in Figure 7

favor of NRE investment and took firm side with the environmentally friendly energies.

5. Discussion

The statistics, the causal loop diagram and the discussion in chapter 4.4 reveal that the challenges and opportunities in the energy portfolio management in the country are real and quite complicated. The current supply system, which is exposed openly to free market in striving to meet uncontrollable and disintegrated sectorial demands, is obviously problematic. The current energy mix vision with the supporting policy instruments issued to date have not succeeded in taking the energy journey of Indonesia to the desired destination. This is partly due to the absence of a clear model of the ongoing system and a traceable origin of the current energy mix vision.

Building a more appropriate, long-termly viable energy system is needed to ensure a sustainable energy supply. The literature review revealed that a limited number of publications are available on this topic, and identified that the energy supply quality system with the unique factors of developing country like Indonesia constitutes a research gap, to which the work was subsequently directed to find a more reliable modeling. Subsequently, assessing the present government policy helped identify the barriers, and at a later stage, find the solutions to ease the penetration of renewable energies into existing energy systems.

System dynamics modeling is recognized as an excellent methodology with strong advantages for such holistic approaches in energy supply management, all of which makes it a valid alternative to the most well-known

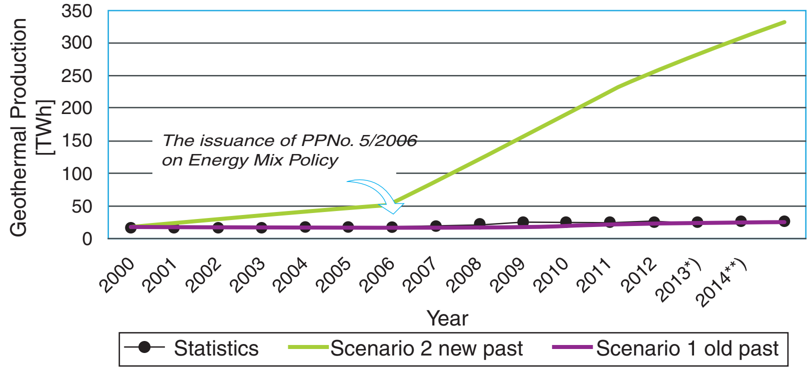

Figure 18: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total geothermal power production by means of the same as in Figure 7

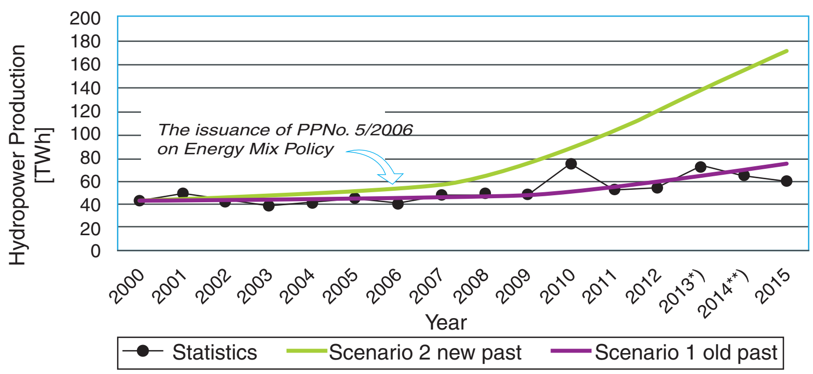

Figure 19: Comparing statistics [5] with simulation results (Scenario 1 and 2) for total hydropower production by means of the same as in Figure 7

and used forecasting techniques in the context of energy economics and confirmed the superiority of system dynamics modeling compared to the traditional non-simulation approaches. So, this modelling approach itself and its focus on the unprecedented energy supply quality mix of an archipelagic country and in the inclusion of a series of new variables discussed early make this research are interesting and rather unique.

