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Essays on the Development of Oil Refinery and Power Generation in Indonesia: Optimization and System Dynamic Model

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Essays on the Development of Oil Refinery and Power Generation in Indonesia: Optimization and System Dynamic Model

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Abstract

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This study intends to develop the optimal oil refinery and power generation development in Indonesia and its impact on the energy security index. The energy security index has to consider several dimensions: availability, acceptability, affordability, accessibility, and intensity. The development of the oil refinery or power generation sector may increase one energy security dimension while at the same time also decrease the other dimension.

Energy Security is a concept to assure adequate, reliable supplies of energy at a reasonable price and in ways that do not jeopardize major national values and objectives. The focus of energy security issues is the continuity of its energy supplies, including how

one country can provide oil and gas or any form of primary and secondary energy from domestic and import activities to fulfill their domestic energy demand. One of the most effective policies is to put appropriate development of the transformation sector. Indonesia's energy balance's two highest transformation processes are in the oil refinery and power generation sector. Optimized oil refinery and power generation development are crucial in the continuation delivery of the energy supply to the demand.

In the first part of the study, we analyzed the importance of optimal size of oil refinery development needed in Indonesia to reduce fuel oil import dependence. We first used the Mixed Integer Linear Programming (MILP) model, and then used system dynamic model to analyze each input factor's correlation, both from the oil demand and supply side to the energy security index in oil refinery development. The result shows that Case 1 Additional Refinery is the only case which increases the energy security index by 15.81% on average compared to Base Case because of the reduction of fuel oil import and increasing domestic fuel oil production.

In the second part of the study, we analyzed the importance of optimal power generation development in Indonesia through optimization, its impact on energy security, and the system dynamic model. The optimization with constraints of a 30% renewable energy share and 30% reserve margin will increase the energy security in the power generation development perspective. It suggests increasing the average share of Geothermal Powerplant by 11.2% and Large Hydro Powerplant by 2.4%. From fossil power generation, the share of Coal Fired Powerplant will be decreased by 25.7% while

Combined Cycle Powerplant increased by 18.2%.

In addition, we added an evaluation of the introduction of electric vehicle policy to the analyzed oil refinery and power generation developments and energy security index. This dissertation contributes to the improvement of energy security in Indonesia through analyzing optimal oil refinery and power generation development. Our specific contributions are the following:

a. Providing an evaluation of oil refinery and power generation development to increase energy security in Indonesia and reduce the energy import dependence from 2018-2050 through optimization analysis and system dynamic model;
b. Providing an evaluation of energy security index from an oil refinery and power generation perspective in Indonesia;
c. Providing an evaluation of electric vehicle introduction policy to the oil refinery, power generation, and energy security in Indonesia from 2018-2050;

Keywords: Energy Security, Oil Refinery, Power Generation, Indonesia

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Chapter 1. Introduction

1.1 Motivation

Based on the International Energy Agency (2018), the energy balance in Indonesia shows that the total primary energy supply (TPES) and the total final energy consumption (TFEC) has reached 505.6 MTOE and 155.9 MTOE respectively. The fact shows that Indonesia's highest energy transformation process is coming from the oil refinery and power generation sector. The oil refinery has consumed 52.5 MTOE or 10.4% of TPES and produced fuel oil products for 51 MTOE or 32.7% of the total final energy consumption. On the other hand, the power generation sector has consumed 92.2 MTOE or 18.2% of TPES and produced electricity for 24.4 MTOE or 15.7% of total final energy consumption. These conditions indicate how the oil refinery and power generation development is crucial in delivering the energy supply to the demand and maintaining the country's energy security.

Energy Security is a concept to assure adequate, reliable supplies of energy at a reasonable price and in ways that do not jeopardize major national values and objectives(Andrews, 2005). The focus of energy security issues is the continuity of its energy supplies, including how one country can provide oil and gas or any form of primary and secondary energy from domestic and import activities to fulfill their domestic energy demand. The importance of the energy security concept has been developed worldwide since the oil crisis phenomenon in the 1970s. Many countries believe that each of them shall protect their energy security because it can significantly impact their economic growth and political stability. Even most industrialized countries put energy security issues as their main energy agenda(Cohen et al., 2011).

(Sai et al., 2017) found in the previous researches that the energy concept was developed from three main dimensions: the availability of energy supply, economic affordability, and social acceptability. The fraction of these dimension indicates the operational security, accessibility, social welfare, and sustainable development as the goal of energy security. The availability of energy supply focused on energy demand, production, and geographical existence, while the economic affordability emphasizes the importance of the economy, price, and investment. The social acceptability has developed with the concern of environmental impact and energy efficiency.

Each country shall consider the relationship between energy demand, supply, and transformation sectors to improve its energy security. Especially in the transformation sector, (Sai et al., 2017) also suggest for each country to put attention on the development of energy carrier (transformation), which consist of the provision of transportation fuel with an oil refinery, electricity with the powerplant, and heat with the heat-generating plant. For Indonesia, the focus is only on transportation fuel and electricity because there is no significant demand for heat provision.

The development of oil refinery and power generation in Indonesia's objectives are to increase domestic transportation fuel products and electricity and reduce energy import dependence, which is good for energy security. Energy security has several dimensions that need to be considered: availability, acceptability, affordability, accessibility, and intensity. The development of the oil refinery or power generation sector may increase one energy security dimension while at the same time also decrease the other dimension. Indonesia may have a different perspective from the other countries on their way to define energy security itself. Indonesia's energy sector characteristics show that it has sufficient oil production but now declining due to the low addition of new oilfields. From domestic oil production, Indonesia still does oil export activity, although performs high fuel and crude import at the same time.

On the other hand, high fuel consumption was also occurred due to a dramatically increasing number of motorcycles. It also has sufficient electricity production despite most of the area’s not getting a good quantity and quality. Due to stable economic growth, electricity consumption keeps increasing. The government highly controls the energy sector in Indonesia. Solely, the government decides the retail price of fuel and electricity. Consequently, high fuel and electricity subsidies occurred due to regulated tariffs especially for underdeveloped communities if the energy price increases. The electrification rate almost reached 100%, but the reliability of the supply is still low. Indonesia produces an adequate number of natural gas, but it has bound to the long-term export contract. The same situation happens in coal production. Indonesia has been acknowledged as the highest coal exporter globally, although its coal reserves are not that high compared to the other coal producer countries. It also shows the high potential of renewable energy, but no impactful policy made the utilization very low.

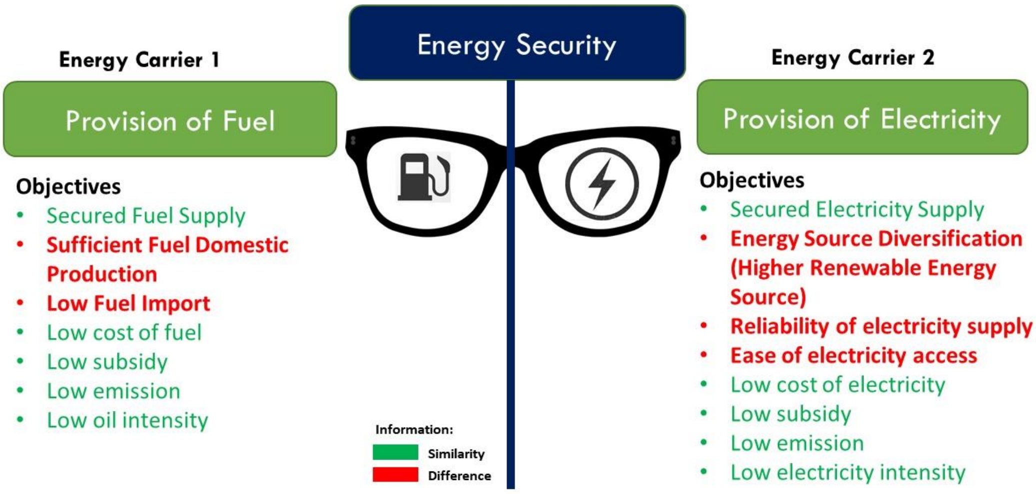


Figure 1. Indonesia energy security from the perspective of fuel and electricity provision

The provision of transportation fuel in Indonesia has several objectives: secured of fuel supply, sufficient domestic fuel production, and reduction of fuel cost, fuel subsidy, emission, and oil intensity. The focus is on how Indonesia can generate domestic fuel production and reduce its fuel import. The provision of electricity from the power generation sector has similar objectives in the secured electricity supply, low electricity cost, low electricity subsidy, low emission, and low electricity intensity. The focus of electricity provision is slightly different from transportation fuel, mainly to diversify the energy source (higher renewable energy), higher electricity reliability, and ease of electricity access for all Indonesian (Figure 1).

The current energy condition shows that Indonesia has become the net importer of crude oil due to the decreased oil production and the increasing number of crude oil consumption. Furthermore, the condition worsens because they also import fuel oil products such as motor gasoline, jet fuel/avtur, and diesel from the other countries because of the domestic refinery limited capabilities. Total import costs from petroleum products became the highest import commodities with 14.1 Billion USD or about 9.0% out of total import commodities in 2017. This oil import dependence has been the most difficult burden for Indonesia's government expenditure, and it has a lot of impact on economic stability. The government expects oil import activity to prevent a shortage of oil supply and fulfill the domestic oil requirement. This situation shows how Indonesia has a high dependence on the global oil market condition and the fluctuation of global oil prices.

There is a dilemma if the global oil price fluctuation has occurred. When the global oil prices are low, the government could efficiently distribute oil to a domestic refinery in a sufficient volume and affordable cost. In contrast, government revenue of oil export will decrease as well. On the other hand, the government will get more revenue from the sale of domestic oil production when the oil price is increasing but get difficulties in providing a subsidy for imported fuel oil from overseas refineries.

Recent data shows that Indonesia’s fuel oil consumption has increased almost four times from 1986-2017, while the domestic refinery production only grew by about 60% in the same period. Fuel oil consumption has surpassed the domestic production in 2002, which means the fuel oil import has started to supply the demand. In 2017, the fuel oil consumption was 2.25 times higher than oil refinery production, or the fuel import was bigger than the domestic refinery capability in providing fuel oil. Without any new effort to reduce its dependence on imported fuel oil, it will always bring problems to government expenditure, energy security, and economic stability. Moreover, this country has an abundant renewable energy source despite its utilization indicating only 7.4 GW out of 781 GW or 0.9% of its potential.

The government of Indonesia has stated in their national energy policy that renewable energy utilization shall reach 23% of total energy final in 2025 and 31% in 2050 to increase the level of energy security. Higher renewable energy share may increase energy security in Indonesia. It creates lower dependence on the limited fossil energy and lower carbon emission for environmental sustainability, although it will increase the Levelized Cost of Electricity (LCOE). The development of power generation is vital due to most of the renewable energy transformation will produce electricity.

To generate a solution for this problem and meet the government energy target, it is necessary and important for the Indonesian government to consider the optimal development of domestic refinery capacity and power generation sector, especially on its impact on energy security. This study investigates how the oil refinery and power generation in Indonesia may affect the energy security index. This research framework will then elaborate on oil refinery and power generation development through a system dynamic model to understand the correlation of several input factors both from the supply and demand side to the energy security (Figure 2). Furthermore, the introduction of the electric vehicle policy also is conducted through the sensitivity analysis process to identify whether this policy can be a solution in the oil refinery and power generation development process.

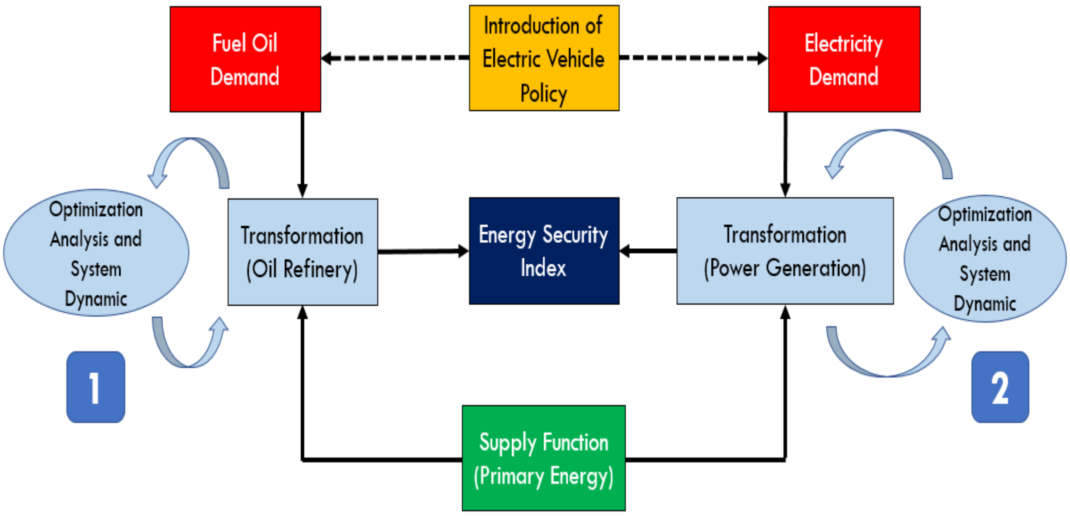


Figure 2. Thesis Research Framework

1.2 Research Purposes

This study investigates to answer the following research questions:

1. How to optimize the required capacity of reliable domestic refinery and power generation to secure energy supply and reduce energy import dependence in Indonesia?
2. How to analyze the effect of oil refinery and power generation development on the energy security index in the system dynamic model?

3. How to analyze the energy security index from an oil refinery and power generation development perspective in Indonesia?
4. What is the impact of electric vehicle policy introduction in oil refinery and power generation development and how it will influence the energy security index?
5. What policies and strategies do oil refinery and power generation development require to maintain the Indonesia energy security index in the future?

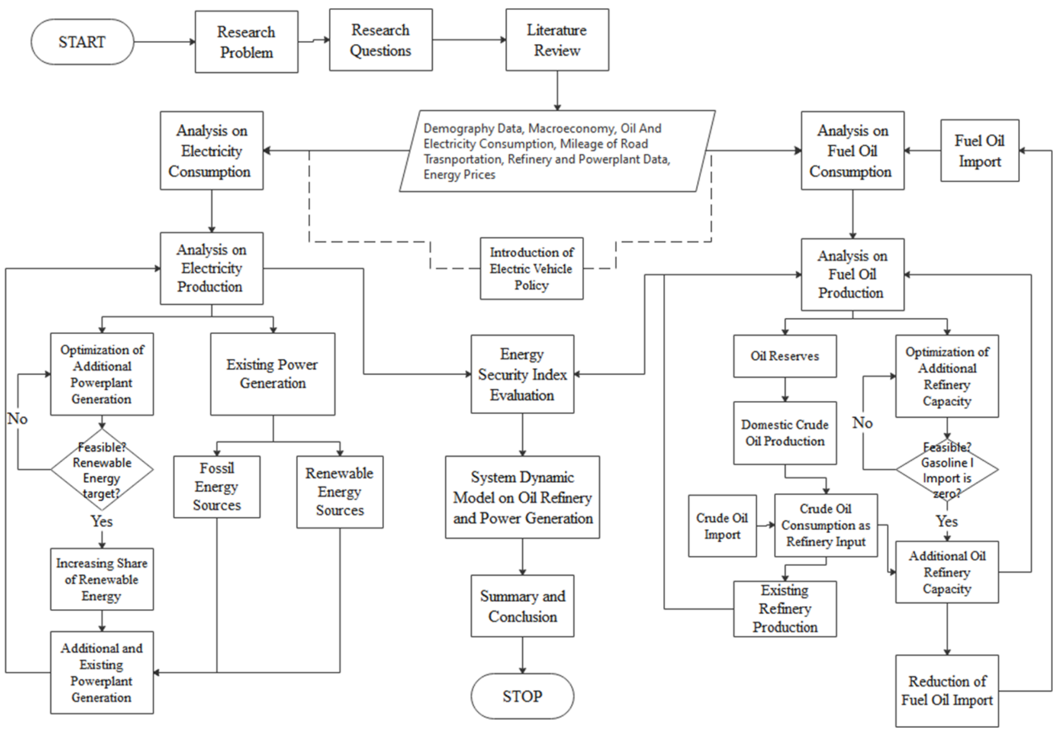


Figure 3. Thesis Research Logic Diagram

This research was conducted based on the evaluation of oil refinery and power generation development optimization and its impact on the energy security index (Figure 3). Then, the system dynamic model analyzes each input factors correlation, both from the oil demand and supply side to the energy security index in oil refinery and power generation development. In general, this study was carried out through the following six main steps:

1. Conducting a broad literature review to understand the current state of oil refinery and power generation development in Indonesia, the predefined research area, and the existing problems, government target and the need gaps to be filled.
2. Analyze the energy security indexing process and calculate the energy security index from the oil refinery and power generation development perspective.
3. Design a research model with Mixed Integer Linear Programming (MILP) and LEAP model to address the optimization of oil refinery and power generation problems (Figure 4).

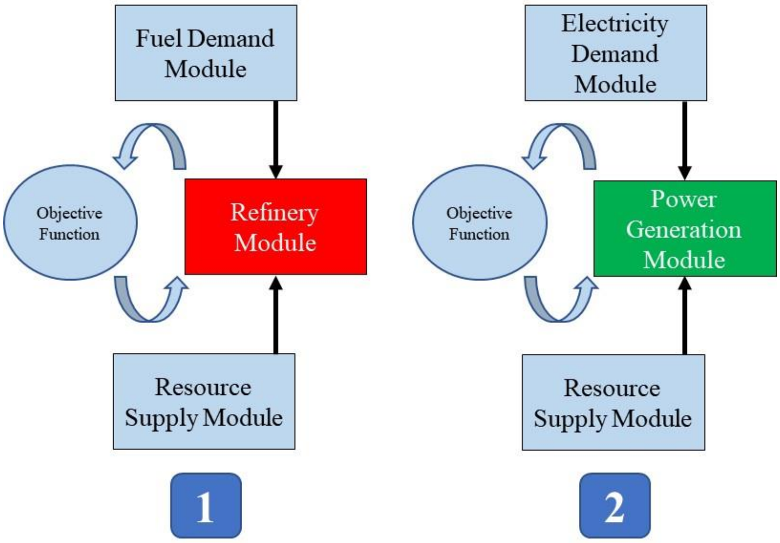


Figure 4. Optimization of Transformation Function Analysis Framework

4. Analyze the input factor impact, from both demand and supply side to energy security index in the oil refinery and power generation development by using system dynamic model (Figure 5).

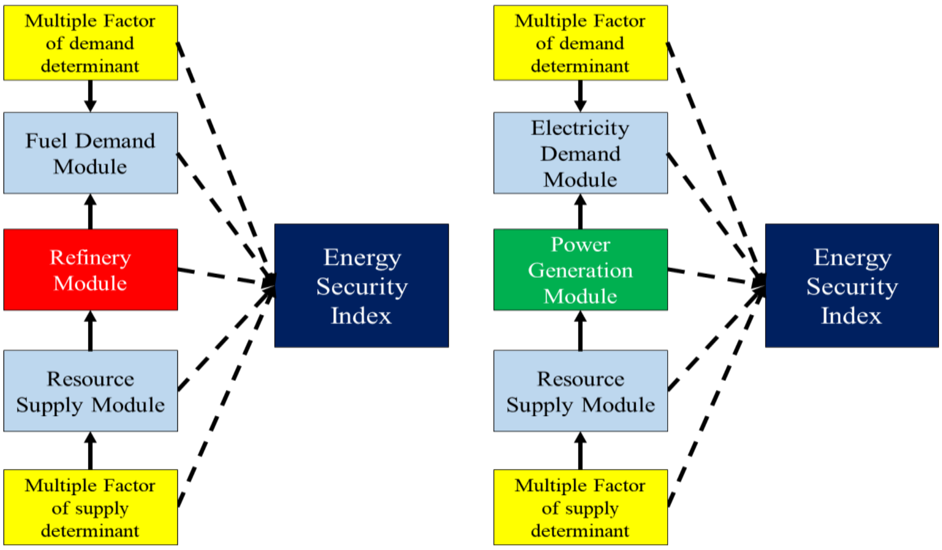


Figure 5. System Dynamic Analysis Framework

5. Analyze the introduction of electric vehicle introduction impact on an oil refinery, power generation development, and energy security index (Figure 6).

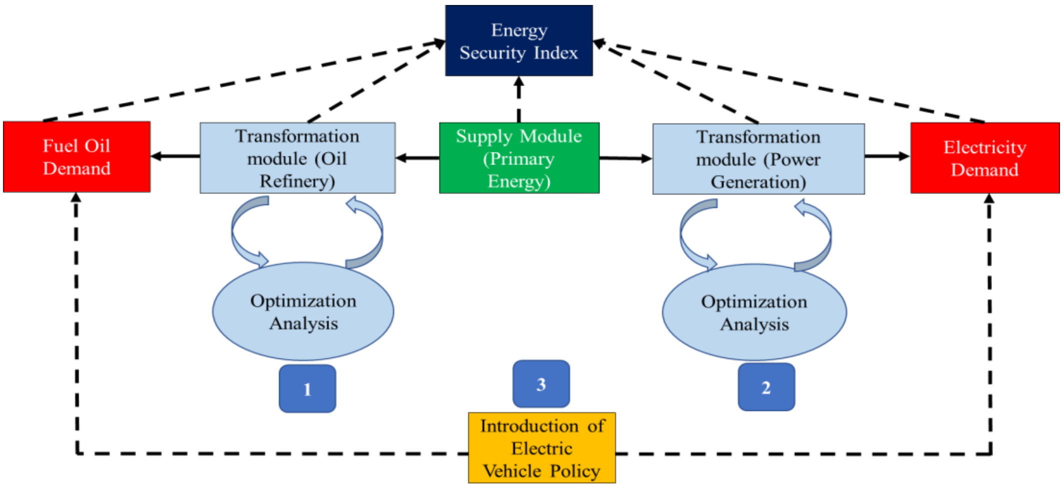


Figure 6. Introduction of Electric Vehicle Policy Analysis Framework

6. Propose a policy implication framework to support the oil refinery and power generation development to increase Indonesia’s energy security index.

