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Model conceptualization for policy analysis in renewable energy development in Indonesia by using system dynamics

Akhmad Hidayatno, Regina Dhamayanti, Arry Rahmawan Destyanto*

Systems Engineering, Modeling and Simulation Laboratory, Industrial Engineering Department, Faculty of Engineering Universitas Indonesia, Depok 16424, Indonesia

Abstract

The energy demand of Indonesia is continuously increasing because of the development of some main influencing factors. At the same time, the Indonesian government is concerned about the importance of sustainable development, which is one of the elements related to environmental protection. The large energy demand and the sustainable development concerns have led the Indonesian government to create a target of new and renewable energy (NRE) contribution in the final energy mix and to enact some policies to achieve this target. However, there are some challenges in the implementation of these regulations, such as business schemes and incentives, which are perceived to be not lucrative enough by investors. The objective of this research is to understand the dynamics of the system, the variables involved, and their interconnections in the development of NRE in Indonesia, particularly with regard to the price of electricity sold by power producers to the State Electricity Company (PT. PLN) and the tax facilities. This research aims to develop a generic, validated, and verified causal loop diagram that will serve as a conceptual model for system dynamics modeling for the analysis of similar energy policies on the basis of a case study in Indonesia.

Keywords: System dynamics, policy analysis, renewable energy, electricity generation, developing country, Indonesia

1. Introduction

The energy demand of Indonesia is continuously increasing because of the development of some main influencing factors, such as population growth, economic growth, technology development, and energy price. The energy demand of Indonesia is projected to reach 248.4 million tons of oil equivalent in 2025 [1]. At the same time, the Indonesian government is concerned about sustainable development, which is one of the elements related to environmental protection. This is indicated by some commitments of the Indonesian government, such as Indonesia's commitment to the United Nations Framework Convention on Climate Change Conference of the Parties 21 to reduce greenhouse gas emission by 26% in 2020 with its own effort and 41% with international help or Indonesia's implementation of the National Action Plan For Reducing Greenhouse Gas Emissions, the National Energy Plan, and some other policies. The massive energy demand and the sustainable development concerns have led the Indonesian government to create a target of new and renewable energy (NRE) contribution in the final energy mix, which is presented in Government Regulation (GR) No. 79 of 2014 [2] and The National Energy Plan or Rencana Umum Energi Nasional [1]. The target is 23% of NRE in the final energy mix in 2025 and 31% in 2050. The energy mix in this context is the amount of energy supply for each type of energy. However, despite the immense potential of NRE in Indonesia, which can reach up to 443,208 MW, the contribution of NRE is only 5% of the final energy mix as of 2015 [1].

Related to the effort in reaching the target mentioned in GR No. 79/2014, the government has enacted some policies: 1) GR No. 9 of 2016 on Income Tax Facilities on Capital Investment of Particular Business Fields and/or in Particular Regions [3] and 2) Ministry of Energy and Mineral Resources

* Manuscript received May 20, 2018; revised December 1, 2018.
Corresponding author. Tel.: +21-822-6000-4761; *E-mail address*: arry.rahmawan@eng.ui.ac.id.
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(MEMR) Regulation No. 43 and 50 of 2017 on Utilization of Renewable Energy for Electricity Supply Purposes [4][5]. However, there are some challenges in the implementation of these regulations, particularly from the perspective of investors. It is perceived that the selling price of electricity supply to PT. PLN (State Electricity Company), which is regulated in the aforementioned MEMR Regulation, is not lucrative enough for investors despite the fact that the current system requires PT. PLN to buy all the electricity produced by power producers. The other challenges involve the tendency of NRE development projects to be small and scattered in different areas, as well as the high prices of NRE, different perspectives regarding NRE development between different stakeholders, and societal resistance.

Given the presence of controversies and different interests from different stakeholders, a system-based analysis is needed to analyze alternative policies that can achieve the optimal effect. The objective of this research is to understand the critical factors and their relationships in the development of electricity generation in terms of renewable energy (RE) development in Indonesia. A causal loop diagram resulting from this research is a generic, validated, and verified causal loop diagram that serves as a platform for system dynamics approaches for similar energy policy modeling and simulation.

This study developed a conceptualization model in the form of a validated and verified causal loop diagram that will support further research in analyzing policies related to electricity generation development from the perspective of RE development in Indonesia. The contribution of the causal loop diagram resulting from this research will help relevant studies by establishing the concept of RE development in Indonesia and by highlighting the variables that need to be considered. New energy is not included because of the minimal development of new energy in Indonesia, as well as the limited data available for a valid research.