The principle causal-loop diagram illustrated in Figure 5 demonstrates the complexity of the energy supply realm, the balancing loop C at the core of the system has apparently been dragging the entire causal loop feedbacks tapped into it and involved in the problematic energy circle. This old circle has traditionally been maintained by the supporting balancing loop B involving the government policies that treated fossil energies as preference and to have caused strong dependence on it. This situation was driven by the major loop A, which also begins with the government policies that regulated various incentives in favor of fossil energy investment, PLN tariff barriers, oil import cartel that led to robust fossil energies development and otherwise hindering the growth of NRE power systems. This fossils-based economic system is in turn resulting in environmentally unfriendly economic growth, with the associated green-house gas issues and has impeded the country in building its sustainable and self-sufficient power system, even though it is geologically blessed many types of renewable energy potential. The initial simulation of the stock and flow model is quite encouraging in that, through the 2 scenarios developed, it is succeeded in building an initial model structure that is able to simplify the past complex energy supply dynamics and to imitate the historical trends, except for some incidental fluctuations. While comparison of the two scenarios demonstrates that under the better second scenario, great improvement could have been achieved in all sectors of the national energy realm should it have been well implemented in the past. Both are important as basis to understand the model structures and non-linear behaviors of the complex energy supply system over the time frame for future policy design. How interactions of the different variables of the internal feedback loops, table functions and time delays have jointly mathematically been shaping the different behaviors of the complex energy issues and problems. It is obvious that among the key variables that cause unproductive energy supply system behavior include poor energy mix and uncommitted green energy policies, dominant oil imported, low public participation in NRE investment, and long delays in policy designing, communication and implementation. By gaining insight the model behaviors, policy instruments may be designed so as to lead the energy supply system to behave productively controllably. This model is for those reasons potentially reliable as an alternative model for building a new Energy Supply Mix Vision if the main challenge facing the modelling may be resolved. It includes investigating the factors influencing the long-terms supply and demand of energy as key variables that potentially dictate the energy industry in the future, to gain insight into their uncertainties and to simply formulate them into the model.

6. Conclusion

It is finally concluded that the qualitative model identifies the presence of a "vicious circle" in the energy supply system in Indonesia, in which oil sector (and other fossil energies) are prioritized in meeting the national energy demand and treat new and renewables sector as the last resort in the energy portfolio management. By identifying and mapping these historical barriers, a better alternative models may be developed. The quantitative model succeeds in building model structures and gain insight the non-linear behaviors of the complex energy supply system over the set timeframe as basis for future policy design in Indonesia.

The initial simulation runs are quite encouraging in that it succeeds in developing, comparing and contrasting two scenarios represent the old fashion system as is (scenario 1 old past) and new fashion model (scenario 2 new past) as if all selected best practices were implemented. Compared to the past statistics, the results of the simulation runs are quite promising, the old past model (Scenario 1 old past) obviously shows similar trends, both graphs resemble one another, and the model simulation moderately succeeds in delineating the historical data.

However, it is recognized that this simple initial simulation failed to capture some deflection points shown by historical data trends that is believed to corresponding to more non-linear feedback loops involved in the energy supply system. Meanwhile, if the two scenarios are compared, it is obvious that under Scenario 2 new past, great improvement could have been achieved in all sectors of the national energy realm if the second scenario was well implemented. This model is potentially reliable as an alternative approach for policy design and in the efforts to build a new and more viable Energy Supply Mix Vision.

Future work recommendation: Engineering of the model to the envisaged patters and subsequently examined and fine-tuned through focus group discussions may offer a more viable solution. Ideally, the energy demands and economics are explicitly included to get more holistic understanding and representative behaviors. Meanwhile new energies such as tidal turbines, second and third generation biofuels, solarpanel positioning robots, photovoltaic transparent glass, space-based solar power, micro-nuclear reactors, and thorium reactor are more relevant in the future to include as the race and challenges for energy supply increase and the technology evolve rapidly.