This dissertation contributes to the improvement of energy security in Indonesia through oil refinery and power generation development. Our specific contributions are the followings:

a. Providing an evaluation of energy security index from oil refinery and power generation in Indonesia
b. Providing an evaluation of oil refinery and power generation development to increase energy security in Indonesia and reduce the energy import dependence from 2018-2050;
c. Providing an evaluation of electric vehicle introduction policy to the oil refinery, power generation, and energy security in Indonesia from 2018-2050;

1.3 Thesis Outline

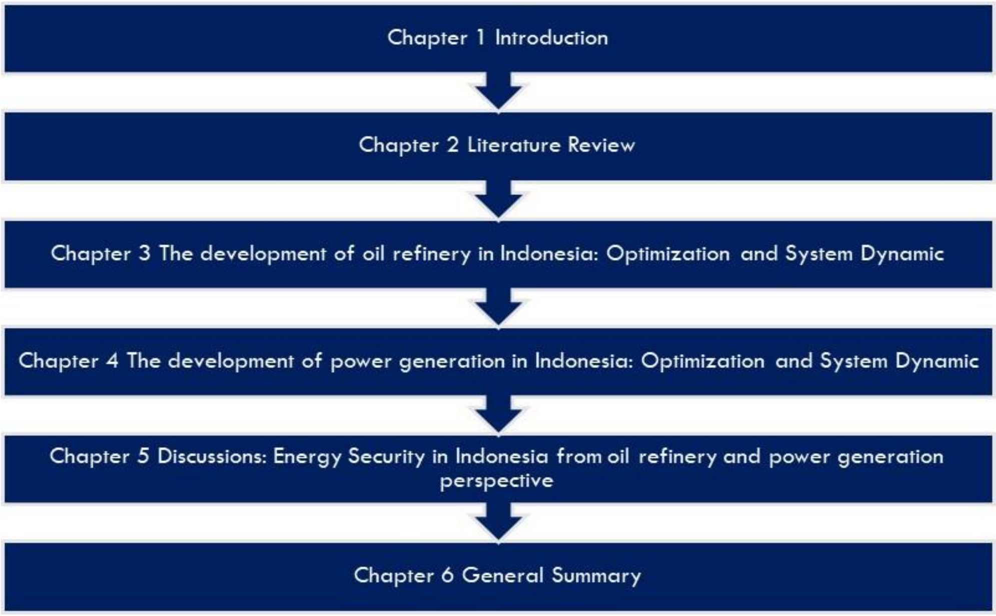


Figure 7. Thesis Outline

This study will be structured based on the outline above (Figure 7). The explanation is as follows: Chapter 2 conducted the literature review of previous researches and studies of optimization and system dynamic model of oil refinery and power generation sector. Then, it also discussed the literature on energy security index by both Indonesia and international literature. The process was followed up with theoretical frameworks that gave the foundation of this research. Chapter 2 was meant for providing information into literature evidence and theories that the importance of oil refinery development and power generation to energy security. Chapter 3 investigates the optimization of oil refinery development in Indonesia using a Mixed-Integer Linear

Programming (MILP) model in GAMS Software. It will also analyze the possibility of a new financing source mechanism for oil refinery development through the percentage of crude oil export revenue or the increasing fuel oil price. The result of the optimization impact will be evaluated by using the energy security index. The system dynamic analysis will then be conducted to see the impact of each input factor from both the demand and supply side in oil refinery development to the energy security index.

Chapter 4 focuses on optimizing power generation development in Indonesia by using the Long-Range Energy Alternatives Planning (LEAP) model and OSEMOSYS. The result of the optimization impact will be evaluated by using the energy security index. Then, the system dynamic analysis will be conducted to see each input factor's impact both from the demand and supply side in power generation development to the energy security index.

Chapter 5 analyzed the further discussions of energy security in Indonesia from the oil refinery and power generation perspective by explaining of energy security index evaluation, indicators selection, and the procedure in the energy security indexing process. There will be an analysis of the energy security indicator from the perspective of oil refinery and power generation development. Both perspectives will have a similarity and difference in the selection of indicators. Furthermore, the electric vehicle introduction policy analysis impact on the oil refinery development and energy security index will be conducted. The electric vehicle will shift the overall energy consumption in the transportation sector from fuel consumption into electricity consumption. The utilization of electric vehicles will reduce fuel oil consumption. On the other hand, the electric vehicle introduction policy's impact on the power generation will also be conducted after the analysis in refinery development is finished. An electric vehicle may increase electricity consumption from the transportation sector.

Finally, Chapter 6 presents the study's overall conclusion by giving a summary of all results in the study. The contribution of this research work has been added from an academic point of view. Then, policy implications and recommendations will be developed to help decision-makers' work more comfortable with quantitative evidence facts. This study was closed with the limitations experienced during the studies and suggestions on future research work to contribute to this field of study.

Chapter 2. Literature Review

2.1 Oil Refinery Development

2.1.1 Oil Refinery Technology

An oil refinery is a sophisticated industrial plant that process crude oil and other required feedstock to be processed petroleum product or fuel oil(Gary et al., 1984; Kaiser, 2017). An oil refinery's basic principle is to separate and improve the hydrocarbon compounds in the crude oil into a saleable petroleum product within a specific regulatory requirement. The processes contain three main steps, which are the separation, conversion, and treatment process. Each process will need to satisfy several parameters, including temperature, pressure, and necessary catalyst to do the process. The separation process by sing distillation unit is a basic process where all of the modern refineries have. However, several of them don't equip with conversion and finishing process equipment. Different technology in the refinery will decide the refinery's complexity and cost (Rana et al., 2013).

Crude oil as an input in oil refinery has multiple hydrocarbon compounds and molecules. Firstly, the oil refinery will separate each molecule based on the weight characteristic by boiling it in the distillation tower. A longer carbon chain means higher temperatures are needed to boil it. The distillation unit will cut the hydrocarbon compound into fractions based on their similar boiling point, blend it with a physical or chemical process, improve and change the molecules properties into a specifically required fuel (Speight, 1998). The conversion process in a modern oil refinery is converting heavy, lower value distillation fraction into lighter high-value products such as gasoline by using cracking (breaking), alkylation, or reforming method. Thermal cracking is a process to increase gasoline production by decomposing the hydrocarbon molecules into lower molecular weight products (Speight, 2003). Thermal cracking can use a catalyst (catalytic cracking) or hydrogen (hydrogen cracking). The treatment process is the process where petroleum products get a final treatment such as hydrodesulfurization, hydro-treating, chemical sweetening, acid gas removal, and de-asphalting process.

Refinery products can be classified by form with solid form contains coke or asphalt; liquids contain gasoline, kerosene, and diesel and gases such as methane, ethane, or propane. The other products are non-fuel products (lubricant, solvent, and waxes) and petrochemicals feedstock (ethylene, propylene, and benzene). A barrel of crude oil or 42 gallons can be processed into 19 gallons of gasoline, 11 gallons of distillate fuel oil, 4 gallons of jet fuel, 1 gallon of residual fuel oil, 2 gallons of hydrocarbon gases, and 6 gallons of other petroleum liquid products (EIA, 2018).

This study also conducts a literature review on the supporting related study about the refinery optimization model. Previous studies use linear programming models, both MILP and MINLP, for their methodology, depending on their parameter, variable, and model objective functions. The other methodology used is the LEAP model based on the accounting model, input-output model, and robust optimization. The usage of linear programming in oil refinery development has started in (Adams, 1972). The study is conducted to see the relationship between linear programming and the forecasting model in the US refinery. This study used econometric techniques to develop petroleum product demand, prices, and technical adjustment. Then, linear programming was used to generate refinery production, cost minimization, crude oil input determination, required capacity, and refinery product. This paper also indicates that the increasing price of crude oil will directly affect the price of refinery products.

It continues with (Sahidis, 1989) who investigated the multiperiod of mixed-integer linear programming in the process design and refinery capacity and proposed several approaches to handle the refinery model complexity. They improve the model with new formula through linear programming relaxation(M.-L. Liu & Sahinidis, 1996). (Grossman, 1996) developed a model using MILP to find a solution to operation and capacity expansion problems with the shortest path algorithm. (Lee et al., 1996) put a focus on the short term scheduling of crude oil supply in a single refinery. MILP was used to find optimal oil supply scheduling, including tankers, piers, storage tanks, substations, and refineries(Más & Pinto, 2003).

(Pinto et al., 2000) focused the production scheduling of oil refinery for crude oil, fuel oil, asphalt, and LPG. (Ponnambalam et al., 1992) analyzed the simplex method of linear programming to solve the multiperiod planning model of an oil refinery. (Elkarnel, 2008) uses the Mixed Integer Non-Linear Programming (MINLP) model to generate the maximum profit of the oil refinery production process while the CO_2 emission is being reduced. This paper put attention to the environmental constraint, including climate change issue has to be considered in the refinery development. Oil refinery development shall find a way to optimize their production while minimizing greenhouse gas emissions.

MINLP has been proposed to see how the production planning in a refinery process can generate maximum profit while getting a CO_2 emission at the same time. The technique that has been proposed is flow rate balancing, fuel switching, and the construction of carbon capture storage. The model will be developed to see which technique is suitable for the optimization objective. (Moro et al., 1998) has introduced a nonlinear planning model for diesel production in Brazil's refinery. The result of algorithm optimization shows that the new point of refinery operation will increase valuable oil production and create more profitability. (Pinto et al., 2000) has generated the nonlinearity in the optimization of oil refinery production by putting non-linear blending equations and physical properties for the petroleum products. They added uncertainty of product demand and prices to consider the model with discrete scenarios and probabilities. The nonlinear programming approach is also conducted in a production planning of a single refinery extension. The objective is to optimize the refinery expansion production, which is connected to multiple refineries through pipelines(Neiro & Pinto, 2003). It continues with a nonlinear programming method (MINLP) in developing a production plan in a single period with a different type of crude oil, successfully implemented in the Petrobras Refinery (Neiro & Pinto, 2005). (Guerra & Le Roux, 2011) also utilized a non-linear empirical model to optimize the refinery planning process, especially in the operation of crude distillation unit and fluid catalytic cracking to create economic benefit for an oil refinery.

However, other findings (Menezes et al., 2015) utilized MILP and input-output models to generate capital investment planning analysis in oil refinery development. This paper found that MILP can handle such complicated investment models with good accuracy better than MINLP. They divide the refinery investment process into three types, which are revamping, retrofitting, and repairing. (Göthe-Lundgren et al., 2002) explained how MILP could generate a refinery production planning that produces bitumen and naphthenic special oil in Sweden. Several optimization models were used in oil refinery development. The robust optimization method has been proposed to deal with the uncertainty of the refinery product price, yield, and demand in refinery planning(Leiras et al., 2010). (X. Liu et al., 2013) developed bottom-up optimization and input-output model to analyze the energy-savings potential for refining and conversion processes in the context of technological change in China's petroleum refining industry. Optimization with the mathematical model was developed to minimize the transportation cost of refinery products, including the optimization in the refinery, railway, ship, and pipelines through multi-product and multi depot system(MirHassani, 2008). Optimization by using a hybrid SD-LEAP model was used to assess the potential of CO_2 emission reduction in the Korean petroleum refining industry through the introducing new refinery technology.

Some tools have been used to generate the optimization of an oil refinery with mathematical programming by using PIMS (Bechtel, 1993), RPMS (Moore, 1979), and OMEGA (DeWitt et al., 1989). Refinery configuration is defined by the refinery product the requirement and the connection among its equipment and unit. A planning model shall allow the proper blending option and intermediary stream to find the required quantities and qualities of the final product with cost minimization and maximum profit(Moro, 2000).

2.1.2 Indonesia Fuel Oil Consumption

Fuel demand in a high growth economy has increased rapidly, and it takes the provider of fuel and refinery owners to find on optimizing their refinery capabilities(Walls, 2010). Recently, Southeast Asia shows positive economic growth performances and dramatically increased in energy consumption by 60% over the past 15 years. Ten member countries of ASEAN now collectively are the world's seventh-largest economy and fifth largest destination for foreign investment in 2016. With a total population of almost 10% of the world population, this region will require a lot of energy to support its economic development. Fuel oil availability is important in this region to support several productive sectors such as the industrial and commercial sectors as well as the transportation and residential sectors. Energy demand in this region has increased by 80% since 2000, with a significant portion of the shares is coming from the consumption of fossil fuels, including fuel oil consumption. As the biggest country in this region, Indonesia shows the highest fuel consumption by 1.65 Mbopd or 35% of total oil consumption (4.7 Mbopd).

Indonesia was known as an oil producer in the 1990s that make this country a part of OPEC Member. However, oil production is now decreasing, and fuel oil consumption surpassed it in 2002. This condition has forced this country to fulfill its demand with oil import activity for crude oil and fuel oil products. Moreover, Indonesia has experienced a stable, progressive economic growth for a decade at an average of 5%, which means that it may be followed by higher fuel oil consumption in the future.

Historically, Indonesia's economic development has been affected a lot by its oil resources in the past decades. The oil crisis in the 1970s was a blessing in disguise by creating a massive amount of revenue for the government. The oil and gas sector is one of the Indonesia’s crucial sectors because it is related directly to people's basic needs. The development of the oil and gas sector needs a government role to guarantee that this sector is well developed and provides sufficient facilities to support economic activities. The national oil and gas development sector’s objective is to ensure national sustainable development with increasing state revenue, supply domestic fuel requirement, create industry feedstock development, and stimulate a multiplier effect on economic activity. The oil and gas sector shall get appropriate attention from the government because it is involved in high technology applications, high capital, and high risk.

The government owns oil and gas resources and the utilization of its resources shall be used to create prosperity and wealth for the Indonesian people. According to Indonesia Law No 22 the Year 2001 regarding Oil and Gas, Oil and Gas business shall be based on the people's needs, integration, benefit, shared prosperity and welfare, safety, and environment friendly. Business regulation in the oil and gas sector divides into four categories with different objectives in each category. The first category is upstream business regulation, with the objective is to provide efficient and liable oil and gas management. The second category is downstream business regulation to assure the oil and gas supply in an efficient and adequate amount. The third category is supporting business regulation to develop competent oil and gas supporting businesses. The last category is oil and gas industry technology regulation, with the objective is reliable, safe, and environmentally friendly oil and gas installation.

This regulation also demonstrates the fuel policy in Indonesia, including the security of fuel supply, fuel classification, pricing policy, fuel diversification, fuel specification, and fuel conservation. Fuel supply is vital in the energy sector to be guaranteed by the government no matter how much the cost will be spent. The government shall guarantee that every citizen can get equal access to the fuel supply.

By National Energy Policy (Government Regulation No 79 the Year 2014), the Indonesian government shall initiate several programs to accelerate oil and gas infrastructure provision, including refinery, transportation, and distribution facility to ensure fuel supply security. The program shall consider the geographical conditions, including remote areas and scattered islands. Indonesia crude oil and petroleum product distribution Indonesia starts with the allocation of Indonesia crude oil production. According to the production sharing contract, the government and oil contractor will get their oil production shares in the 70:30 portion.

For example, if Indonesia crude oil production generate 1,000 kbopd, then 700 kbopd will be allocated to government entitlement and PT Pertamina as a state-owned company. The other 300 kbopd will be allocated to the oil contractor. Pertamina will place 200 kbopd in export, exchange, and repayment activity and let the 500 kbopd for the crude oil domestic refinery input. Oil contractors will export 200 kbopd of their crude oil product and let 100 kbopd exchange crude for domestic refinery input. Unfortunately, 600 kbopd crude oil for refinery input is insufficient to generate petroleum products in domestic refinery and requires importing big amounts of crude oil from overseas sources with 400 kbopd.

It can be concluded that the recent percentage of domestic crude oil contribution to Indonesia's domestic refinery is only approximately 60% of its requirement. The rest will be fulfilled from imported crude oil and some import High Octane Mogas Component (HOMC) and natural gas. Indonesia domestic refinery produces fuel or petroleum products: Avtur+JP5, Avgas, RON 88, RON 92, RON 95, Fuel Oil, IDO ADO, Kerosene, and LPG(Pusdatin, 2018). The other issue that was also regulated is the fuel subsidy, which consists of government expenditure for low-income people in buying fuel such as gasoline and diesel fuel. This policy was arranged to support equal rights for people in getting the fuel, as stated in Indonesia Basic Law. Gasoline and diesel fuels that get a subsidy are RON 88 Fuel, ADO (Automotive Diesel Oil), and IDO (Industry Diesel Oil). Based on government expenditure data from 2007-2017(Keuangan, 2017), Indonesia's fuel subsidies may vary from 3-23 Billion USD per year.

The highest fuel subsidy occurred in 2013 where the global oil price increased by 23.1 Billion USD. The government decided to reduce the fuel subsidy cost when the current government starts a new period, and the global oil price decreased. From 2015-2017, Indonesia's fuel subsidy has been decreased to 3.2-5.5 Billion USD or deducted

75% from the previous period. The decision to reduce fuel subsidy is because the previous subsidy is not on proper target and some people who have a good income also enjoy this subsidy. The government feels that the massive amount of fuel subsidy puts a burden on the government budget. It will be better if it can be transferred to more useful infrastructure development. The graph of Indonesia's fuel subsidy in 2007-2017 will be described in Figure 8.

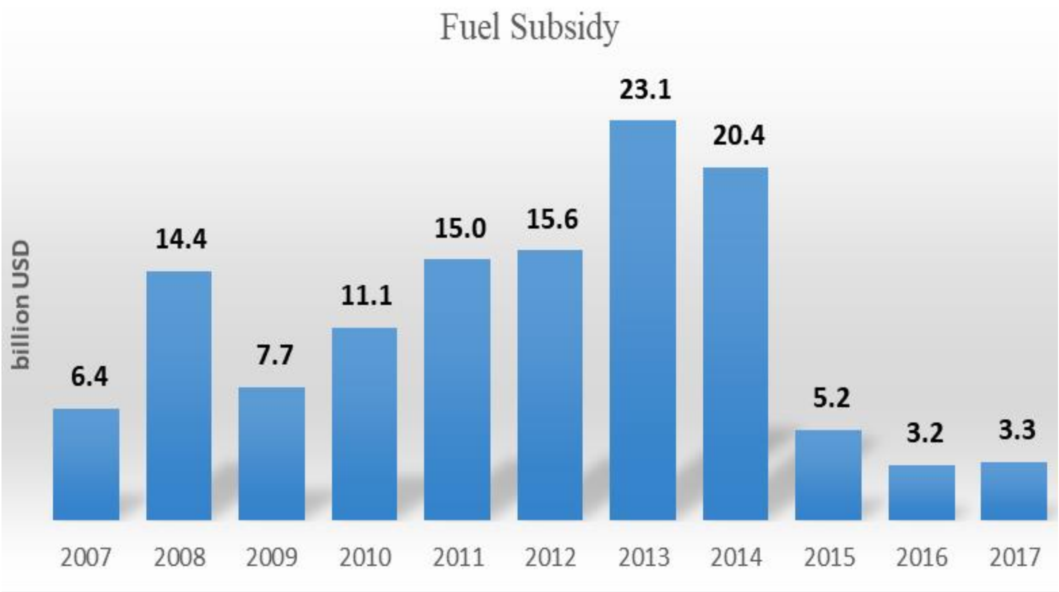


Figure 8. Indonesia Fuel Oil Subsidy in 2007-2017

Source: (Keuangan, 2017)

The current government also initiate a new policy in MEMR Regulation No 39 the Year 2016 regarding the “One Price” fuel policy for Fuel in Indonesia. With the length of 5,150 km and 17,504 islands, Indonesia’s distribution of fuel was categorized as one of the most complicated ones. This condition creates various transportation costs of fuel distribution if we transport fuel through land transportation, ship transportation, or plane transportation. In many cases, the price of fuel in the eastern part of Indonesia, in which the infrastructure is not developed well, boosted to two or three times higher than the price in the western part of Indonesia. With one price fuel policy, the government thinks that all of the people in Indonesia can access the same quality of fuel at the same affordable price. This policy works well and gets a positive reaction from the eastern side people. Still, it is also bringing a consequence with the new projected additional distribution cost of about 0.2 Billion USD until 2019(Antara, 2018).

Indonesia's domestic crude oil availability will be decreased and only cover less than 50% of domestic refinery capacity because it has projected to be declined by 27% in 2020. However, Indonesia’s demand for petroleum products grows significantly with gasoline demand projected to grow 8% per year until 2020, and diesel demand will grow 5% per year until 2025. High demand for petroleum products has occurred because the increasing number of vehicles in Indonesia shows positive trends with an average growth of 12% in the last ten years. The number of vehicle in Indonesia in 2016 is 129 Million which consist of 14. 5 Million Cars, 2.4 Million Buses, 7 Million Trucks, and 105 Million Motorcycles. Due to the limited capability of a domestic refinery, the domestic production of petroleum products can’t fulfill the growing demand, and let overseas sources will supply approximately 40% of the consumption. This condition indicates Indonesia will have a high dependence on crude oil import and petroleum/refinery product import.

2.1.3 Indonesia Oil Refinery Development

The fuel business implementation in Indonesia comprises several sections: exploitation, refining, transportation, storage, trading, and usage section. An oil refinery in the refining process is an industrial process plant where crude oil is transformed and refined into a more useful product such as naphtha, gasoline, diesel fuel, kerosene, fuel oil, and other petroleum products(Gary et al., 1984). The demand for petroleum products in Indonesia has been increasing at a stable rate. The future demand will be influenced by economic growth, government petroleum product subsidy, and substitution with an alternative product such as gas or biofuel. Dreadfully, domestic refinery production can’t fully supply domestic consumption, and the government has to import fuel or petroleum products from overseas refineries.