2. Literature Review

Many studies have been performed to study the effect of government policies to NRE development. Various methodologies, including system dynamics, have been used to create outcomes that help stakeholders understand and use the system for decision making. Ref. [6] focuses on energy transition to renewable and sustainable energy in Azerbaijan by using the interdisciplinary triangle of sustainable development. Ref. [7] focuses on the energy transition in Indonesia by using the interview method. Ref. [8] studies RE policy evaluation in Oman by using system dynamics. Ref. [9] is also another model-based policy analysis, but it focuses on fiscal transfer policy in Indonesia and uses computable general equilibrium as the tool. Ref. [10] uses system dynamics to understand the dynamics of electricity generation capacity in Canada. Ref. [11] discusses energy transition management, policy evaluation, and electricity generation capacity in Japan by using transition theory.

However, there is a gap in current studies on RE, policy analysis, and electricity generation in Indonesia regarding the use of the system dynamics approach. In this study, a causal loop diagram is developed as a conceptual model for system dynamics modeling because an effective conceptual model is essential for the development of an effectively conceptualized system dynamics to achieve the best result of the simulation [14].

In this study, a causal loop diagram is developed because it is an important tool for representing the feedback structure of systems. It displays how important variables to the system interrelate to one another by using text, arrows, and symbols. The interaction between two variables is represented by a causal connection (arrow running from the "cause" to the "effect") and a polarity (indicated by a "+" or "-"). Assuming that all else is held constant in the system, the positive ("+") polarity indicates that perturbations in the "causal" variable will result in perturbations in the same direction in the "effect" variable. Similarly, a negative (-) polarity on a causal arrow indicates that perturbations in the "causal" variable will result in perturbations in the opposite direction in the effect variable by again assuming that all else is held constant. The causal relationships create feedback loops that are denoted as either balancing (B) or reinforcing (R), and each loop is given a name to facilitate the discussion of the model [12].

The novelty of this research is on the topic it covers and the tool it uses. Regarding the topic, this study covers energy transition management from conventional energy to RE, policy analysis, and electricity generation capacity in Indonesia. Regarding the tools, this study constructs a validated and verified causal loop diagram as a conceptual model by system dynamics, which can be used for further RE policy analysis research in Indonesia.

3. Methodology

This study develops a conceptual model by using a causal loop diagram, which is based on system dynamics modeling approach. System dynamics modeling was first developed during the mid-1950s by Professor Jay W. Forrester of MIT to analyze complex behaviors in social sciences in the context of management via computer simulations [13]. System dynamics is a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations [12].

The model conceptualization process begins with problem definition and then by causal loop diagram development. An effective conceptual model will result in an effectively conceptualized system dynamics model, which must integrate two perspectives. On the contrary, the model must portray decision-making processes and organizational relationships in the system being modeled in terms that are both familiar and meaningful to an actor in the real system. However, it must also provide a sufficiently new view of the system in terms of new organizing concepts, highlighting of relationships, and creation of potentially new terminology to move decision makers in the system toward a deeper understanding of policy choices [14].

To build the model, this research utilized information from reports, journals, previous studies on similar topics, and discussions with experts.

4. Result & Discussion

In this section, a causal loop diagram is presented as the result of the research (Fig. 1). The causal loop diagram illustrates the relationships between important factors in the development of electricity generation based on RE in Indonesia, particularly between factors related to electricity supply selling price to PT. PLN and income tax facilities.

The causality between variables is represented by an arrow with a negative/positive sign, which indicates an inversely/directly proportional relationship between the two variables.
This paper constructs a conceptual model to analyze RE policies with three main domains of sustainability: 1) economic, 2) social, 3) environmental [8]. This paper modified the first category into energy and economy because there is an additional important indicator aside from GDP (economic indicator), namely, total RE-based electricity production (energy indicator).

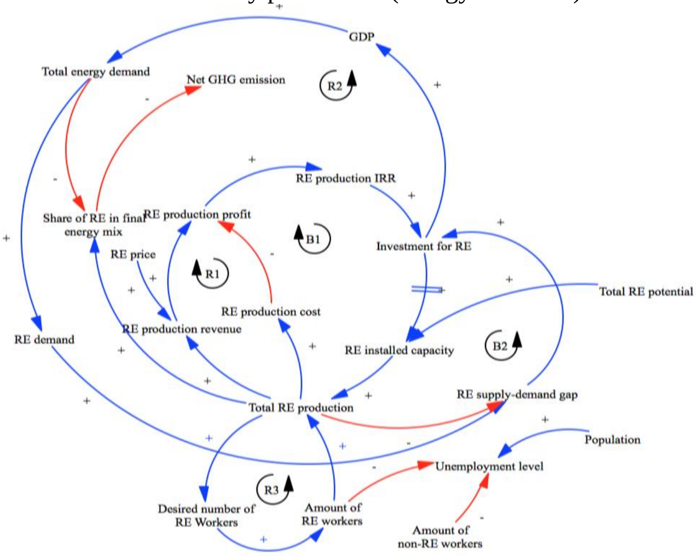

Fig. 1. Causal loop diagram of the dynamic behavior of the RE development system of Indonesia