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APPENDIX A

Table of key variables, units and functions in the initial quantitative modelling of indonesia today

Variable	Unit	Function
population	person	birth - death
birth	person/year	population * birth rate
death	person/year	population * death rate
electricity growth per capita	KWh/person	930+RAMP(7.998.e-05, 2000, 215)
total electricity demand	GWh	electricity growth per capita * population
total demand for non-electric power	GWh	non-electric power growth per capita * population
total energy demand	GWh	total electricity demand + total demand for non-electric power
fossil fuel total capacity	GWh	power generation by oil + power generation by gas + power generation by coal
NRE total capacity	GWh	power generation by biofuel + power generation by geothermal + power generation by hydro + power generation by solar pv + power generation by nuclear
dependency	Dmnl	fossil fuel total capacity/ (fossil fuel total capacity - NRE total capacity)
energy mix	Dmnl	NRE total capacity/ (fossil fuel total capacity + NRE total capacity)
total power generated	GWh	fossil fuel total capacity + NRE total capacity
total domestic power available	GWh	(NRE total power capacity-total biofuel exported)+ (power generation by coal-total coal exported)+ (power generation by gas-total LNG exported)+(power generation by oil-total crude exported)+oil generation by imported+power generation by biomass
total power exported	GWh	total crude exported + total LNG exported + total coal exported + total biofuel exported
total crude exported	GWh	fraction of crude exported * power generation by oil
total LNG exported	GWh	fraction of LNG exported * power generation by gas
total coal exported	GWh	fraction of coal exported * power generation by coal
total biofuel exported	GWh	fraction of biofuel exported * power generation by biofuel
oil generation by imported	GWh	additional energy from imported oil = cf of imported oil*additional of imported oil
additional of imported oil	GWh	fraction of imported oil*domestic supply and demand gap
oil imported change	Dmnl	STEP (Height to oil import change, Time to oil import change)
domestic supply and demand gap	GWh	total energy demand - total domestic power available
power capacity needed	GW	capacity conversion * domestic supply and demand gap *1.3
additional power capacity	GW	power capacity needed * (government ability + public investment)
delay of power development	GW	DELAY1(additional power capacity, delay time1)
delay time1	Year	gf4 + gf5**
delay of policy implementation	Year	DELAY3(energy strategy and policies, delay time2)
delay time2	Year	gf1 + gf2 + gf3**
additional capacity of fossil producers	GW	(delay of power development - additional capacity of
additional capacity of NRE	GW	(energy mix policy + green energy policy) * delay of
poor energy mix policy	Dmnl	IF THEN ELSE (energy mix <0.25, 0.12, 0.12)
uncommitted green energy policy	Dmnl	IF THEN ELSE (CO_2 emission of fossil electric generating > 50, 0, 0)

(Continued)

Table of key variables, units and functions in the initial quantitative modelling of indonesia today *(Continued)*

additional of oil producers	GW	(fraction of oil producers*additional capacity of fossil producers)*(1+Oil supply change)
oil supply change	Dmnl	STEP (Height to oil supply change, Time to oil supply change)
additional of gas producers	GW	fraction of gas producers * additional capacity of fossil producers
gas supply change	Dmnl	STEP (Height to gas supply change, Time to gas supply change)
fraction of LNG exported	Dmnl	LNG exported fraction Avg*(1+LNG exported fraction change)
LNG exported fraction change		RAMP(–0.01, 2000, 2015)
additional of coal producers	GW	fraction of coal producers * additional capacity of fossil producers
coal supply change	Dmnl	RAMP (0.392, 2009, 2015)
additional of biomass producers	GW	(fraction of biomass*additional capacity of fossil producers)* (1+Biomass supply change)
biomass supply change	Dmnl	RAMP (0.8, 2009, 2015)
additional of biofuel pp	GW	(fraction of biofuel * additional capacity of NRE)*(1+biofuel supply change)
biofuel supply change	Dmnl	RAMP (3.5, 2005, 2015)
additional of geothermal pp	GW	(fraction of geothermal * additional capacity of NRE)*(1+geothermal supply change)
geothermal supply change	Dmnl	STEP (Height to geothermal supply change, Time to geothermal supply change)
additional of hydro pp	GW	(fraction of hydro * additional capacity of NRE)*(1+hydropower supply change)
hydropower supply change	Dmnl	RAMP (1.5, 2005, 2015)
additional of solar pv pp	GW	(fraction of solar pv * additional capacity of NRE)*(1+solar pv supply change)
solar pv supply change		RAMP (1.5, 2005, 2015)
additional of nuclear pp	GW	fraction of nuclear * additional capacity of NRE
additional energy from oil	GWh/year	additional of oil producers * cf of oil supply
additional energy from gas	GWh/year	additional of gas producers * cf of gas supply
additional energy from coal	GWh/year	additional of coal producers * cf of coal supply
additional energy from biofuel pp	GWh/year	additional of biofuel pp * cf of biofuel
additional energy from geothermal pp	GWh/year	additional of geothermal pp * cf of geothermal
additional energy from hydro pp	GWh/year	additional of hydro pp * cf of hydro
additional energy from solar cs pp	GWh/year	additional of solar cs pp * cf of solar
additional energy from nuclear power	GWh/year	additional of nuclear pp * cf of nuclear power
CO_2 emission of fossil power generation	mmtonnes	emission by coal + emission by oil + emission by gas
emission by coal	mmtonnes	power generation by coal * factor emission coal
emission by oil	mmtonnes	power generation by oil * factor emission oil
emission by gas	mmtonnes	power generation by gas * factor emission gas