The total national refinery capacity in 2017 is 1,169 Thousand Barrels of crude oil per day (kbopd) (Pusdatin, 2018)**,** with 1,051 kbopd or 89% of total capacity is owned by the state-owned company, PT. Pertamina (Persero) and 118 kbopd are owned by private companies. Pertamina has developed domestic refinery unit in several places all over the country including Refinery Unit (RU) II Dumai (330 kbopd), RU III Plaju (127 kbopd) in Sumatera Island, RU IV Cilacap (348 kbopd), RU VI Balongan (548 kbopd) and Cepu (3.8 kbopd) in Java Island, RU V Balikpapan (260 kbopd) in Kalimantan Island and RU VII Kasim (10 kbopd) in Papua Island. Indonesia's Government plan to establish a new refinery in RMDP Cilacap (370 kbopd), RMDP Balikpapan (360 kbopd), GRR Tuban (300 kbopd), GRR Bontang (300 kbopd), and PT IKP (6 kbopd) (Figure 9).

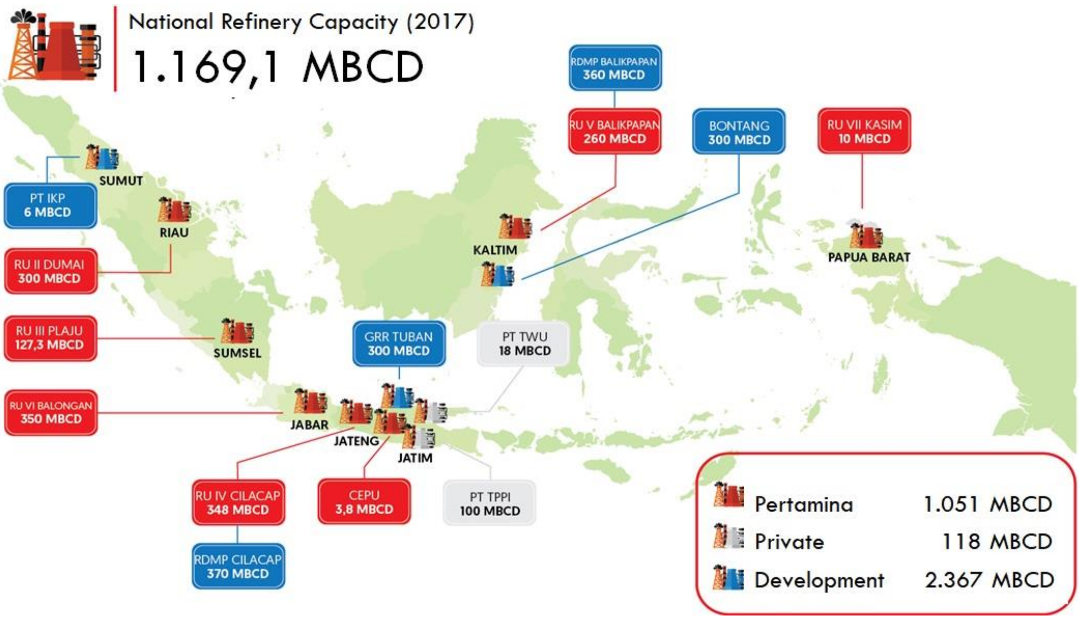


Figure 9. Indonesia Refinery Capacity in 2017

Source: (Pusdatin, 2018)

To increase the capacity of domestic refinery, the government introduce some programs, which are Refinery Development Master Plan (RDMP) and Grass Root Refinery (GRR)(Yulianto, 2014). RMDP is the government program that will be conducted by PT Pertamina to increase the capacity and upgrade the facility of five major existing refineries including RU II Dumai, RU III Plaju, RU VI Balongan, RU IV Cilacap, and RU V Balikpapan. This program's objective is to increase crude flexibility in sulfur handling from 0.4% to 2%, increase the complexity of the process, increase product quality, and increase refinery capacity two times. This program is expected to finish in 2021 with a 4-years construction period and 865 kbopd additional refinery capacity.

On the other hand, GRR or Grass Root Refinery is the construction of a new refinery facility in Tuban and Bontang with the target is the improvement of crude flexibility, crude complexity, product quality, and 380 kbopd additional refinery capacity in 2025. With these programs, the government believes that the domestic refinery product can be improved and fuel import dependence can be decreased.

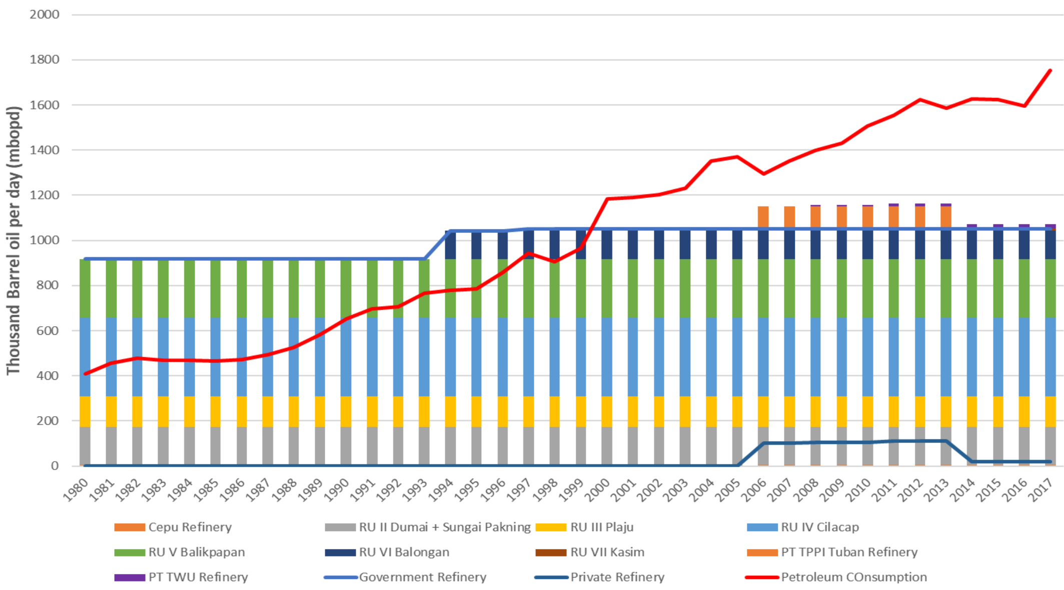


Figure 10. Refinery Capacity and Petroleum Consumption, 1980-2017

Source: (Pusdatin, 2018)

Oil refinery capacity in Indonesia is enough to fulfill the fuel oil consumption from 1980 to 2000. However, the rapid increase in fuel consumption has started to exceed domestic refinery production in 2001. Without any significant development of new oil refinery, total fuel oil consumption in 2017 is almost two times bigger than the oil refinery capacity.

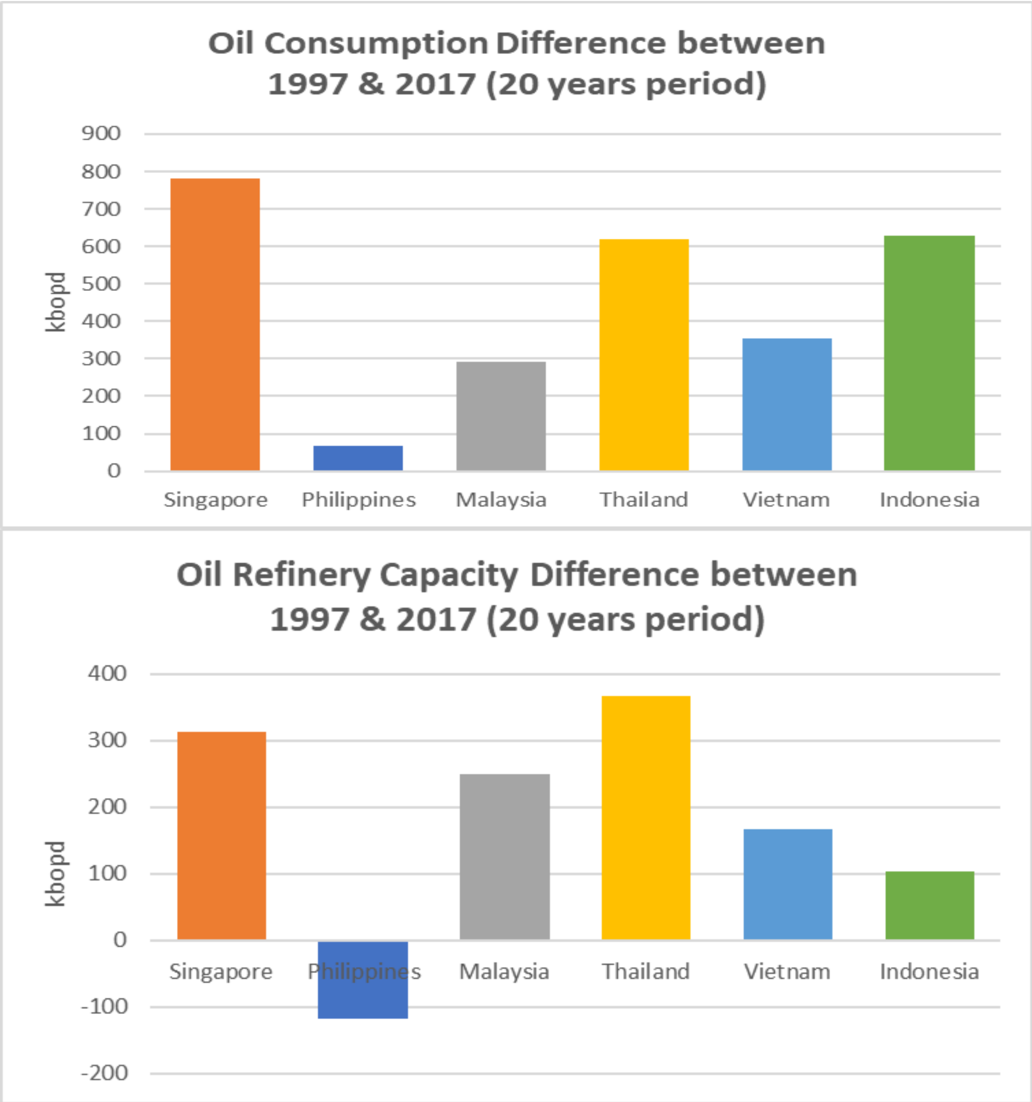


Figure 11. Oil Consumption and Oil Refinery Capacity in ASEAN Country

Source: (Petroleum, 2018)

The other facts indicate that Indonesia has the second-highest growth of fuel oil consumption among ASEAN countries after Singapore from 1997-2017. On the contrary, Indonesia was the second-lowest oil refinery development in ASEAN after The

Philippines due to the low difference in oil refinery capacity during this period. This condition shows that this country did not implement a good plan in the fuel oil provision for its people despite making a lot of revenue through crude oil export activity.

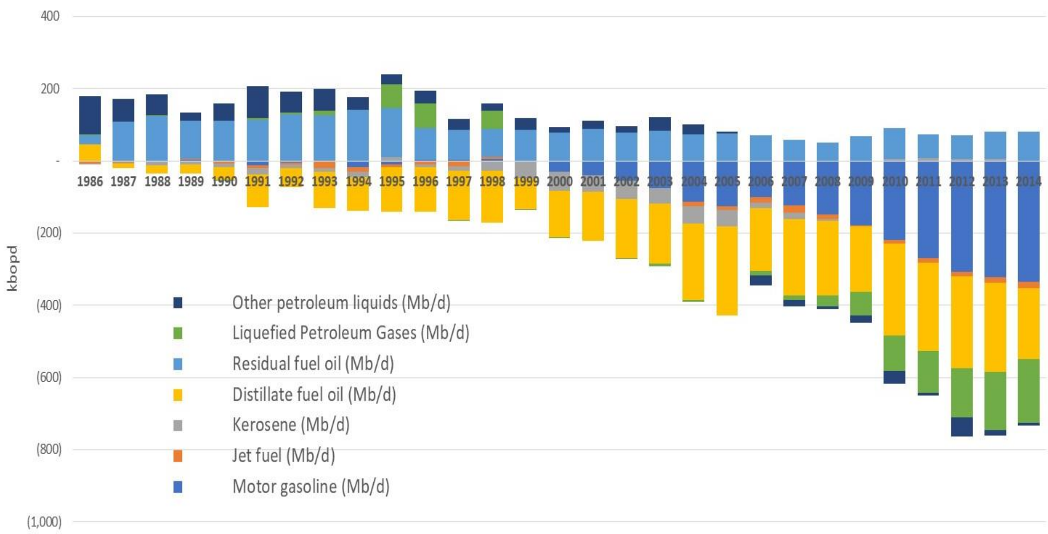


Figure 12. The Difference in Fuel Consumption & Refinery Production, 1980-2017

Source: (Pusdatin, 2018)

The historical data from 1980 to 2017 demonstrate that Indonesia has a surplus of residual fuel oil and other petroleum liquids products. The significant differences between refinery production and fuel consumption have been shown in the distillate fuel oil, motor gasoline, and liquefied petroleum gases product. These three products shall be prioritized to be produced by the additional domestic refinery to reduce fuel oil imports. Especially for the motor gasoline and distillate fuel oil or diesel, they couldn’t be produced in the other transformation technology besides oil refinery while the LPG can be produced with the LPG refinery.

There are several reasons why Indonesia require to build long-term solution for the petroleum product supply and increase domestic refinery capacity, which are:

1. Indonesia population still growing at a fast rate, and the number of consuming class will also increase and have a significant impact on fuel consumption in the future;
2. Indonesia's domestic refinery capability shows low coverage and performance compared to the neighboring refineries. It may seem to possess fuel supply shortage problems in the future if there is no improvement.
3. Import dependence will bring problems if the fluctuation of global energy prices still occurred in the future.

To ensure the fuel supply security in Indonesia, the government may conduct several efforts, including optimizing domestic refineries, revamping existing refineries, new refinery development, and encouraging alternative fuel products such as biofuel. Developing a new refinery could bring new challenges for Indonesia and the stakeholders cooperation is substantially required. The stakeholders will consist of the Ministry of Energy and Mineral Resources as the regulatory bod, PT Pertamina as a state-owned company that gets authority from the government to conduct oil and gas business, and other overseas private sectors which has technology and capability to develop oil refineries.

2.2 Power Generation Development in Indonesia

The electricity sector is one of Indonesia's crucial sectors because it is related directly to people's basic needs. The development of power generation will increase electricity provision for the people. It needs a government role to guarantee that this sector is well developed and provides sufficient facilities to support economic activities. The power generation development sector's objective is to ensure the availability of electricity in adequate quantity, good quality, and affordable prices to increase the welfare of the people and create sustainable development. According to Indonesia Law No 30 the Year 2009 regarding Electricity, the provision of electricity infrastructure, including power generation in Indonesia, is controlled by the central government and local government. The central and local government has a right to establish policies, regulation, supervision, and implementation of electricity infrastructure development. Electricity access is crucial in the energy sector, so that it should be fulfilled by the government no matter how much the cost will be spent. The government shall guarantee that every citizen can get equal access to electricity.

The implementation of electricity infrastructure development, including power generation, in Indonesia is conducted by State-Owned Utility (PLN) and any other local government-owned company as the priority. However, less priority right is also allowed for the private company or any non-government organization to develop Indonesia's electricity. A private company can participate in power generation through the Independent Power Producer scheme. For the regions that don't have any electricity access, the central government or local government may offer an opportunity for business entities such as government state-owned companies or private companies to be electricity business administrator.

Indonesia's electricity sector has shown progressive growth, with average electricity consumption growth was 7.8%. The electrification ratio also increased from 88% in 2010 to 98.89% in 2019. The government set a target to doubled electricity consumption in 2025. Based on the Ministry of Energy and Mineral Resources (MEMR) data, National Installed Capacity in Indonesia reached 60.79 GW in 2017. It contains 41.72 GW supplied by PT PLN (Persero) as a State-Owned utility company in Indonesia, 14.24 GW supplied by Independent Power Producer (IPP), 2.43 GW supplied by Private Power Utility (PPU), and 2.39 GW supplied by Captive Power. However, despite the intensive acceleration program that has been supported by the government, the development of power generation in Indonesia just indicates a 4.4% average annual growth in 2013-2017. In Indonesia, power generation infrastructure is not spread evenly throughout the country with most of the powerplant (64%) built in Java and Bali Island. 76% of the powerplant is owned by the national utility (PLN), and the rest is a private company that runs it in the IPP business model. The national utility also single-handedly operate and own the power transmission and distribution infrastructure.

The capacity mix by the type of power generation shows 50% is generated by Coal power plant (30.2 GW), 28% by Gas power plant (16.9 GW), 12% by New and Renewable Energy power plant (7.4 GW), and 10% by Diesel power plant (6.3 GW).

Moreover, the total length of transmission lines in Indonesia is 49,225 kmc which contains 5,074 kmc of 500 kV T/L, 3,098 kmc of 275 kV T/L, 35,802 kmc of 150 kV T/L, and 5,035 kmc of 70 kV T/L.

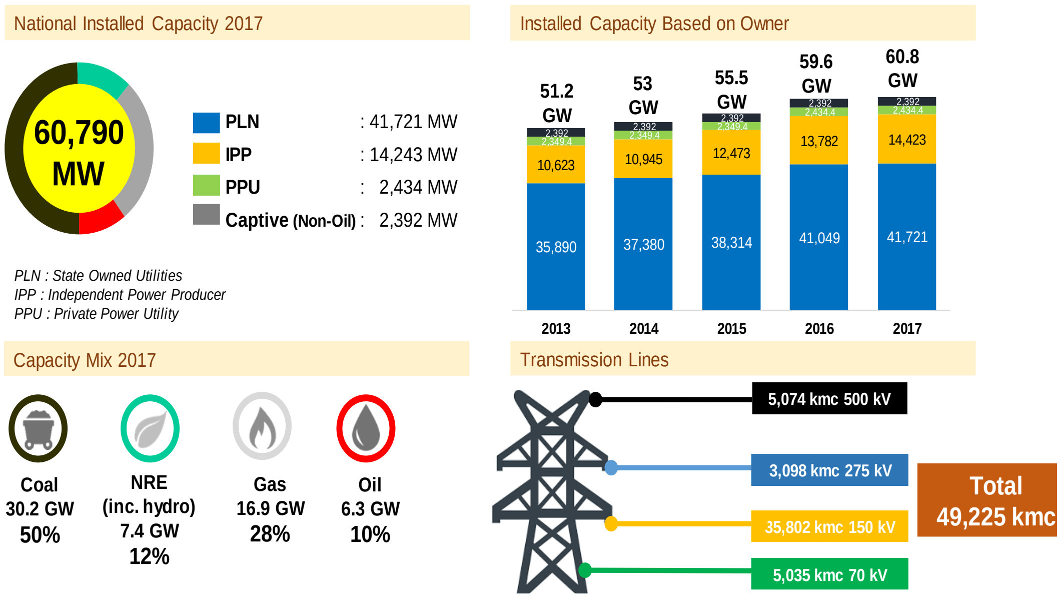


Figure 13. Indonesia Electricity Infrastructure in 2017

Source: (Ketenagalistrikan, 2018)

Indonesia, located in the equator and consists of 17.504 islands, has an abundant energy source, both fossil and renewable energy. With the length of a span from west to east is 5,150 km and a total area of 1.9 million km^2, the energy potential has been widely spread in every province. Indonesia has 156,619 MT of coal, 7,305 MMSTB of oil, and 151,331 BCF of natural gas as fossil energy potential. On the other hand, Indonesia's renewable energy potential contains 29.5 GW of geothermal, 113.5 GW of wind power, 32.5 GW of bioenergy, 75 GW of hydropower, and 532 GWp of solar power. However, despite its abundant energy resources, the utilization of renewable energy in Indonesia indicates low percentages. In 2017, the utilization of Hydropower was 5.4 GW or only 7.2% of its potential, solar power is 17 MWp or 0.003% of its potential, geothermal is 1.8 GW or 6.1% of its potential, wind power is 1.12 MW or 0.001% of its potential, and bioenergy is 91 MW or 0.27% of its potential (Ketenagalistrikan, 2018).

These data determine the low progress of renewable energy development in Indonesia. It is difficult for the Indonesian government to utilize renewable energy resources if there is no supporting infrastructure to deliver energy to the load. Furthermore, renewable energy utilization could not be expected because of the low demand for energy near the energy source. Additionally, the geographical conditions with hilly mountains and scattered communities will also impact the effectiveness of power transmission and distribution. Java Bali and Nusa Tenggara Island have abundant energy sources such as natural gas, geothermal, solar power, wind power, and the highest electricity demand in 2017 is 174 TWh. Sumatera Island has abundant energy sources such as coal, gas, geothermal, and hydropower and the electricity demand in 2017 is 45 TWh. For Kalimantan Island, Sulawesi Island, Maluku Island, and Papua Island with low electricity demand, it can provide sufficient energy supply with abundant energy sources such as coal, natural gas, geothermal, hydropower, wind power, and solar power.

2.3 Optimization in Power Generation Sector

Several studies focused on the optimization of power generation development. These studies are mostly looking the possible way to generate affordable electricity costs that can satisfy some constraints such as environmental requirements, government targets, or specific energy mix. (Matsuo et al., 2018) explained the optimal possibility of the power generation mix in Japan towards 2050 with the utilization of imported hydrogen to reach the zero-emission target. It utilized the Optimal Power Generation Mix model. A high share of intermittent will increase the total system cost to 20-30 JPY/kWh. The utilization of nuclear power will help to reduce the cost of escalation. (Wiese et al., 2018) used the Balmorel model to generate a suitable energy system model with the additional cleaner energy. This model is open and widely used as optimization of energy policy analysis. This model's strong characteristics are the flexibility of time and space dimension and the combination of operation and investment approach. (Farnoosh et al., 2014) investigated current and future power generation situation in Saudi Arabia by using CPLEX solver in GAMS. There are several scenarios of alternative resources. The optimal generation in this country will save more oil for export.