4.1. Energy and economy submodel

The main variable in this causal loop diagram is total RE-based electricity production because this will affect the contribution of RE in the final energy mix, which is the indicator of RE development in Indonesia at the time.

In the first loop, which is indicated by R1, shows that once the amount of total RE-based electricity production increases, it will increase RE-based electricity production revenue, thus increasing RE-based electricity production profit [8] and RE-based electricity internal rate of return (IRR). In the perspective of investors, a higher IRR corresponds to higher chances that they will accept or realize the investment [15]. The increase in investment in the RE sector will increase RE installed capacity, which will increase the total RE-based electricity production; therefore, this process is called a reinforcing loop. MEMR Regulation No. 43 and 51 of 2017 will affect RE-based electricity production revenue because the main revenue stream of an electricity generator or power producer is electricity sales to PT. PLN.

The second loop, which is indicated by B1, shows a similar relationship to loop R1; however, the profit is seen from another element, namely, RE-based production cost. The increase in RE-based production cost will decrease RE-based production revenue, thus ultimately resulting in the decrease in the amount of total RE-based electricity production. Therefore, it is called a balancing loop. GR No. 9 of 2016 will affect RE-based electricity production cost via changes in net income, depreciation, amortization, and several other cost elements.

The third loop, which is indicated by B2, shows the effect of the RE supply–demand gap to the investment in the RE sector [16]. The RE supply–demand gap is affected by two variables: total RE-based electricity production and total RE demand. This third loop is related to the effect of the earlier variable, which is total RE-based electricity production. By assuming that RE demand remains constant, an increase in total RE-based electricity production will lead to a decrease in RE supply–demand gap and total RE-based electricity production and will form a balancing loop.

The fourth loop, which is indicated by R2, shows that investment in the RE sector is directly proportional to GDP [8]. The result of changes in GDP will be directly proportional to the changes in total energy demand [17], which will positively affect RE demand, affect RE investment, and create a reinforcing loop.

4.2. Social submodel

This submodel shows that RE production pushed the desired number of RE workers, and this situation will affect the actual number of RE workers (those who have gone through the recruitment process and training). The amount of RE worker will then allow RE production and thus, a reinforcing loop is created.

Another significance of this submodel is to see the effect of RE development to the social aspect, which is represented by the unemployment level influenced by the number of workers generated by activities in RE development [8].

4.3. Environment submodel

A feedback loop is not present in the environment submodel because environmental concern has a very minimum contribution in driving RE investment in Indonesia, and the majority of investment in Indonesia is driven by profitability assessment.

However, this submodel is important to study so that the effect of RE development to the environment aspect, which is represented by net GHG emission, can be understood. Net GHG emission means that it has considered all the GHG emissions along with all GHG emission absorption from various efforts of the Indonesian government.

5. Conclusions & Recommendations

This study established the conceptual basis in the form of a causal loop diagram for evaluating policies related to RE development in Indonesia on the basis of system dynamics approach, particularly for policies related to electricity selling price from power producers to PT. PLN and tax facilities. This paper covers topics about energy transition management from conventional to RE, as well as policy analysis and electricity generation capacity using model-based policy analysis, specifically system dynamics.

The causal loop diagram in this paper is developed on the basis of information from reports, journals, previous studies in similar topics, and discussions with experts. The validated and verified causal loop diagram can be used for further research related to the policy analysis of RE development in Indonesia.

From this paper, it can be concluded that RE development in Indonesia is affected by investments in the RE sector partly because there is still a huge uninstalled RE potential in Indonesia. To achieve high growth in RE development, the government must make investment lucrative by creating an investment-friendly environment via policies that consider the revenue, cost, and IRR of investment and business operations. Furthermore, demand for RE must also be kept attractive to boost investor confidence in the survivability of their business from the demand side.

The recommendation for further research involves building stock-and-flow diagrams by a causal loop diagram to realize the quantitative and qualitative analyses of related policies. The process of stock-and-flow diagram development means that it involves gathering and processing relevant data to generate quantitative relationships between variables.

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