** = *contributors of delay time variables corresponding to Ghaffarzadegan's characteristic impediment in policy designing, communication and implementation*

gf1 = *"under estimated policymakers" variable in policy designing*

gf2 = *"scapegoat minded perspective" variable in policy designing*

gf3 = *"political link & lobbying" variable in policy designing and policy communication*

gf4 = *"policy acceptance" variable in policy implementation*

gf5 = *"rate of trials and errors" variable in policy implementation*

APPENDIX B

Table of Initial Values of Variables for Simulation Modelling of Indonesia's Past Energy (2000–2015)

Variable	Unite	Initial Value
population	person	205,840,000
birth rate	1/year	16.72/1000
death rate	1/year	6.73/1000
capacity conversion	GW/GWh	1/(365*24)
government ability	Dmnl	0.4
public investment	Dmnl	0.6
gf1+gf2+gf3**	Year	0.5+0.2+0.3
gf4+gf5**	Year	0.4+0.6
fraction of oil producers	Dmnl	581
Fraction of oil exported	Dmnl	0.43
height to oil supply change	Dmnl	-0.5
time to oil supply change	Year	2008
fraction of gas producers	Dmnl	193
height to gas supply change	Dmnl	-1.1
time to gas supply change	Year	2008
LNG exported fraction avg	Dmnl	0.27
fraction of coal producers	Dmnl	75
Fraction of coal exported	Dmnl	0.793
fraction of biomass	Dmnl	50
fraction of biofuel	Dmnl	0.1 (0.3)
fraction of geothermal	Dmnl	0.032
height to geothermal supply change	Dmnl	4
time to geothermal supply change	Year	2006
fraction of hydro	Dmnl	0.248
fraction of solar pv	Dmnl	0.001 (0.131)
fraction of nuclear	Dmnl	0.0001
cf of oil supply	(GWh/GW*year)	-0.525
cf of gas supply	(GWh/GW*year)	-0.674
cf of coal supply	(GWh/GW*year)	62
cf of biomass	(GWh/GW*year)	5.25
cf of biofuel	(GWh/GW*year)	0.1
cf of geothermal	(GWh/GW*year)	0.032 (0.32)
cf of hydro	(GWh/GW*year)	0.248
cf of solar pv	(GWh/GW*year)	0.001
cf of nuclear	(GWh/GW*year)	0.0001
factor emission coal	mmtonnes/GWh	318.37/106
factor emission oil	mmtonnes/GWh	249.65/106
factor emission gas	mmtonnes/GWh	181.08/106
power generation by oil	GWh	879,426
power generation by gas	GWh	1,167,010
power generation by coal	GWh	624,025
power generation by biomass	GWh	437,233
power generation by biofuel	GWh	0
power generation by hydro	GWh	42,908
power generation by geothermal	GWh	16,308
power generation by solar pv	GWh	0
power generation by nuclear	GWh	0
oil generation by imported	GWh*Year	133,599
height to oil import change	Dmnl	1.1
time to oil import change	Year	2005