(Kosugi, 2016) developed stochastic programming to generate a power-planning model that endogenizes the probability of nuclear-exit. The model minimizes the total cost in the power-generation sector stochastically. A major nuclear accident is assumed to trigger a complete nuclear exit. Considering the nuclear exit reduces the optimal nuclear dependency. (Wiebe & Lutz, 2016) introduced the renewable power generation module optimization, which complements large-scale macro-econometric input-output models by introducing technological change endogenously into the model. (Asiedu et al., 2019) analyzed eleven power plant technologies in fuel type, fuel cost, and carbon dioxide emissions by using linear programming. An economic analysis of each power plant was conducted. With the help of screening and load-duration curves, the optimum generation mix was determined. (Danthurebandara & Rajapaksha, 2019) used life cycle analysis (LCA) assessment to explain the environmental impacts of electricity generation in Sri Lanka. This work discusses the environmental merits and demerits of different power generation mixes. (Min & Chung, 2013) utilized optimization model by Monte Carlo simulation for long-term power generation mix. It shows the potential replacement of nuclear in the South Korean power system.

(Lap et al., 2020) has assessed the reliability under high penetration of variable renewable energy in Brazil's power system. Hydropower is a suitable balancing agent for solar and wind energy. Low biomass supply increases peak load due to the growing number of electric cars. Differences in temporal resolution result in additional costs of 3–12 billion US$/year. (Matsuo et al., 2018) developed a dynamic high time resolution optimal power generation mix model to analyze Japan's long term energy planning. The result shows nuclear phase-out and carbon regulation will quadruple power generation costs in 2050. Higher PV shares present challenges to make LNG a combined cycle powerplant as a profitable ramp generator. Power saving is an economical option to treat an imbalance caused by PV output. (Karlsson & Meibom, 2008) investigated a possible long-term investment path for the Nordic energy system by using the Balmorel model. It has focused on renewable energy in the supply sector. Hydrogen will be the main fuel for transportation, covering up to 70% of all transport in 2050. (Handayani et al., 2017) has developed optimization for the Java Bali Island power system with the constraint of electrification and climate change mitigation. The reduction of CO_2 emission will be reached through several efforts in the energy mix, especially by shifting coal to natural gas and increasing the renewable energy share.

2.4 National Energy Policy in Indonesia

Indonesia has issued the National Energy Policy into regulation as stated in Government Regulation No. 79/2014. This regulation defines how this country will manage its energy with the principle of fairness, sustainability, and environmental impact consideration. The goal of this policy is to create energy independence and energy security in the country. The period of this policy is 36 years, from 2014-2050. This policy has several objectives, which are as follows:

1. Energy resources shall not be utilized as an export commodity but as national development support.
2. Domestic energy sources shall be prioritized to fulfill the availability of energy supply
3. Energy management shall be optimal, integrated, and sustainable
4. Energy access shall be fair and equitable for everyone
5. Energy industry shall be independent and increase human resource quality

6. Energy industry shall create more jobs and preserve the environment.

The national energy policy has set an energy provision target with the primary energy supply has to reach 400 MTOE in 2025 and 1000 MTOE in 2050. It is in line with the target of primary energy use per capita with 1.4 TOE per capita in 2025 and 3.2 TOE per capita in 2050. For the power generation sector, it determines shall fulfill the capacity of 115 GW by 2025 and 430 GW by 2050. Hence, the electricity use per capita shall increase three times from 2500 kWh per capita by 2025 to 7000 kWh per capita in 2050.

Furthermore, the primary energy mix target has also been set to increase renewable energy share from 23% in 2025 to 31% in 2050. On the other hand, the share of oil shall be reduced from 25% in 2025 to 20% in 2050. The role of coal as a baseload power generation would be decreased from 30% in 2025 to 25% in 2050. Natural gas shall be increased from 22% in 2025 to 24% in 2050 to maintain the energy supply for the industry. The existence of nuclear power generation was not shown in this policy due to the decision to put nuclear energy as the last energy supply option after the other form of energy.

Energy security is a complex parameter that requires a multivariable evaluation. It is not only about the physical existence of energy but also related to the economic, technological, environmental, social, and geopolitical issues (Ridhanda, 2016). The assessment of each dimension can start evaluating energy security as a goal of energy policy in Indonesia. Commonly, there are four dimensions of energy security: availability, accessibility, acceptability, and affordability(APERC, 2007; Cherp & Jewell, 2014;

Hughes, 2007; Kruyt et al., 2009a). The other recognized dimension is the intensity that is looking for energy to produce economic value in GDP(Sovacool, 2011; Sovacool & Brown, 2010; Vivoda, 2010). The availability dimension focuses on how the country provides energy supply by the number of resources, both fossil energy and renewable energy(Hughes & Shupe, 2010). The highest energy commodity that is highly used in Indonesia is a petroleum product and electricity. The availability dimension goals have been stated in Law No. 30 the Year 2007, which are energy independence, secure energy supply from domestic source and import activity, the sustainability of energy resource management, reducing fossil fuel share, and promoting renewable energy share in the energy mix.

The accessibility dimension can be evaluated by the number of physical energy access and the ease of getting energy access. Several barriers can be obstacles to energy access such as political factors, economic factors, or technological factors. Even (Kruyt et al., 2009a) defines accessibility as a geopolitical element in energy security. The Indonesian government has to generate energy supply access equal and easy for the people without any difference in the economy or social class. One of the indicators to evaluate accessibility is access to electricity through the electrification ratio.

Affordability concentrates on how the price of energy can be affordable for the people and the cost of infrastructure development such as oil refinery or power generation. It would be evaluated on the cost of the energy services or commodities that can be utilized by the people at a specific time(Hughes & Shupe, 2010). The affordability dimension goals in energy law are to increase the ease of energy access for the underdeveloped communities and create an affordable price of energy by providing subsidies and incentives.

The acceptability dimension is related to how the provision of energy supply can manage the environment's impact, especially climate change issues and emission. Emission intensity and emission per energy consumption are the indicators to measure the acceptability dimension(Erahman et al., 2016; Prambudia & Nakano, 2012). The goal of the acceptability dimension in energy law is to support environmental conservation through sustainable development policy.

The efficiency dimension is evaluated by measuring energy intensity or how energy consumption can generate more capital gain (Martchamadol & Kumar, 2012). Similar energy consumption with more GDP growth or less energy consumption with similar GDP growth. The utilization of advanced technology, energy conservation, and fuel switching may increase the level of efficiency dimension. The efficiency dimension goals in energy law are to encourage efficient use in energy supply and reach an energy intensity level below one in 2025.

By the Issuance of Government Regulation No. 79/2014 regarding Energy Policy, Indonesia has guidance on the vision of future energy transition vision in the country for 2014-2050. However, this policy's implementation couldn't cope with its ambitious target, such as high renewable energy share and electricity consumption per capita. Energy policy in Indonesia will be influenced by many factors, including the energy prices, geographical existence of energy sources, resource scarcity, supporting energy infrastructure and the environmental concern related to climate change.

There are several issues in the energy policy-making process in Indonesia. Firstly, Indonesia's policymaking process has been influenced by the strong culture, long and inefficient process. It will address all of the stakeholder's interests while making it difficult to be implemented. Indonesia also has a problem with its policy analysis accuracy due to inadequate and inaccurate data and information (Hutagalung, 2014). The political factor also influences the decision-making analysis. For example, the ruling party which dominates the government may decide different approaches on solving energy problems, such as the implementing renewable energy incentives from feed-in tariff to the capping price from local generation cost after the election is over. The implementation of energy policy in Indonesia is low due energy policymakers' low ability and professionalism in analyzing the problem and implementing the solution. The government official tends to create a short-term solution rather than the long one.

(Mahar Diputra, 2018) has investigated the absence of comprehensive decision-making analysis in the planning of the energy sector in Indonesia due to the government's inability to provide a sufficient and sustainable energy supply in the past decades. On the other hand, the energy demand side has an increasing trend due to stable and progressive economic growth, growing population, and middle-income class. Despite high-energy potential, both fossil and renewable energy, Indonesia is still facing a shortage of electricity and high fuel import dependency. The preference of priority in energy policymaking process is crucial in developing comprehensive and sustainable policy. This study has analyzed the criteria and sub-criteria, which are important to Indonesia's energy planning and policy assessment. The result shows that energy resources are the most important criteria, followed by pollutant and emission, resource durability, resource availability, the volatility of energy prices, noise, and distance to the user. Another study conducted by (Zussida, 2019) also used Analysis Hierarchy Process (AHP) to investigate the most important criteria and sub-criteria on selecting renewable energy development for rural electrification in Indonesia. The results indicate that the most important criteria are the energy source and technologies, followed by the environmental, socio-political, technical, and economic criteria.

Moreover, the availability of energy sources is the most important sub-criteria, and profitability is the least priority in the global ranking. Among all the potential of renewable energy sources in Indonesia, the experts also pointed out that the most suitable renewable energy alternatives are micro-hydro. Then, followed by biomass, solar power, geothermal, and wind power.

Furthermore, one parameter that also needs to be considered in Indonesia's energy policymaking process is the impact of energy policy on energy affordability. (Widiyanto, 2016) indicates that Indonesia's energy subsidy for the fuel and electricity will bring a lower cost of energy for the people. Simultaneously, it may bring excessive energy consumption, wrongly targeted subsidy, and burden to the government budget. The energy subsidy removal might generate an impact on economic growth and people's welfare. The objective is to analyze the possible effect of energy subsidy removal on fuel subsidy and electricity subsidy by using input-output analysis. The results show that energy subsidy removal will impact the oil refinery, electricity, and transportation sector. Energy subsidy removal will reduce energy consumption and total emission in the energy sector by 1.2% and 1%, respectively, in 2009. It also decreases the GDP by 0.53% and employment reduction by 0.84 Million labors. Energy subsidy removal will also affect real income and purchasing power especially for middle-income urban areas.

The reformation, deregulation, and introduction of the energy sector's market mechanism can be proposed to achieve the least cost of energy provision. (Nababan, 2013) indicates the evaluation of Indonesia's natural gas regulatory framework by comparison with the other country's experiences. The focus is on the process of regulation, deregulation, and liberalization in the natural gas industry and pricing. The government faces a dilemma on choosing the priority of natural gas allocation on export activity to other countries or selling it to the domestic market to generate the multiplier economic effects. The government's concern is to establish an efficient domestic market with a lower price but still profitable for each stakeholder. The option of liberalization might not be feasible in the recent natural gas market, while deregulation might be a better option to increase the efficiency of the market and protecting the local industries. Two important factors for the domestic gas market is the security of the supply and low prices. Natural gas shall be affordable to increase the competitiveness of local industries' products with international standardized products.

Furthermore, (Yunita, 2018) has developed scenario analysis to minimize the power generation cost and reduce carbon emissions in the Maluku region (eastern part of Indonesia). The goal of power generation development is to get the least cost with a better environmentally friendly approach. The substitution of oil-oriented to gas-oriented power generation is highly recommended due to the reduction of generation cost and emission. However, the eastern part of Indonesia lacks gas-supporting infrastructure so that this transition will not be easy to implement. (Meilandari, 2020) also analyzed the optimization of electricity planning in the biggest power system in Java Island and found that the high penetration of renewable energy will increase investment and production cost while reducing CO_2 emission. An energy efficiency program by replacing lighting technology could be an option to reduce total investment cost in the power system.

A comprehensive energy policy that focuses on getting a least cost in the appropriate energy mix while promoting more sustainable energy development is important to help Indonesia manage its energy security in increasing energy consumption trends (Ridhanda, 2016). Energy security became an important parameter to measure energy management in Indonesia. The Ministry of Energy and Mineral Resources has put energy security as a priority issue in providing a sufficient energy supply to domestic energy demand. Two main parts of energy security in Indonesia are the self-sufficiency and the diversification of energy mix. Self Sufficiency is the way for one country to generate the energy supply from its domestic production, including the provision of fuel oil from the oil refinery. The diversification of the energy mix will be focused on how more sustainable energy sources such as renewable energy can be penetrated to the energy mix, especially in the development of power generation sector. The reduction of energy subsidy in the fuel and electricity is also needed to be considered by the government to increase the energy's affordability issue.

On the other hand, environmental concern in the energy sector is focused on CO_2 emission. The high share of coal in the power generation mix will have a massive contribution to Indonesia's high CO_2 emission. The diversification of energy mix towards high renewable energy penetration will help to reduce the dependency of coal. Indonesia is also facing a high import of oil, both crude oil and fuel oil, due to declined oil production and progressive domestic oil consumption. Indonesia needs to reduce its reliance on oil and observe solutions from the supply or demand side, whether the diversification of energy sources or lowering oil consumption. The objective of oil import reduction and the diversification of energy sources policy can be decided by a comprehensive analysis in oil refinery and power generation development.

2.5 System Dynamic Model in the Energy Sector

System dynamics is an approach to understanding a complex system's dynamic behavior using several functions, including stocks, flows, and time delays. It is commonly used in the development of government policy analysis. The basis of the method is the development of the system structure. There will be a relationship of each parameter in a circular, interlocking, or time-delayed connection. Each parameter will have different behavior and may develop a causal loop diagram among them. A causal loop diagram is a simple form of a system with all components that develop them and their interactions. The reference key papers for selecting the system dynamic model in this Thesis are described as follows:

Table 1. Key Paper for the System Dynamic Model in Energy Sector

No	System Dynamic Model in the Energy Sector	Source
1	System Dynamic Model for Oil and Gas Production and Consumption sector in Iran	(Kiani & Pourfakhraei, 2010)
2	System Dynamic Model for Oil development under different oil prices scenario	(Hosseini & Shakouri, 2016)
3	A system dynamic analysis of China's oil supply chain: Over-capacity and energy security issue	(Pan et al., 2017)
4	System Dynamic Model in the UK Natural Gas Industry	(Chi et al., 2009)
5	System Dynamic of Energy Consumption and Policies in Iran Iron and Steel Industry	(Ansari & Seifi, 2012)
6	Simulation of demand growth scenarios in the Colombian electricity market: An integration of system dynamics and dynamic systems	(Morcillo et al., 2018)
7	A decision support system for evaluating effects of Feed-in Tariff mechanism: Dynamic modeling of Malaysia's electricity generation mix	(Shahmohammadi et al., 2015)
8	Understanding the dynamics of electricity generation capacity in Canada: A system dynamics approach	(Qudrat-Ullah, 2013)

There are two kinds of causal loop diagrams that are positive reinforcement loop and negative feedback loop. The positive reinforcement loop shows the parameter will have positive feedback and grow more significant over time. The negative feedback loop will show the opposite result when the parameter will decrease over time. Causal loop diagrams aid in visualizing a system's structure and behavior and analyzing the system qualitatively. It will transform into a stock and flow diagram to perform a more detailed quantitative analysis. A stock and flow model helps in studying and analyzing the system quantitatively. A stock is a term for any entity that accumulates or depletes over time. Flow is the rate of change in a stock.

The energy sector's system dynamic model has started when (Naill, 1972) did it in US natural gas lifecycle analysis. It continues with the US petroleum lifecycle system dynamics in oil exploration, recovery, technology, and demand(Davidsen et al., 1990). The other researcher then tries to do a system dynamic model of the oil and natural gas market in New Zealand (Bodger & May 1992). (Chowdhury & Sahu, 1992) developed the oil and gas industry long-term dynamic behavior in India and the required policy to mitigate the oil crisis. A similar approach was generated to find long-term policy analysis and system behavior in in the UK natural gas industry (Chi et al., 2009). This research found that the supporting policy couldn't be assessed only on the supply-side.

The objective of the system dynamics model in the energy sector can be varied in several motives, especially in the development of capacity expansion, improvement of the performance, and policy analysis(Ansari & Seifi, 2012; Guo & Guo, 2015; Hosseini & Shakouri, 2016; Jeon et al., 2015; Jiao et al., 2014; Ochoa & Van Ackere, 2009; Shih & Tseng, 2014). (Guo & Guo, 2015) developed the model of China's Photovoltaic development by using system dynamics in technical and economic considerations.

(Hosseini & Shakouri, 2016) investigated the system dynamic model to generate oil development in several scenario analysis of oil price. (Qudrat-Ullah, 2013) introduced the system dynamic model of electricity demand and supply in Canada.

The system dynamics model shall consider each element's causal relationship in the model and how it may generate feedback. Several considerations need to be examined such as government energy policy and management, energy prices and economic structure, supporting technology and geopolitical condition, underdeveloped energy resource, and the production capability, limitation of energy potential, energy waste and environment consideration, relationship with other countries through import and export activity, energy investment and potential revenue(Kiani & Pourfakhraei, 2010). Each country has a different characteristic or structure in its energy sector. The energy policies shall be analyzed to increase energy production, efficiency, and intensity while decreasing energy consumption. Thus, the system dynamic model is suitable to represent the condition of Indonesia's oil refinery and power generation development.

According to (Ding et al., 2018), the Agent-Based Model and System Dynamic model are the most popular approaches to seeing system's complexity. However, both model has each strength and weakness in its approaches. System Dynamic (SD) is usually used to analyze problems from a macro and holistic-thinking perspective. It is a "top-down" modeling approach that can avoid the limitations of one-sided thinking (e.g., the micro perspective) and help understand the structure behind a complex phenomenon (Swanson, 2002). A System Dynamic model can be used to study a dynamic evolution process under different situations. The philosophical foundation is reductionism. Reductionism is a process of breaking complex entities, concepts, or phenomena down into their smallest constituents; it can transform ideas into simple forms (Ding et al., 2018). However, System Dynamic is often criticized because a complex system cannot be fully understood by dealing with a single discipline. System Dynamic cannot explain the system's micro behaviors, because it ignores the relationship between the macro behavior and micro behavior.

On the other hand, the Agent-Based Model (ABM) provides a dynamic approach by building a virtual system. It follows a "bottom-up" procedure that emphasizes the spatial or social interactions between individuals and their environment (Railsback & Grimm, 2019). The importance of holistic analysis is emphasized; meanwhile, the composing parts are also involved (Ding et al., 2018). ABM is an effective cross-scale modeling method that combines time dimension with space dimension and bears the characteristics of heterogeneity, space discretization, time discretization, and discrete states(Railsback & Grimm, 2019). Through computer simulation, the microscopic mechanism of complex macro phenomena can be revealed.

However, (Wang & Deisboeck, 2008) claimed that ABM also has some weaknesses as follows:

1. The required data is high on details in order to simulate over a long period because of the large number of parameters and rules, making parameter identification difficult and requires extensive sensitivity analyses to determine the prediction robustness.
2. ABM is sensitive to small variations; thus, current ABM can only process a relatively small number of agents. Thirdly, ABM ignores the interactions between agents and macro factors.

Thus, SD and ABM have their advantages and disadvantages for analyzing complex systems. SD focuses on the “flow” relationships and feedbacks to longitudinally simulate a system’s dynamic behavior. It is appropriate to analyze the interactions between different elements and cumulative longitudinal effects. However, spatial factors are not covered in the SD modeling process. In contrast, ABM considers spatial interactions. However, the feedback effect of various social and economic factors on agents is ignored.

Due to the limitation of available data in this Thesis, the system dynamics is more preferable to be the model to generate the complexity in the development of oil refinery and power generation in Indonesia.

2.6 Introduction of Electric Vehicle Policy in Indonesia

Recent air pollution from fossil fuel burning by transportation, industrial, and power generation sectors has generated a crucial impact on the global environment. Climate change, fluctuation of energy cost, and high dependence on fossil fuel utilization are the important issues that need to be considered. Many researchers worldwide try to give more attention and emphasize the solution for these problems with clean energy utilization(Rezaee et al., 2013). One of the most promising utilization of clean energy is the contribution of electric vehicle implementation. An electric vehicle can substitute conservative fossil fuel transportation with lower energy consumption and less emission(Sabri et al., 2016). The replacement of internal combustion engines in the existing vehicle with EV will bring economic benefit because of the utilization of electronic components as a major part of the vehicle. Electric vehicles were classified into Battery EVs, Battery EV and Range Extender, Fuel Cell Electric Vehicle, Hybrid EV, and Plug-in Hybrid EV. This classification is commonly based on the energy source, charging mechanism and the existence of additional fuel tank. The introduction of electric vehicle is a one of global agenda to solve climate change issue. Several government has started to encourage the utilization of electric vehicle through restriction policy of fuel combustion vehicle purchase in the big cities, subsidies for the electric car manufacturer, rapid development of electric charging infrastructure or low tax burden for this product.

As one of the most populous countries, Indonesia produced a high number of passenger vehicles for 15.4 Million units and motorcycles for 113 Million units in 2017.

It has increased more than two times since 2008 due to the stable, increasing growth of the economy and larger number of middle-class income families. Indonesia is the biggest automotive market in Southeast Asia, with 32% of the total market share. Every year the number of passenger vehicles has increased by 2.2 Million units and motorcycle for 8.5 Million units. This number shows that the automotive market in Indonesia will continue to increase, especially the motorcycle market. The motorcycle market is a big potential for reducing fuel consumption by introducing the electric vehicle to the Indonesian automotive market.

According to Presidential Regulation No 22 the Year 2017 regarding national energy planning, Indonesia should initiate the electric vehicle's development and deployment to substitute existing fossil-fueled vehicles from the prototype stage until the commercial stage. Indonesia has a vision of developing an electric vehicle with 2,200 units for 4-wheel vehicles and 2.1 Million units for the 2-wheel vehicle in 2025. This number will increase the portion of electric vehicles in Indonesia to 10% of total mass transportation. To support this target, the government shall prepare for the incentive package and fiscal policy for electric vehicle producers to ensure its deployment to consumers. The development of the EV charging station system shall also be considered with the target of 1,000 units in 2025.

Table 2. Indonesia Electric Vehicle Development Target

Source: (Ketenagalistrikan, 2018)

Electric Vehicle Development Target	**2025**	**2050**
Charging Station	1000	10000
Electric Cars	2200	4.2 Million
Hybrid Electric Cars	0,71 Million	8.05 Million
Electric Motorcycle	2.13 Million	13.3 Million

There are a lot of EV components and parameters, which are different from the fuel combustion vehicle such as charging plugs, charging voltage, communication between EV and the charger, fast charging systems, energy storage, EV performance, electricity billing, safety measures for users, especially against electric shock.

In Indonesia, the transportation sector is the collaboration of energy sources, energy conversion, energy consumption with domestic and imported material, industrial process, and public needs. The transportation sector's existence and sustainability are crucial in supporting economic activities and social opportunities for the communities(Zhang et al., 2011). Two important factors need to be considered in the transportation sector energy use: the contribution of the transportation sector to air pollution and how the energy sector can sufficiently supply the energy demand in this sector(Ediger & Çamdalı, 2007). As one of the most populated nations and stable growing economies, Indonesia has increased the number of middle-class income families and their mobility needs. The fact shows the number of vehicles in Indonesia has increased by 12% on average for the last ten years. Since 2004, Indonesia has been a net oil importer because of decreased domestic oil production and increased oil consumption. The transportation sector's contribution to oil consumption has reached 60% of this consumption and 70% of this share comes from road transportation(Widyaparaga et al., 2017). Based on the National Bureau of Statistics, the number of road vehicles in Indonesia is 129.2 Million. The details are 14.5 Million of passenger cars, 2.4 Million of Buses, 7.0 Million of the truck, and 1-5.1 Million of passenger motorbike. This number has been increased by 7-8 Million vehicles on average in a year because of higher individual income, road infrastructure development, and limited public transportation facilities(Indonesia, 2017). On the other hand, fuel combustion engines in recent vehicles have reduced air quality, especially in metropolitan cities such as Jakarta, Surabaya, and Medan. The air quality index in Jakarta as a capital city has shown 191 or categorized as an unhealthy air quality and its worse than the other capital city in ASEAN countries like Ho Chi Minh City, Bangkok, Kuala Lumpur, and Singapore.

The Indonesian government shall introduce new regulations to decrease oil consumption and lower oil import dependency by shifting the utilization of fuel combustion vehicles to electric vehicles. The electric vehicle became one of the most promising solutions to reduce CO_2 emission in the transportation sector. An electric vehicle can bring improvement in traffic, a healthier environment, and sustainable mobility(Pereirinha et al., 2005). The utilization of electric vehicles in Indonesia will increase national energy security. There are four energy security elements relating to electric vehicle introduction policy in the transportation sector: availability, accessibility, affordability, and acceptability(Kruyt et al., 2009a). Electric vehicles will increase the availability indicator by reducing oil import dependency and increasing local and renewable energy utilization. It will also improve the accessibility indicator because recent electricity infrastructures have comprehensive coverage and reliable supply. Higher efficiency in an electric vehicle will help the vehicle user to increase affordability by reducing energy costs for the distance that they take by using their vehicle. Moreover, no air pollution at the internal combustion and lower CO_2 emission from the energy supply sides are the reason why the people can easily accept electric vehicle if we look from environmental and social acceptance.

The benefit of electric vehicle utilization in the future are as follows:

a. It can be the implementation of government commitment to reducing CO_2 emission by 29% in 2030 as stated in Intended National Determined Contribution(Siagian et al., 2017)
b. The electric vehicle has a higher efficiency (28%) than conventional fuel combustion vehicle (14%)(Subekti, 2002)
c. Electric vehicle emits lower air pollutant emission because there is no internal fuel combustion like a conventional vehicle(Girardi et al., 2015)

d. The electric vehicle will reduce maintenance cost in the vehicle utilization because of fewer moving component in this technology by 50% compared to combustion vehicle(Chan, 1993)

It is important to understand that the electric vehicle introduction policy shall be considered, especially on the additional electric vehicle target introduced in the market. The number of electric vehicles shall be supported by sufficient infrastructures such as charging stations, workshops, and aftersales services. (Asfani et al., 2020) introduced the progress of electric vehicle research in Indonesia. The utilization of electric vehicles is in line with the government planning to increase renewable energy utilization. The higher renewable energy share with lower electricity production costs will create affordable electricity, primarily for the transportation sector. The electric vehicle will be a favorable option than fuel combustion vehicles, especially when the battery price decreased. It is also important to provide sufficient infrastructure like vehicle-to-grid connection(Huda et al., 2019). The recent condition shows that Indonesia's existing grid still has limited capability to be a flexible grid with a high share of renewable energy. If the electric vehicle charging and discharging process can be controlled properly, it will create good support for the flexibility of the grid.

(Damayanti et al., 2020) investigate the user acceptance of electric vehicles in Indonesia and found several important parameters to be considered in adopting EV, such as the financial benefit, infrastructure readiness, EV performance, and promotion. The other researchers also found that the electric vehicle adoption especially the electric motorcycle reached 82.90% with a crucial thing to be prepared for is infrastructure readiness and affordable cost(Utami, Yuniaristanto, et al., 2020). The vehicle user tends to accept the electric vehicle if it improves this travel time and reduce the cost because of congestion.

Unfortunately, electric vehicles' strong point in reducing emission and noise was only accepted for mass vehicles such as public buses and not personal vehicles like cars or motorcycles (Prasetio et al., 2019). Low supporting regulation and an unclear incentive scheme for the electric vehicle are also highly considered an obstacle in adopting electric vehicle(Utami, Haryanto, et al., 2020).

Chapter 3. The Development of Oil Refinery in Indonesia: Optimization and System Dynamic

3.1 Introduction

Indonesia has become the net importer of crude oil due to the decrease in oil production and the increasing crude oil consumption. Furthermore, the condition is worsens because they also import fuel oil products such as motor gasoline, jet fuel/avtur, and diesel from the other countries because of the limited capabilities of a domestic refinery. Total import costs from petroleum products became the highest import commodities with 14.1 Billion USD or about 9.0% out of total import commodities in 2017. The high fuel oil consumption and fluctuation of global oil prices can endanger energy security in Indonesia.

Energy Security is a concept to assure adequate, reliable supplies of energy at a reasonable price and in ways that do not jeopardize major national values and objectives(Andrews, 2005). The focus of energy security issues is the continuity of its energy supplies, including how one country can provide oil and gas or any form of primary and secondary energy from domestic and import activities to fulfill their domestic energy demand. The importance of the energy security concept has been developed worldwide since the oil crisis phenomenon in the 1970s. Many countries believe that each of them shall protect their energy security because it can significantly impact their economic growth and political stability. Even most industrialized countries put energy security issues as their main energy agenda(Cohen et al., 2011). The development of oil refinery in Indonesia's objectives is to increase domestic fuel oil production and reduce fuel oil import dependence, which is good for the energy security index. However, it will also increase the crude oil import due to increasing oil refinery input and the emission from the oil refinery process will also rise to a higher level. Energy security has several dimensions that need to be considered: availability, acceptability, affordability, accessibility and intensity. It is important to know how the optimization of oil refinery development will have an impact to the energy security in Indonesia.

Based on the Indonesia Ministry of Energy and Mineral Resources (MEMR) data (Figure 14), the number of oil production in Indonesia has decreased by year and meets the lowest production with 304 Million Barrels in 2015 despite slight increase again in 2018. Oil production in the period 2007-2017 shows a decreasing 16% from 348 Million Barrels in 2007 to 292 Million Barrels in 2017. Furthermore, Indonesia's oil reserves indicate 7.5 Billion Barrels in 2017, with 3.2 Billion Barrels of proven reserve and 4.4 Billion Barrels of potential reserves(Pusdatin, 2018). With the current production rate, Indonesia oil reserves will run out in 11 years if the government can't find any other new oil reservoir to be exploited.

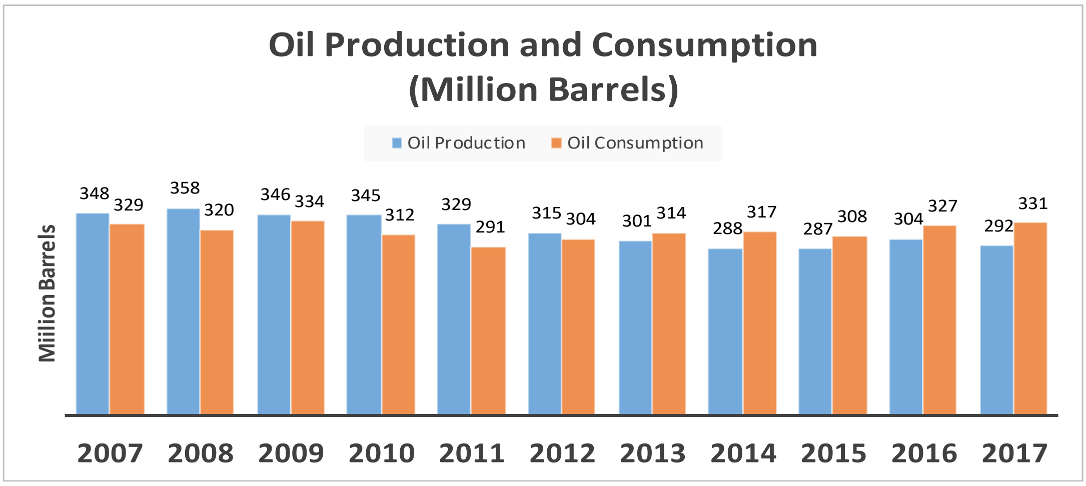


Figure 14. Indonesia Oil Production and Consumption 2007-2017

Source: (Pusdatin, 2018)

Indonesia, located in the equator and consists of 17.504 islands, has an abundant fossil energy source including oil, natural gas, and coal. Indonesia becomes the oil producer and exports its domestic production to other countries. Indonesia was also registered as a member of the Organization of Petroleum Exporter Countries (OPEC) in 1962. However, the consumption of oil in Indonesia also shows stable positive growth and even surpasses the number of domestic production in 2002 and initiate import activity for oil products in Indonesia. The number of Indonesia oil consumption in 2017 Indonesia shows 331 Million barrels, and it requires 142 Million barrels of imported oil to fulfill this consumption or 42% of total consumption.

The increasing number of vehicles (129.2 Million), utilization of diesel power generation, and industrial purposes requirement have affected the high number of imported oil. Additionally, total Indonesia import commodities in 2017 are 156.9 Billion

USD, and the highest contribution is coming from the processed petroleum oils category with 14.1 Billion USD or 9.0% of total import cost in Indonesia (Figure 15).

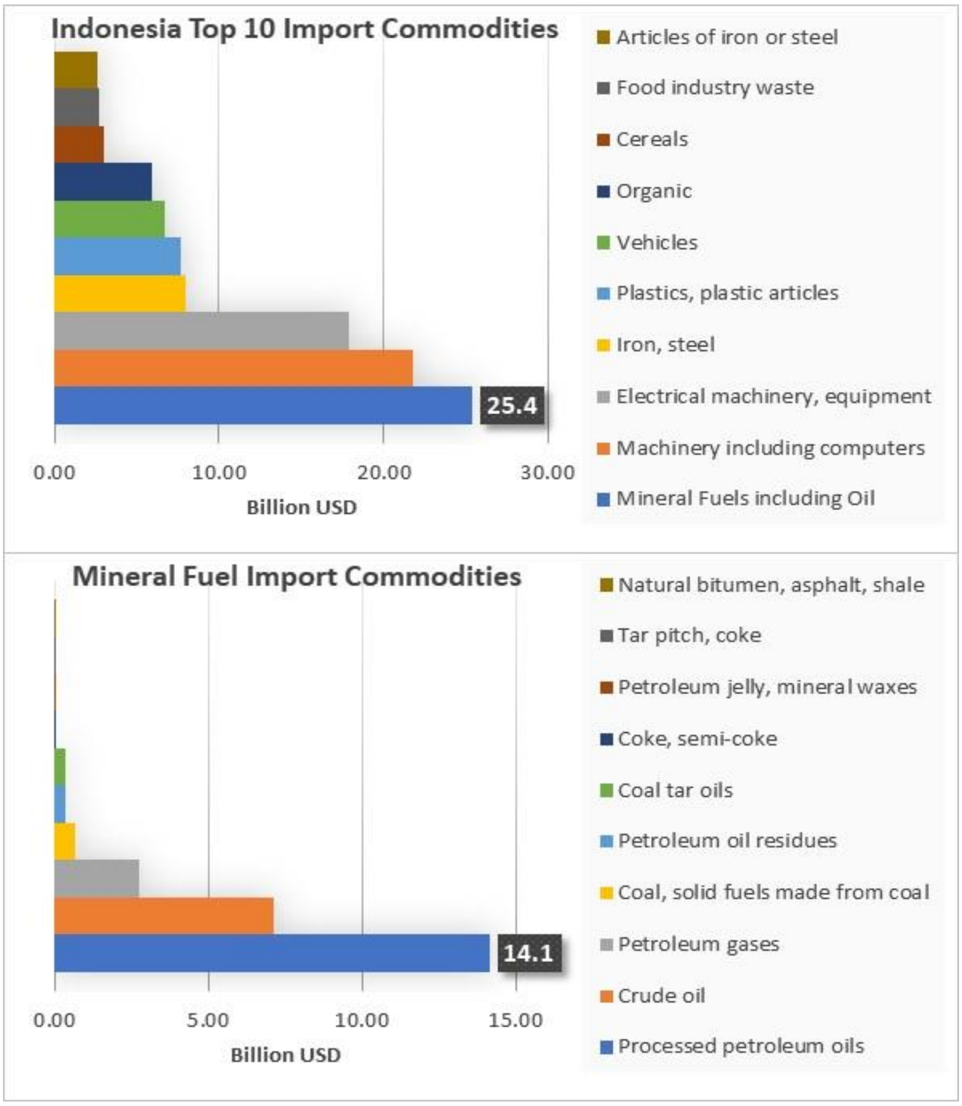


Figure 15. Indonesia Import Commodities in 2017

Source: (Indonesia, 2017)

This oil import dependence has been the most difficult burden for Indonesia's government expenditure, and it has a lot of impact on economic stability. The government expects oil import activity to prevent a shortage of oil supply and fulfill the domestic oil requirement. This situation shows how Indonesia has a high dependence on the global oil market condition and global oil prices. There is a dilemma if the global oil price fluctuation has occurred. When the price of global oil is low, the government could efficiently distribute oil to a domestic refinery in a sufficient volume at an affordable cost, while that the government revenue of oil export will decrease as well. On the other hand, the government will get more revenue from the sale of domestic oil production when the oil price is increasing but get difficulties in providing a subsidy for imported fuel oil from overseas refineries.

Recent conditions show that Indonesia's fuel oil consumption has increased almost four times from 1986-2017 while the domestic refinery production only grew by about 60% in the same period. Fuel oil consumption has surpassed the domestic production in 2002, which means the fuel oil import has started to supply the demand. In 2017, the fuel oil consumption was 2.25 times higher than oil refinery production, or the fuel import was bigger than the domestic refinery's capability in providing fuel oil. Without any new effort to reduce its dependence on imported fuel oil, it will always bring problems to government expenditure, energy security, and economic stability.

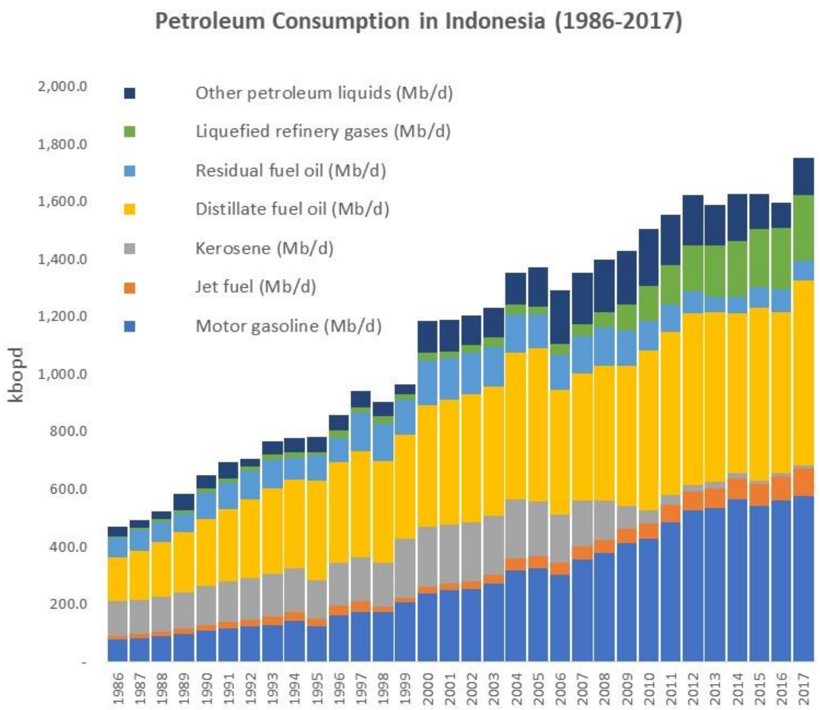


Figure 16. Indonesia Fuel Consumption, 1986-2017

Source: (Pusdatin, 2018)

It is necessary and important for the Indonesian government to consider the expansion of domestic refinery capacity to generate a solution to this problem. It will secure fuel supply and minimize fuel import dependence. Due to government budget limitation, the acceleration of Indonesia's domestic refinery capacity expansion may initiate a policy to develop a new source of financing from the revenue of the crude oil export or by engaging public participation in increasing the price of petroleum products. This study investigates the optimized capacity of domestic refinery facilities to secure fuel supply and reduce fuel oil import dependence in Indonesia during the period 2018-

2050 and analyzes the impact of oil refinery development on the energy security index. This research will also elaborate on energy security from the perspective of oil refinery development through a system dynamic model to understand the correlation of several input factors that impact fuel oil consumption and production. Furthermore, the introduction of an electric vehicle policy will be conducted through the sensitivity analysis process to identify whether this policy can be a solution in the oil refinery development process.

3.1.1 Research Questions

Research questions in this study are as follows:

1. How to optimize the reliable domestic refinery's required capacity to secure fuel oil supply and reduce petroleum import dependence in Indonesia?
2. How to analyze the effect of oil refinery development on the energy security index in the system dynamic model?
3. What policies and strategy implications are required to overcome future fuel oil product consumption in Indonesia?

3.1.2 Research Objectives

This study aims to analyze the optimal oil refinery development to reduce fuel oil import dependence in Indonesia and its impact on the energy security index. The other objective is to elaborate on the introduction of electric vehicle policy in the transportation sector and its impact on the oil refinery development and energy security index.

3.1.3 Expected Research Result

The expected result of this part are as follows:

1. The optimization of refinery capacity development in Indonesia for 2018-2050;
2. Analysis of refinery development impact to energy security index in the system dynamic model;
3. Policy recommendation framework to support the oil refinery development in Indonesia.

3.1.4 Research Methodology

The research steps and methodology in this part will be determined as follows:

1. Mixed Integer Linear Programming as an optimization model of oil refinery development for the period of 2018-2050;
2. System dynamic model to analyze the correlation of each input factor, both from oil demand and supply side to the energy security index in oil refinery development.

3.2 Research Design and Methodology

3.2.1 Optimization Model of Oil Refinery Development

This paper will utilize Mixed Integer Linear Programming (MILP) with data processing from the historical data of petroleum products consumption and existing refinery production.

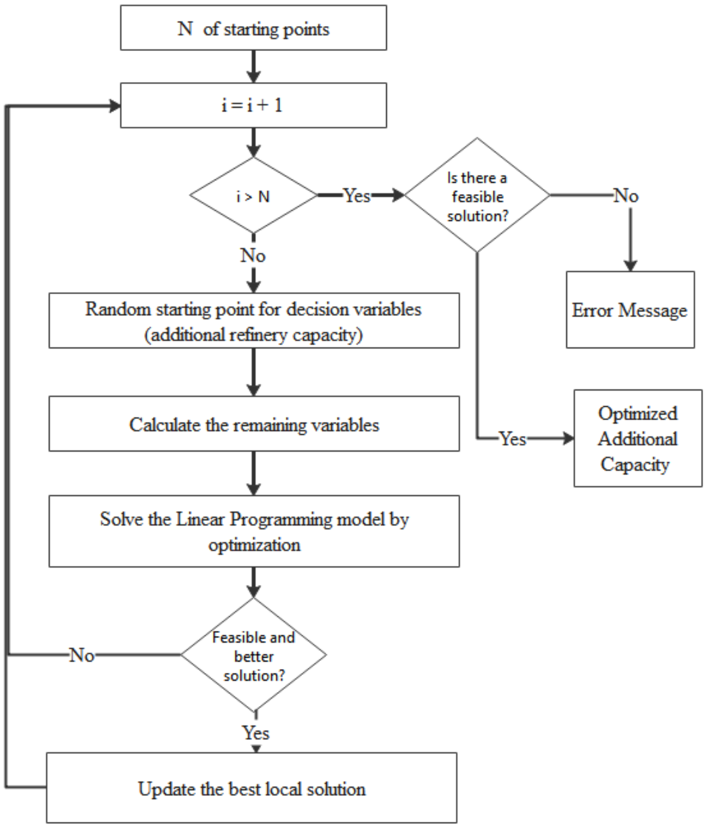


Figure 17. Flowchart of Linear Programming Model

The implementation of the linear programming model both MILP and MINLP has been widely used to analyze the optimization and scheduling of the petroleum refining process(Carson & Hanemann, 2005) (Elkarnel, 2008) (Neiro, 2005). Mixed Integer Linear Programming (MILP) is the most used methodology to conduct oil refinery optimization. This method was conducted by (Adams & Griffin, 1972), (Sahidis, 1989) (M.-L. Liu & Sahinidis, 1996) (Grossman, 1996) (Göthe-Lundgren et al., 2002) (Más & Pinto, 2003) (Elkarnel, 2008) (Menezes et al., 2015). The objective function of this optimization is to find the minimum cost of additional refinery development. The production of additional refinery development will generate a certain percentage of fuel oil products. However, the requirement of fuel consumption is the accumulative number in a year without any specific operation of refinery during that year. There will be no particular load shape on demand for fuel products. According to (Khoshniyat & Törnquist Krasemann, 2017), the strengths of MILP methodology in optimization are capable of doing practical timetable analysis and provide a good feasible solution.

This method aims to find the optimal solution for refinery production to meet the petroleum products demand. The linear programming model will demonstrate how the model will meet the objective function while also fulfilling the required variables or constraints. There will be an iteration process to find the most optimized solution in several trials and errors. The result can be used as a pre-guidance for Indonesia's energy planner to look at the applicable capacity of a refinery for the demand. The model can be extended to be more complicated with the additional constraint or variables. However, the refinery's capacity in this model will be generated by the refinery's capability in producing several petroleum products that will be represented by the refinery yield.

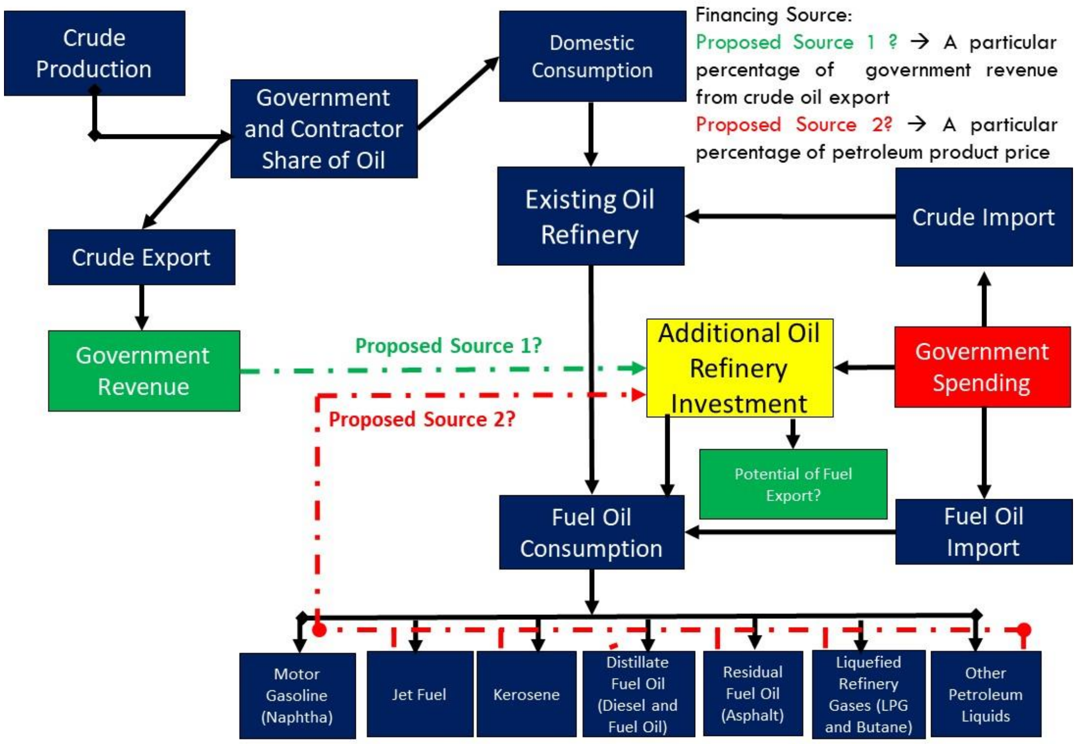


Figure 18. Indonesia Oil system in the model and the proposed source of financing

Figure 18 shows that the model's oil system has been started from domestic oil production and domestic petroleum consumption. Domestic oil production will lead the model to the revenue that the government can get from the crude oil export activity. Domestic petroleum consumption will be derived from the number of petroleum products needed by the people in the country, ultimately as a fuel for the transportation sector. The petroleum product will be classified into six categories, which are motor gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, liquefied petroleum gases, and other petroleum liquids. The existing refinery will firstly served the requirement of petroleum products. However, if the demand surpasses the domestic supply, then the petroleum import will be conducted to meet the petroleum product demand. Indonesia usually gets its petroleum import from Singapore. The additional refinery development is required to generate more petroleum products and fulfill the gap between current demand and the existing refinery supply. The additional refinery development will be categorized as a government spending together with the crude oil import and petroleum product import. This study will also look at the possibility of an alternative financing source for refinery from the percentage of revenue of crude oil export or the percentage of the increasing price of petroleum products. This study has collected historical data of petroleum product consumption, production, and refinery output from the US Energy Information Administration (EIA) for 34 years from 1983-2017. The optimization model of the refinery development is derived from these equations as follows:

Crude Oil Production at year t (OP_t) equations:

$$OP_t = OPG_t + OPC_t;\ OPG_t = 70\%\ OP_t; OPC_t = 30\%\ OP_t \quad (1)$$

OPG_t: Oil Production for Government Share; OPC_t: Oil Production for Contractor Share based on Production Sharing Contract.

Crude Oil Export at year t (OE_t) equations:

$$\mathrm{OE}_t = OEG_t + OEC_t; OEG_t = k_1.OPG_t; OEC_t = k_2.OPC_t \quad (2)$$

OEG_t: Oil Export for Government Share; OEC_t: Oil Export for Contractor Share; k_1, k_2: export share.

Government revenue from Oil Export at year t (GR_t) equations:

$$GR_t = \sum OEG_t . P_t$$ where P_t: Oil Price at year t (3)

Domestic Crude Oil Consumption at year t (DC_t) equations:

$$DC_t = OP_t - OE_t + OI_t = ORI_t$$ where OI_t: Oil Import at year t (4)

Oil Refinery Output at year t (ORO_t) equations:

$$ORO_t = ORI_t . \eta$$ where η: refinery efficiency (5)

Petroleum Consumption at year t (PC_t) equations:

$$PC_t = MG_t + LG_t + RF_t + DF_t + KE_t + JF_t + OT_t \quad (6)$$

MG_t : Motor Gasoline consumption at year t
LG_t : Liquified Refinery Gases consumption at year t
RF_t : Residual Fuel Oil consumption at year t
DF_t : Distillate Fuel Oil consumption at year t
KE_t : Kerosene consumption at year t
JF_t : Jet Fuel consumption at year t
OT_t : Other petroleum products consumption at year t

The crude oil production at year *t* will be allocated to the government and contractor at a certain particular share based on the production sharing contract agreement. It will decide the number of crude oil export and revenue that the government may get from the crude oil export activity. On the other side, the domestic crude oil consumption will be calculated by the difference between crude oil production, crude oil export, and crude oil import at year t. This domestic crude oil consumption will be treated as an input for the domestic refinery development. Oil refinery output at year t also is decided by the oil refinery input multiply by each refinery efficiency. The next equation is petroleum consumption at year t, based on the total consumption of motor gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, liquefied petroleum gases, and other petroleum liquids.

The objective function is to minimize the cost of additional refinery development: (7)

$$Z = \min, v_{obj} = \sum_{t=1}^{n} cap_t \times c_{r,t}^f$$

Cost of refinery development equations: (8)

$c_{r,t}^f = \sum_{t=1}^{n} I_t + \sum_{t=1}^{n} O_t$ where I_t: Refinery Investment and O_t: Operation and Maintenance cost at year t

An additional capacity of refinery equations: (9)

$$cap_t = cap_{1st\ 10\text{year}} + cap_{2nd\ 10\text{year}} + cap_{3rd\ 12\text{year}}$$

The constraints are as follows:

a. Supply and demand balance : (10)

Refinery production (P_t^f) & fuel import (IP_t^f) = fuel export (EP_t^f) & fuel oil demand (D_t^f)

$$\sum_r P_t^f + \sum IP_t^f = \sum EP_t^f + \sum D_t^f$$

b. Technology Constraints: (11)

Refinery production ($P_{r,t}^f$) ≤ existing ref. production & additional ref. production：

$$\sum_r P_t^f \leq \sum_{existing} P_t^p + \sum_{additional} P_t^p$$

(12)

c. Motor Gasoline Import shall be zero constraints:

$$\sum_{t=1}^{n} IP_t^{MG} = 0; \tag{13}$$

d. Refinery production equal to refinery capacity multiply by refinery production yield share constraints:

$$\sum_r P_t^f = \sum_{t=1}^{n} cap_{r,t} \times \sum_f rys^f \tag{14}$$

e. Total refinery production yield share equal to one constraint:

$$rys^f = \mathrm{rys}^{MG} + \mathrm{rys}^{\mathrm{JF}} + \mathrm{rys}^{KE} + \mathrm{rys}^{DF} + \mathrm{rys}^{RF} + \mathrm{rys}^{LPG} + \mathrm{rys}^{OT} = 1$$

Nomenclature:
r : refinery, t: time, f: fuel, c: cost, MG:motor gasoline, JF: jet fuel, KE: Kerosene
DF: diesel oil, RF: residual fuel oil, LPG: Liquid petroleum gases, OT: Other petroleum liquid

The model's objective function is to minimize government spending on petroleum imports by developing the optimized cost of additional refinery development. The cost of additional refinery development is calculated by the total investment cost and operational cost that will be generated. The development of each additional refinery will be divided based on the ten years of development, which will be generated only in 2018, 2028, and 2038. This decision is based on the average period of refinery development from the planning until the first operation, usually takes ten years. There are several constraints in this MILP model: technology constraint, supply and demand balance, and petroleum import cost minimization. Refinery domestic production and import is equal to the total petroleum demand and export activity. The production of domestic petroleum products shall be not more than the production of existing refinery and petroleum products from the additional refinery. The target if petroleum import cost for motor gasoline shall be equal to zero.

The capacity of the oil refinery will be multiplying by the refinery yield for each product. The government losses can be indicated if the government spending from the petroleum import cost of the actual condition or without optimization of the additional refinery development is higher than the development cost of the additional refinery development optimization. The optimization model in this study will be conducted in the future period in 2018-2050 (32 years) to analyze the appropriate capacity of a refinery for Indonesia's domestic consumption. The following flowchart is the process that will be conducted in this study (Figure 19).

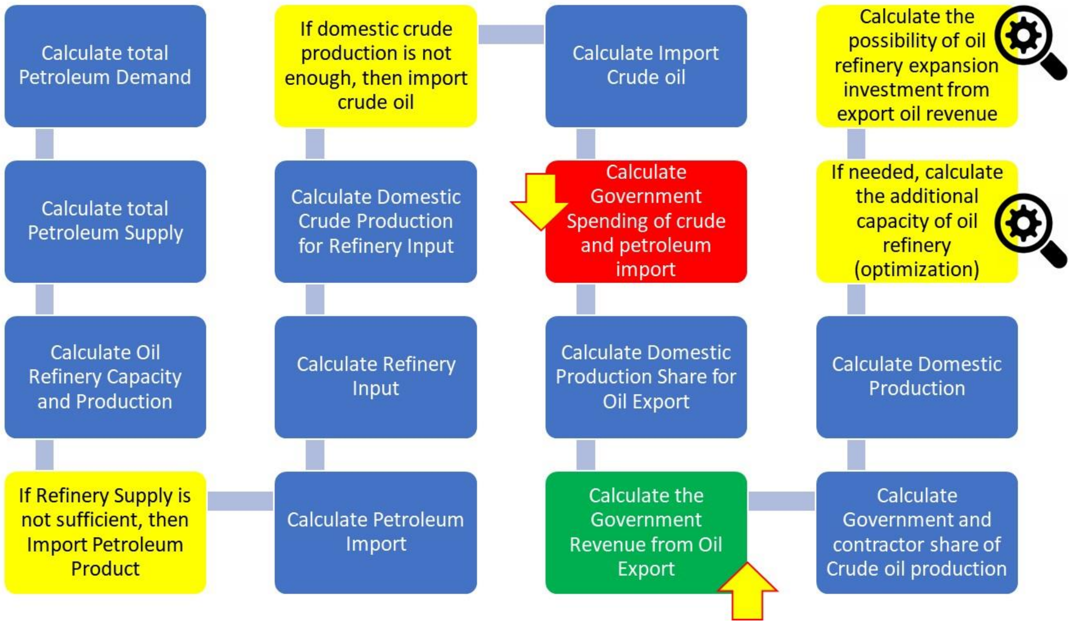


Figure 19. Linear Optimization Flowchart

Zero Import of Motor Gasoline is a crucial objective of the oil refinery development in Indonesia due to several reasons as follows:

a. The high impact of oil sector expenditure on government budget stability. This high expenditure is coming from the import of fuel oil and crude oil. Indonesia has imported fuel oil products such as motor gasoline, jet fuel/avtur, LPG, and diesel from the other countries because of the domestic refinery's limited capabilities. Total import costs from petroleum products became the highest import commodities with 14.1 Billion USD or about 9.0% out of total import commodities in 2017. This oil import dependence has been the most difficult burden for Indonesia's government expenditure, and it has a lot of impact on economic stability. The government expects oil import activity to prevent a shortage of oil supply and fulfill the domestic oil requirement. This situation shows how Indonesia has a high dependence on the global oil market condition and the global oil prices. This condition has also occurred in other countries, such as China(Downs, 2017), India (Clarke & Graczyk, 2010) and Brazil (Simoes & Hidalgo, 2017). Motor Gasoline and Diesel are the highest imported fuel commodities in Indonesia. Fuel Import has been the highest import commodities in Indonesia for the last 20 years. The yearly average share of duel import is about 11.9% of the total import cost. Along with the crude oil import, the oil sector has dominated Indonesia's import commodities with an average share of 19.3% of total import commodities or around 20.93 Billion in a year.

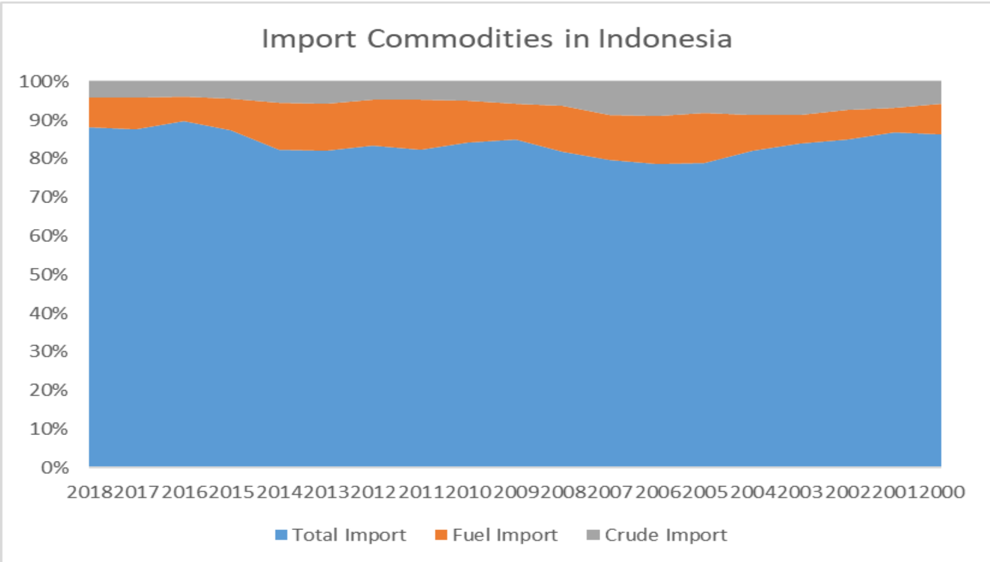


Figure 20. Fuel and crude import in Indonesia, 2000-2018

Source: (Simoes & Hidalgo, 2017)

b. Indonesia also generated a high fuel subsidy, consisting of the subsidy from government expenditure for low-income people in buying fuel such as gasoline and diesel fuel. This policy was arranged to support equal rights for people in getting the fuel, as stated in Indonesia Basic Law. Gasoline and diesel fuels that get a subsidy are RON 88 Fuel, ADO (Automotive Diesel Oil), and IDO (Industry Diesel Oil). Based on government expenditure data from 2007-2017(Keuangan, 2017), Indonesia’s fuel subsidies in Indonesia may vary from 3-23 Billion USD per year. The highest fuel subsidy occurred in 2013 where the global oil price increased by 23.1 Billion USD. The government decided to reduce the fuel subsidy cost when the recent government starts a new period, and the global oil price decreased. From 2015-2017, Indonesia’s fuel subsidy has been decreased to 3.2-5.5 Billion USD or deducted 75% from the previous period. The decision to reduce fuel subsidy is because the previous subsidy is not on proper target and some people who have good income also enjoy this subsidy. The government feels that the huge amount of fuel subsidy puts a burden on the government budget. It will be better if it can be transferred to more useful infrastructure development.

c. Indonesia's population is still growing at a fast rate, and the number of consuming classes will also increase and significantly impact fuel consumption in the future. The number of motor gasoline import is the highest among the other fuel products;

d. Indonesia's domestic refinery capability shows low coverage and performance compared to the neighboring refineries, and it may possess fuel supply shortage problems in the future if there is no improvement.

e. Import dependence will bring problems if the fluctuation of global energy price still occurred in the future. The Fuel import in Indonesia has a similar trend with the fluctuation of global oil price, which means that higher global oil price might increase the fuel import cost in the future.

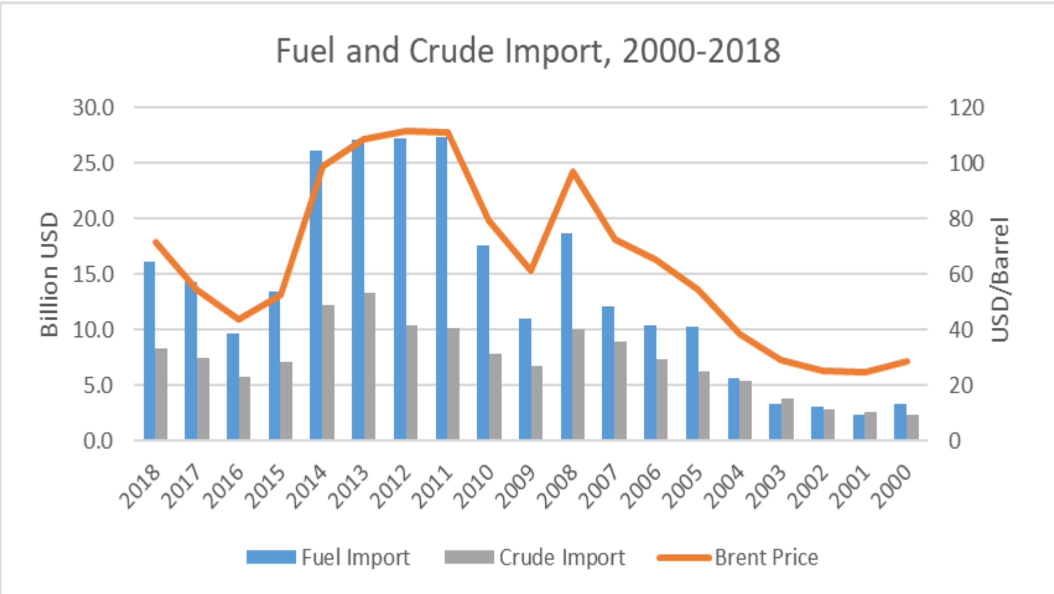


Figure 21. Fuel and Crude Import, 2000-2018

Source: (Petroleum, 2018; Simoes & Hidalgo, 2017)

f. There is a possibility of transfer technology in the development of domestic refinery from the refinery technology advanced country to Indonesia.

3.2.2 Oil Refinery Development Optimization Result

Based on National Energy General Plan (Presidential Regulation No. 22/2017), the projected demand for fuel oil in Indonesia is expected for 1.76 Million barrels of oil per day by 2025 and 3.72 Million barrels of oil per day by 2050. The government will try to reduce import dependence on the fuel oil import and stop it by 2025 by developing oil refinery through the capacity improvement of existing refinery and introducing of new oil refinery until 2025. This plan will increase the crude oil import volume consequently.

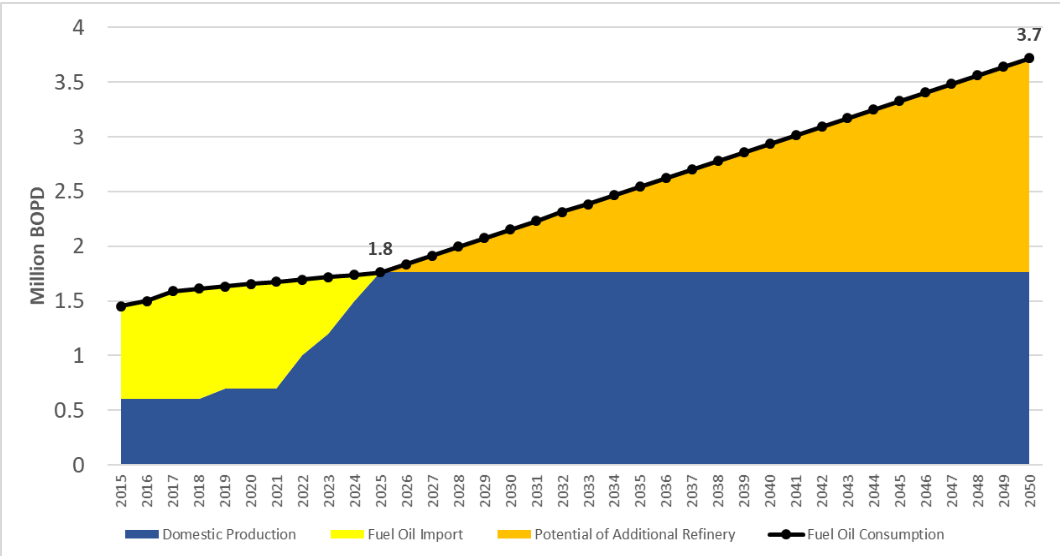


Figure 22. Fuel Oil Forecast Consumption

Source: (Widyaningsih, 2017)

This regulation also indicates the existing capacity and further development plan of an oil refinery in Indonesia. The government will increase the capacity of an oil refinery by improving the existing oil refinery capacity (RMDP) and developing a new grass-root oil refinery (GRR). The existing plan to increase the capacity of domestic oil refinery is only until 2025. The first plan is the introduction of four new oil refinery development plans which are IKP (6 kbopd), GR West 1 Tuban (300 kbopd), Bontang KPS (300 kbopd), and GR West 2 (300 kbopd). The second plan is to conduct capacity improvement of 4 (four) existing oil refineries through the Refinery Development Master Plan Program (RDMP), which are Balikpapan (360 kbopd), Cilacap (370 kbopd), Dumai (257 kbopd), and Balongan (275 kbopd).

										Unit: Thousand BOPD		
No	Refinery Name	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	New Refinery Plan	-	6	6	6	6	6	306	306	606	906	906
	a. Private Refinery		6	6	6	6	6	6	6	6	6	6
	b. Grass Root Refinery West 1							300	300	300	300	300
	c. Bontang Refinery									300	300	300
	d. Grass Root Refinery West 2										300	300
2	Capacity Expansion of Existing Refinery	860	860	860	860	960	960	960	982	1,262	1,262	1,262
	a. Balikpapan	260	260	260	260	360	360	360	360	360	360	360
	b. Cilacap	348	348	348	348	348	348	348	370	370	370	370
	c. Dumai	127	127	127	127	127	127	127	127	257	257	257
	d. Balongan	125	125	125	125	125	125	125	125	275	275	275
3	Existing Refinery	307	307	307	307	307	307	307	307	307	307	257
	a. Sungai Pakning	50	50	50	50	50	50	50	50	50	50	
	b. Kasim	10	10	10	10	10	10	10	10	10	10	10
	c. Cepu	4	4	4	4	4	4	4	4	4	4	4
	d. Tuban	100	100	100	100	100	100	100	100	100	100	100
	e. TWU	6	6	6	6	6	6	6	6	6	6	6
	f. TWU II	10	10	10	10	10	10	10	10	10	10	10
	g. Plaju	127	127	127	127	127	127	127	127	127	127	127
	Total Capacity	1,167	1,173	1,173	1,173	1,273	1,273	1,573	1,595	2,175	2,475	2,425
	Production	782	786	786	786	853	853	1,081	1,105	1,530	1,768	1,734

Figure 23. Existing Refinery Capacity and Development Plan

Source: (Widyaningsih, 2017)

Several parameters will be set as a consideration before the optimization process started with details are as follows:

a. Refined Petroleum Consumption is based on the National Energy Policy (GR No 79/2014) and National Energy Plan (Presidential Regulation No 22/2017).
b. Refined Petroleum Production is based on the existing refinery production and related plan in the future through RDMP and Grass Root Refinery(Presidential Regulation No 22/2017)
c. In this analysis, refined petroleum products are motor gasoline, jet fuel, kerosene, distillate fuel oil, residual fuel oil, liquefied petroleum gases, and other petroleum liquids.
d. Crude Oil import (t) = Domestic Oil Production (t) – Crude Oil Export (t) – Refinery Crude Oil Input (t)
e. Crude Oil export will be decreased with the ten years average decreased rate
f. Crude Reserves (t) = Crude Reserves (t-1) – Domestic crude production (t-1) + additional crude production (t-1)
g. Crude Oil Price will be based on the Refinery Production (t) = Refinery Input (t) + Refinery Processing Gain (t)
h. Refinery Yield for the additional refinery, investment cost, and O&M cost is based on the EIA reference refinery yield (EIA, 2014)

i. The development of oil refinery will be divided into three periods of time which are 1st ten periods (2018-2027), 2nd ten periods (2028-2037), and 3rd for the last 12 year period (2038-2050)

j. The additional refinery option used in the analysis is the medium complexity refinery due to most of the existing refinery in other countries in the range of this type of refinery(Kaiser, 2017). The fuel oil production will consist of 45% gasoline, 27% distillate diesel, heating oil, and jet fuel, 8% propane/butane as liquefied petroleum gases, and 24% heavy fuel oil and other petroleum liquids.

The fuel consumption projection in Indonesia keeps increasing until 2050. However, some research stated the opposite projection of the global fuel consumption projection that might be decreased in the future. According to World Oil Outlook 2040 by (Organization of the Petroleum Exporting Countries, 2017), the global economy's configuration will be changed from the domination of the OECD into emerging economies such as China and India. The clean energy policy, technological development of energy efficiency, and emission reduction in OECD countries will significantly reduce fuel oil consumption. The introduction of electric vehicles, higher fuel emission standards, and efficiency will be the main contributors to this reduction. However, different conditions will occur in developing countries such as Indonesia. Progressive economic growth will bring an impact on increasing fuel demand. The fuel consumption in developing countries will be expected to increase by 1.9% per year from 2015 to 2040.

The main contributors to this condition are the higher population growth, urbanization rate, and economic activity expansion.

The demand in OECD countries might be decreased from 23.6 Mbopd to 16.5 Mbopd with the details of decreasing trend is coming from increasing of fuel efficiency (-4.8 Mbopd), declining of Vehicle Miles Traveled (-1.7 Mbopd), and penetration of alternative fuel vehicle such as electric cars (-2.1 Mbopd). However, the number of the vehicle still give a contribution to increasing 1.6 Mbopd. The demand in developing countries might be increased from 17.4 Mbopd to 29.4 Mbopd with the details of the increasing trend is coming from the increasing number of the vehicle (26.4 Mbopd). There are also decreasing rates that coming from fuel efficiency (-8.0 Mbopd), declining of Vehicle Miles Traveled (-3.6 Mbopd), and penetration of alternative fuel vehicles such as electric cars (-2.8 Mbopd).

Along with this projection, Indonesia, categorized as a developing country with stable economic growth like China and India, will generate more fuel consumption to support its economic growth. Indonesia's number of vehicles has not shown a decreasing trend, with a yearly average growth is almost 12.03%. The number of the motorcycle with the average growth rate, 12.8% showed a dramatic increasing trend (Figure 24).

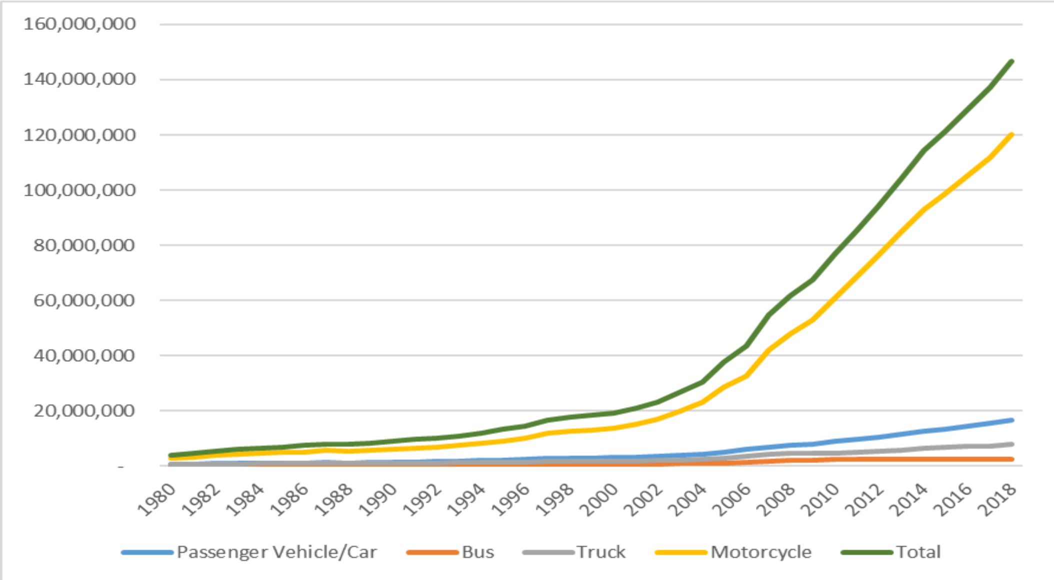


Figure 24. Indonesia vehicle number 1980-2018

Source: (Indonesia, 2018).

Recent energy policy in Indonesia also doesn't show an intention to reduce fuel consumption with oil conservation policy. The introduction of electric vehicle discussion has just been introduced in 2020. Furthermore, the trend of fuel consumption in Indonesia has not been significantly affected by oil prices fluctuation. The fuel oil consumption is still increasing by 3.5 times from 1980-2018. All of these conditions are the reason why fuel consumption projection in Indonesia will be increased until 2050.

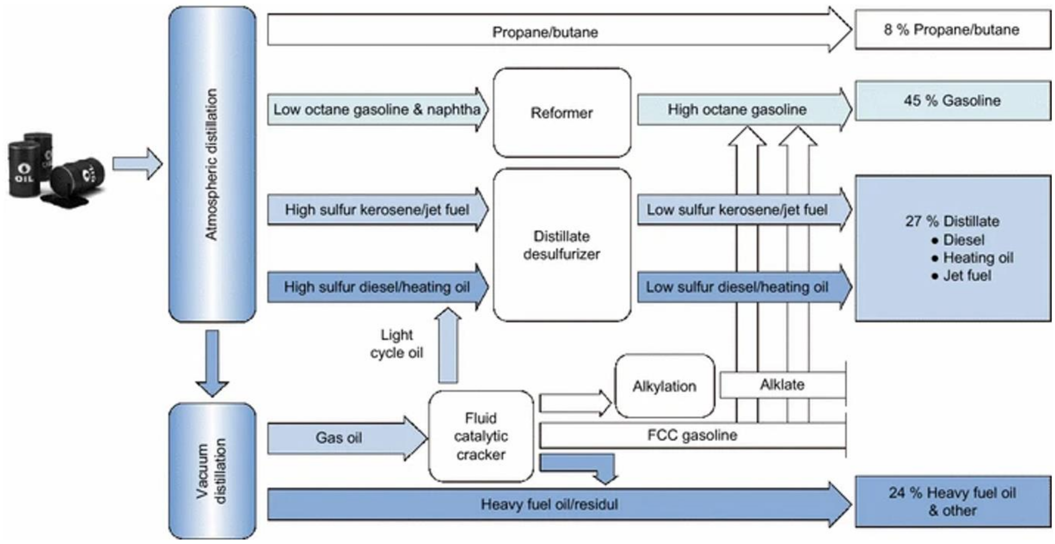


Figure 25. Additional Refinery Type Option

Source: (Kaiser, 2017)

The optimization result shows that Indonesia needs an additional refinery with 898 kbopd (1st period) and 682 kbopd (3rd period). There is no need to build additional refinery development in the 2nd period (2028-2037) due to 900 kbopd additional new refinery will be added as stated in the government plan in 2021-2024. Cumulative additional refinery development from 2018-2050 by 1,580 kbopd. The percentage of Crude Export Revenue that needs to be collected every year as Refinery Development Financing source is 157.91%. This result shows it is impossible to utilize the crude oil export revenue as a source of oil refinery financing because of the required share exceeds 100%.

On the other hand, the percentage of fuel oil prices that need to be added every year as refinery financing source is 2.46%. The idea of refinery development financing from the percentage of fuel oil price is quite possible with some consideration such as the willingness to pay for this increasing price could be accepted by the fuel oil customer. The oil refinery development cost, which consists of the capital investment and operation and maintenance cost requirement from the 2018-2050 period, is 90.86 Billion USD. The unit capital investment for oil refinery is 17.70 Million USD/kbopd, and the operation and maintenance cost is 1.09 Million USD/kbopd per year (IEA, 2014). The fuel oil import cost with the optimization process at the same period will be reduced from the 711.48 Billion USD to 311.59 Billion USD or a 56.2% saving of fuel oil import cost.

Table 3. Optimization Result of Refinery Development

Parameter	**Unit**	**Optimization Result**
Refinery Development Cost (Investment + O&M Cost) 2018-2050	Billion USD	90.86
Percentage of Crude Export Revenue for source of Refinery Development Financing	%	157.91
Percentage of petroleum price as a source of refinery financing	%	2.46
Investment Cost Unit of Refinery (IEA, 2014)	Million USD/kbopd	17.70
Operation and Maintenance Cost Unit (IEA, 2014)	Million USD/kbopd/year	1.09
Total Petroleum Product Import Cost 2018-2050	Billion USD	311.59
Total Petroleum Product Import Cost 2018-2050 without optimized refinery	Billion USD	711.48
Petroleum Product Import Saving after optimized refinery capacity	Billion USD	399.89 (56.2% saving)

The scenario without optimization of additional oil refinery will be stated as a Business as Usual (BAU) scenario. In this scenario, the oil refinery development only occurred from the exiting oil refinery and recent government plan. On the other hand, the scenario with the optimization of additional oil refinery will be stated as an optimization scenario (OPT). This study will compare each energy security indicator result in 2018-2050 between these scenarios to analyze the impact of oil refinery optimization in the energy security index from the oil refinery development perspective.

The availability dimension indicators in oil refinery development show no difference in crude oil production per capita and oil reserve and resource level between these scenarios. However, the total fuel oil production per capita has increased by about 3-7 times in the OPT scenario than the BAU scenario. The self-sufficiency of oil is also increasing 2-4 times in the OPT scenario due to higher fuel oil production from the domestic refinery.

However, the import of crude oil in the OPT scenario is higher about two times than the BAU scenario because the bigger capacity of the domestic refinery will consume more crude oil. From the affordability dimension perspective, there is no difference between the two scenarios on petroleum price per GDP per capita ratio and fuel oil price. However, the cost of the subsidy will be decreased in the OPT scenario by 2-3 times due to lower fuel import means lower dependence on the fluctuation of fuel oil market price. All indicators in the acceptability dimension show that the OPT scenario has increased CO_2 emission, emission intensity, and emission per fuel oil consumption compared with the BAU scenario. The oil intensity indicators did not show any difference between the two scenarios because the indicators related only to fuel oil consumption and GDP but not fuel oil production. The comparison of energy security indicators between BAU and OPT scenario is explained in Table 4.

Table 4. Comparison of energy security indicators in the BAU and OPT scenario

		OPT With additional refinery development optimization					BAU Without additional refinery development optimization				
Parameter	**Explanation**	**2018**	**2028**	**2038**	**2048**	**2050**	**2018**	**2028**	**2038**	**2048**	**2050**
Crude Oil production per capita	Total Crude Oil Production per population	1.2	1.1	0.0	0.0	0.0	1.2	1.1	0.0	0.0	0.0
Fuel Oil production per capita	Total Fuel Oil Production per population	7.3	10.4	11.9	11.2	11.1	3.8	7.3	6.9	6.4	6.4
Self Sufficiency of Oil	Share of domestic production over refined product consumption	1.1	1.3	1.3	1.0	1.0	0.6	0.9	0.7	0.6	0.6
Import of Crude Oil	Share of crude import to total domestic crude consumption	0.7	0.8	1.0	1.0	1.0	0.5	0.7	1.0	1.0	1.0
Import of Fuel Oil (Refinery Products)	Share of refined product import to total domestic fuel oil consumption	0.1	0.1	0.2	0.2	0.2	0.5	0.3	0.4	0.5	0.5
Oil Reserve and Resources	Average crude oil reserve to crude oil production ratio	4.5	0.7	0.0	0.0	0.0	4.5	0.7	0.0	0.0	0.0
Petroleum Price per GDP per capita ratio	Petroleum price per GDP per capita	18.2	7.6	4.7	2.8	2.5	18.2	7.6	4.7	2.8	2.5
Cost of Subsidy	Expenditure in Subsidy per total government spending	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Price of Fuel Oil	The price of fuel oil in Indonesia	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.8	0.8
Emission per fuel oil consumption	CO2 emission related to refinery development per fuel oil consumption	5.4	6.3	6.0	4.9	4.7	2.8	4.4	3.4	2.8	2.7
CO2 Emission	Total CO2 emission	8918.3	14444.2	17681.5	17634.1	17623.0	4607.8	10133.6	10097.3	10049.9	10038.8
Emission Intensity	CO2 emission related to refinery development per GDP	8.9	6.8	4.8	2.7	2.4	4.6	4.8	2.7	1.5	1.4
Oil Intensity	Total fuel oil consumption per GDP	1.7	1.1	0.8	0.5	0.5	1.7	1.1	0.8	0.5	0.5

From this comparison result, this study found that optimization of additional oil refinery development will increase fuel oil production per capita, self-sufficiency, and import of crude oil but decrease the fuel oil import. It will also decrease the cost of subsidy but increase the total emission, emission intensity, and emission per fuel oil consumption.

After the normalization process, this study also analyzed the energy security index based on each dimension with the result indicates that the Oil refinery development Optimization (OPT) scenario with the comparison of the BAU scenario:

1. It will increase the availability dimension due to improving fuel oil production and decreasing fuel import dependence
2. It will decrease the acceptability dimension due to increasing emission from the oil refinery
3. It will increase the affordability dimension due to the decreasing share of subsidy per government spending (higher refinery investment)
4. There will be no difference between two cases for intensity dimension
5. It will not increase the energy security index from 2018 to 2050 due to improvement of availability and affordability dimension but a decrease in acceptability dimension

The comparison of energy security indicators between BAU and OPT scenario is explained in Table 5.

Table 5. Normalization of energy security dimension in BAU and OPT scenario

With additional refinery development optimization

Parameter	2018	2028	2038	2048	2050
Availability	0.76	0.68	0.42	0.36	0.34
Affordability	0.29	0.65	0.80	0.78	0.78
Acceptability	0.42	0.26	0.29	0.51	0.54
Intensity	0.00	0.49	0.75	0.96	1.00
Energy Security Index	0.37	0.52	0.56	0.65	0.67

Without additional refinery development optimization

Parameter	2018	2028	2038	2048	2050
Availability	0.52	0.52	0.13	0.06	0.05
Affordability	0.16	0.58	0.71	0.75	0.75
Acceptability	0.77	0.30	0.58	0.75	0.78
Intensity	0.00	0.49	0.75	0.96	1.00
Energy Security Index	0.36	0.47	0.54	0.63	0.65

3.2.3 Oil Refinery System Dynamic Model in Indonesia

The system dynamic model will analyze the interaction among the oil sector's input and output parameters, especially from the oil refinery development perspective. The input of the system dynamic model will be divided from the demand side and supply side. Input from the demand side will be represented by the GDP, global oil price, and population. Normally, higher GDP and population growth will bring higher fuel oil consumption. On the other hand, the higher global oil price will decrease fuel oil consumption. Historically, Indonesia population has increased with 1.5% average growth from 1980-2014, while GDP increased almost five times in the same period with some decreasing point during the Asian financial crisis in 1997.

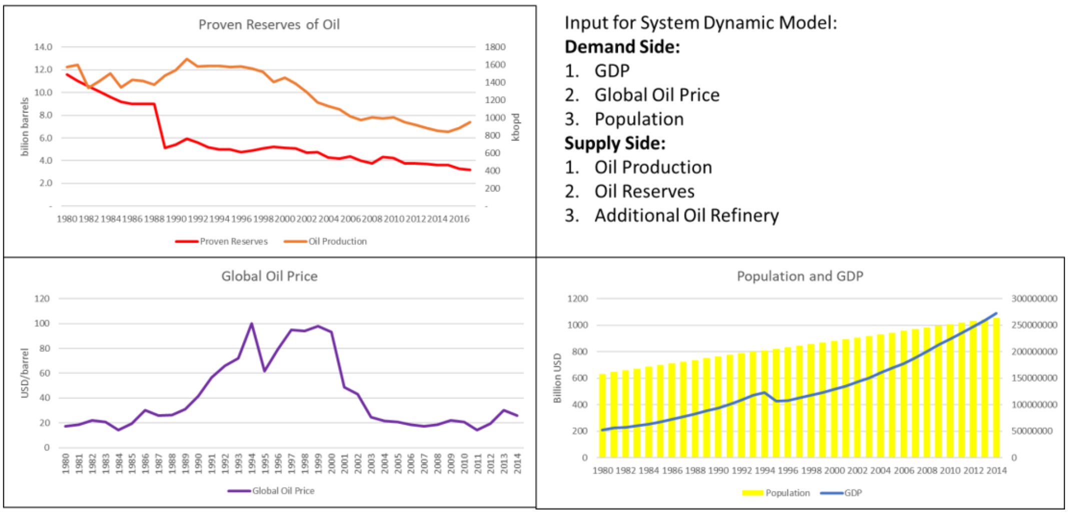


Figure 26. Historical data of system dynamic model input

Source: (Bank, 2018; Petroleum, 2018)

The global oil price has increased four times from around 20 USD/barrel to 100 USD/barrel during 1984-2000 but then decreased to a similar value until 2014. The supply side's input will include domestic oil production, oil reserves, and additional oil refinery. Higher domestic oil production, oil reserve, and oil refinery capacity will increase the crude oil and fuel oil production in the country. Oil production in Indonesia has just decreased due to no significant finding on new oilfield with the proven oil reserve also decreased with a similar trend.

System dynamic model will be derived with the following structure:

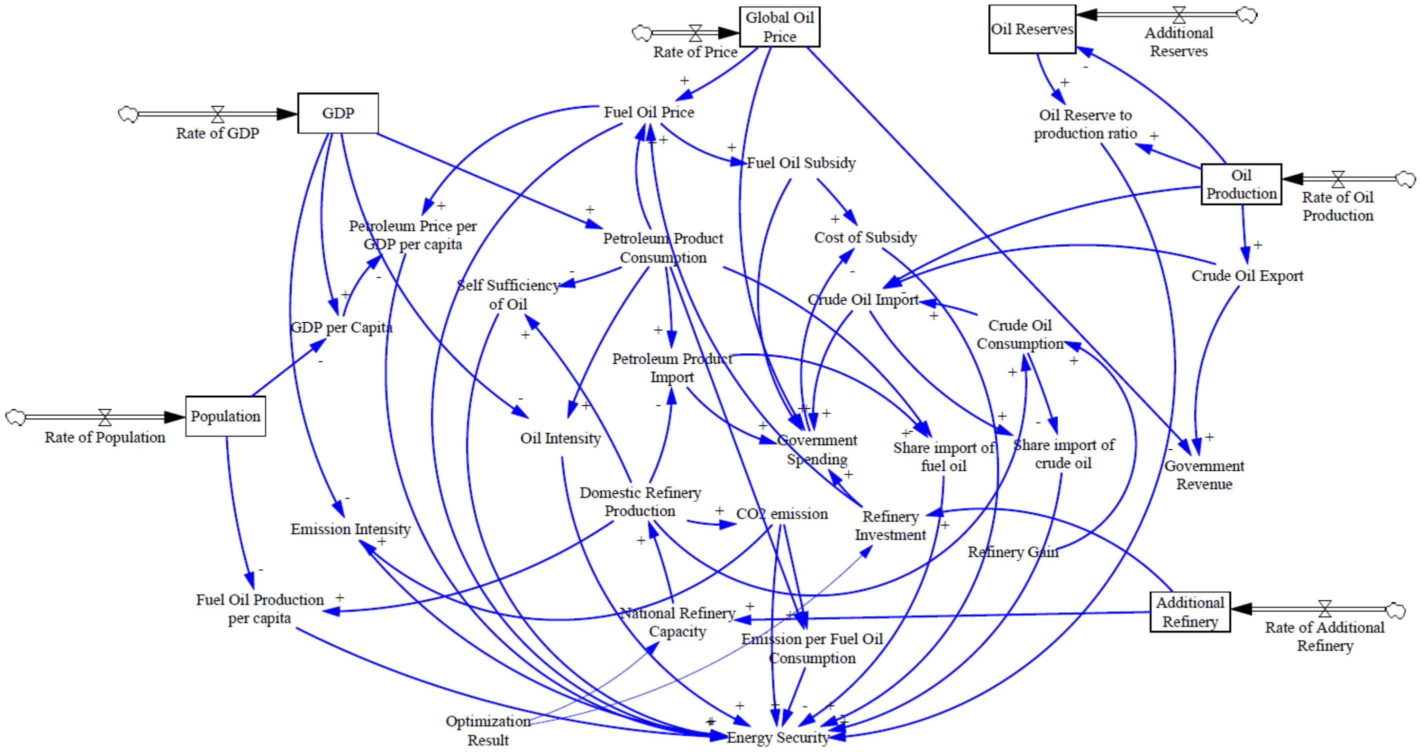


Figure 27. System dynamic model structure in oil refinery development

From the above structure, several equations among each parameter in the oil sector have been developed as follows:

Petroleum products or fuel oil consumption equations:

$PC_t = C_1 GDP_t + \varepsilon_{dt}$ where GDP_t: GDP at year t (15)

Petroleum products import equations:

$PI_t = PC_t - RP_t$ where RP_t: Refinery production at year t

$RP_t = RC_t \times \eta$ where RC_t: Refinery Capacity at year t (16)

$RC_t = ERC_t + ARC_t$ where ERC_t: Existing capacity at year t; (17)

ARC_t: Additional refinery capacity at year t (18)

Crude oil consumption equations:

$CC_t = RP_t - RG_t$ where RP_t: Refinery Production at year t; RG_t: Refinery Processing Gain at year t (19)

Crude import equations:

$CI_t = CC_t - (CP_t - CE_t)$ where CP_t: Crude Production at year t; CE_t: Crude Export at year t (20)

$CE_t = C_3 CP_t$ where C_3: Ratio of export over crude production (21)

$CR_t = CR_{t-1} + ACR_t - CP_t$ where CR_t: Crude Reserve at year t; ACR_t: Additional Crude Reserve at year t (22)

Fuel oil price equations:

$FP_t = C_4 OP_t$ where C_4: Ratio of fuel over the crude price (23)

Fuel subsidy equations:

$FS_t = C_5 FP_t$ where C_5: Ratio of fuel subsidy over fuel price (24)

Government spending equations:

$GS_t = (CI_t \times OP_t) + (PI_t \times FP_t) + FS_t + RI_t$ where RI_t: Refinery Investment (25)

Government revenue equations:

$$GR_t = CE_t \times OP_t \quad (26)$$

Refinery emission equations:

$EM_t = RP_t \times EF$ where EF: Emission Factor (27)

There will be some scenarios to analyze the impact of changing the input parameter on the energy security level and other oil sector parameters. The scenarios will be divided into six scenarios which are the Base scenario where there is no change in the input parameter, scenario 1 with higher additional oil refinery development rate per year, scenario 2 with higher GDP growth rate, Scenario 3 with the higher oil price, scenario 4 with higher oil production and scenario 5 with the higher population growth rate. The parameter change in the scenario analysis is explained in Table 6.

Table 6. Scenario analysis in system dynamic model

Case by the change in the demand or supply input	Additional Refinery Rate	GDP Growth Rate	Global Oil Price Rate	Oil Production Rate	Population Rate
Base	0%	5%	0.08%	-3.7%	0.5%
Case 1 Additional Refinery	1%	5%	0.08%	-3.7%	0.5%
Case 2 GDP	0%	7%	0.08%	-3.7%	0.5%
Case 3 Oil Price	0%	5%	0.16%	-3.7%	0.5%
Case 4 Oil Production	0%	5%	0.08%	-1.8%	0.5%
Case 5 Population	0%	5%	0.08%	-3.7%	1.0%

The system dynamic model result show that case 1 with additional refinery creates the best energy security, although increased crude oil consumption for the refinery input. The result of case 5 with higher oil production creates the worst energy security because it decreases more oil reserves, although it is also decreases crude oil import.

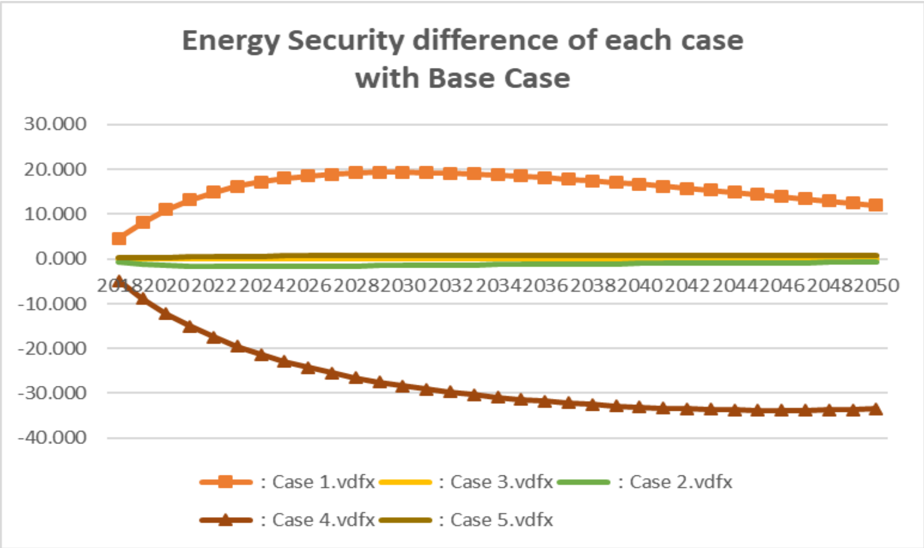


Figure 28. The difference of Energy Security Index for each case with Base Case

Case 2 with higher GDP, Case 3 Oil Price and Case 5 higher population growth will not significantly impact the energy security in Indonesia with yearly average rate difference is about -1.20%, -0.01% and 0.68%, respectively compared to the base case result.

The other result of the system dynamic model identifies that case 2 with higher GDP has the highest petroleum product consumption among the other cases. The petroleum product consumption in Case 2 will generate 1.27 times than other cases in 2050.

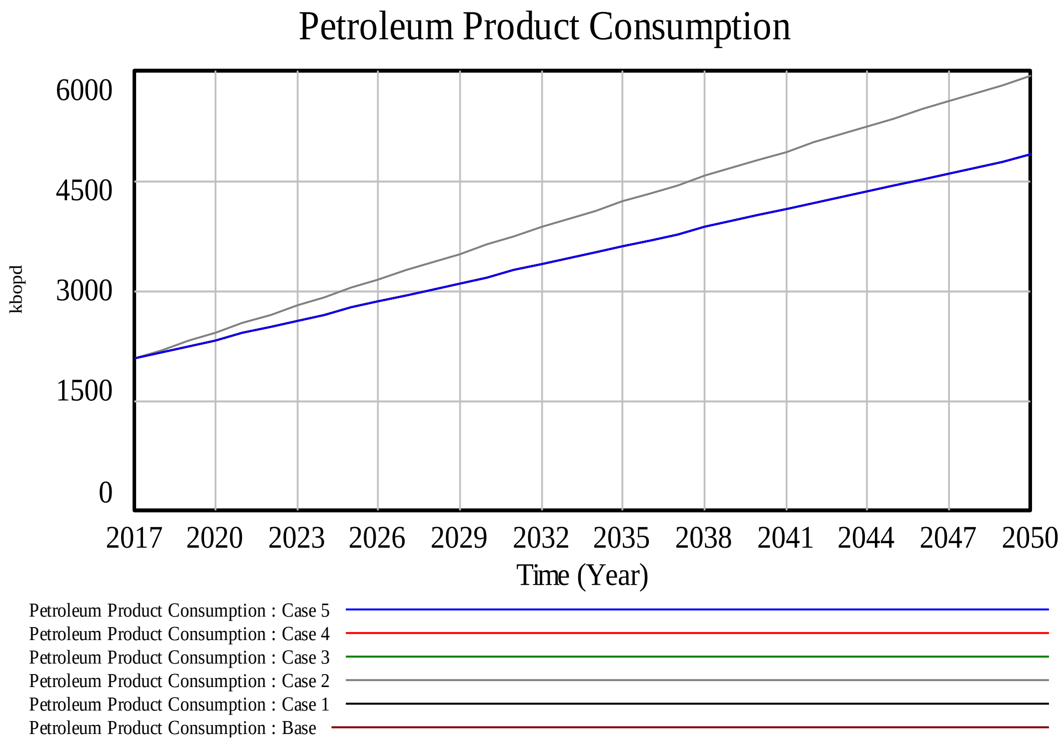


Figure 29. Petroleum Product Consumption Result

Case 1 with additional refinery consumes the highest crude oil consumption and produces more petroleum products. The crude oil consumption in Case 2 will generate 1.41 times than other cases in 2050.

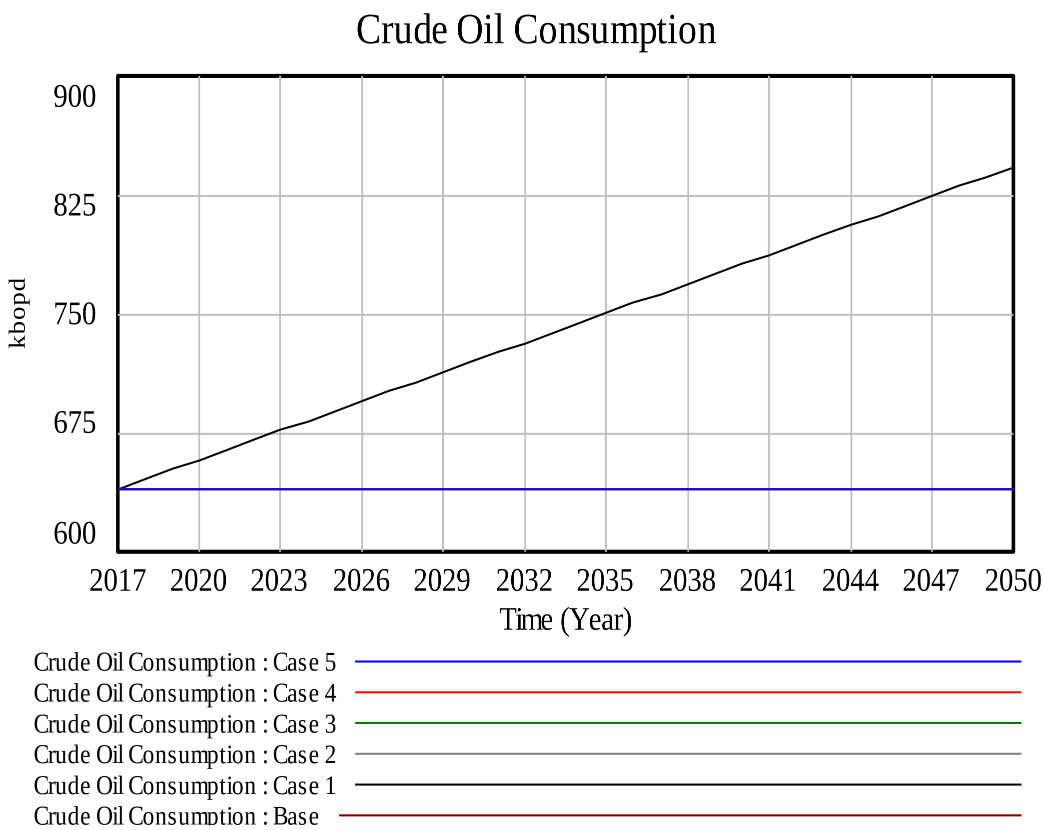


Figure 30. Crude oil consumption result

Case 4 with higher oil production will generate more oil for 1.66 times than other cases in 2050. The analysis also found that case 1 with additional refinery creates the highest crude oil import and lowest petroleum product import. Case 5 with higher oil production creates the lowest crude oil import, while case 2 with higher GDP will create the highest petroleum product import.

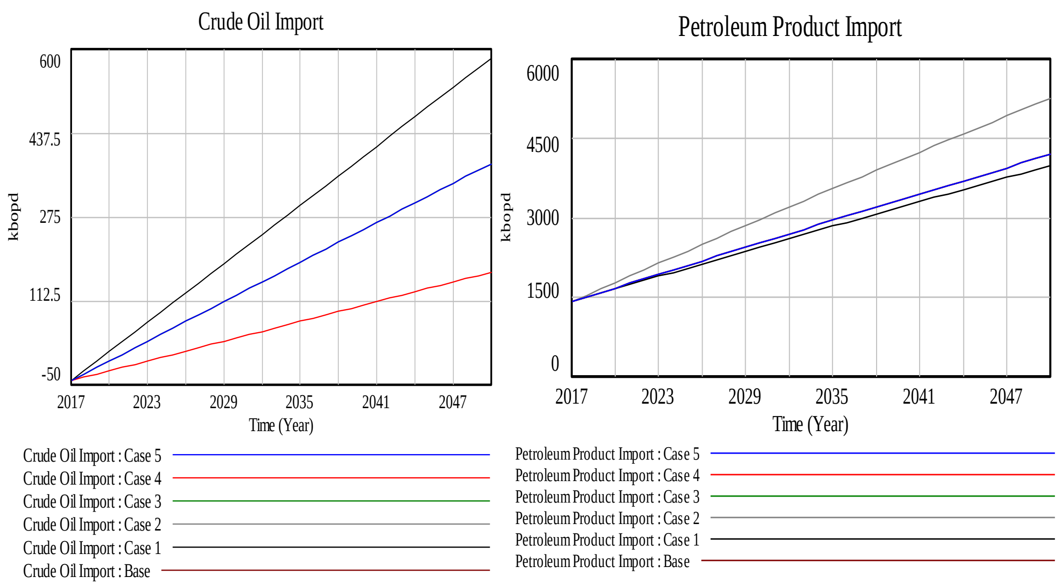


Figure 31. Crude oil and petroleum product import result in system dynamic model

The comparison of energy security index differences among each case has been conducted to see each case's impact on the energy security index in the base case. The findings in this analysis are as follows:

a. Case 1 Additional Refinery is the only case that increases the energy security index by 15.81% increasing on average

b. Case 2 Higher GDP will decrease the energy security index by decreasing 1.20% on average

c. Case 3 Higher Oil Price will decrease the energy security index by decreasing 0.01% on average

d. Case 4 Higher Oil Production will decrease the energy security index by decreasing 27.40% on average

e. Case 5 Higher Population will decrease the energy security index by increasing 0.68% on average

The result shows that the higher additional refinery development will increase the energy security index compared with the base case in a less refinery development and other cases. This study also tried to generate another case analysis with the change of oil reserve level. It means generating the impact of different additional oil reserves in the future to the energy security index. The result found that higher additional oil reserves will increase the energy security level. The findings in this analysis are as follows:

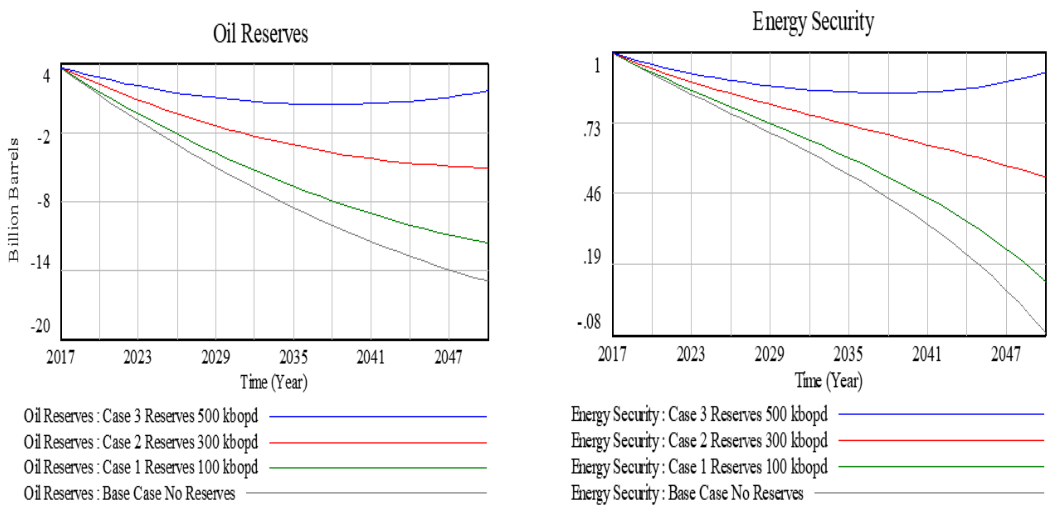
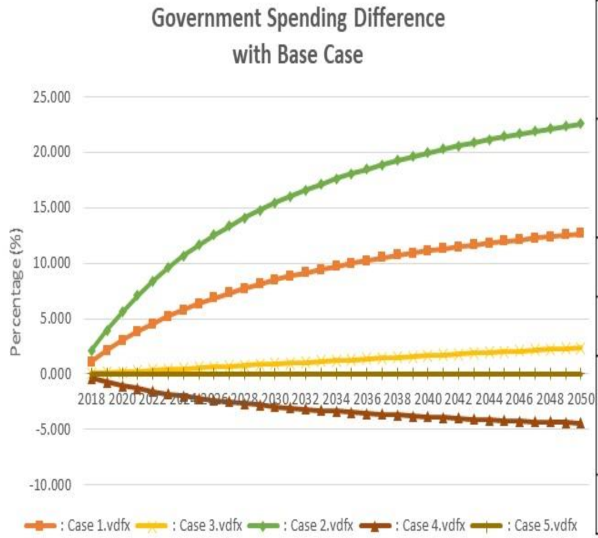


Figure 32. Case analysis with different level of oil reserves

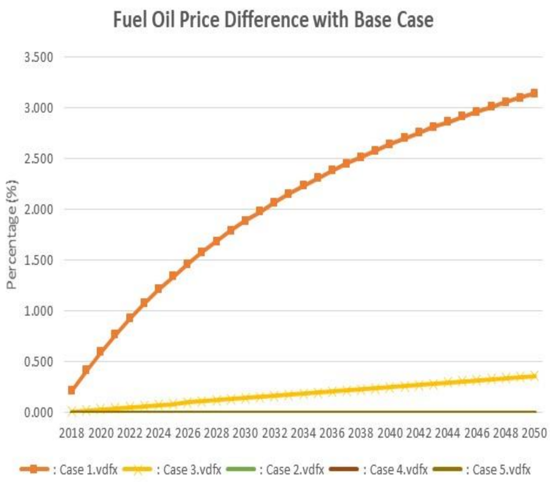
System dynamic analysis on the oil sector indicated that the oil sector's energy security index is not only influenced by the development of oil refinery but also several parameters such as additional oil reserve per year, rate of oil production, and lower fuel oil consumption. Higher additional reserve per year in Billion Barrel will increase oil reserve and resources level, decrease crude oil import, and maintain domestic oil production. Higher rates of oil production will increase crude oil production per capita, increase the self-sufficiency of crude oil, but at the same time also decrease the import of crude oil and oil reserve level. Increasing oil production without a new additional reserve will not increase the energy security index. The Indonesia's government may consider these two-parameter to increase the energy security index level by discovering of new oilfields and the introducing of an attractive fiscal regime for foreign direct investment in the upstream oil business. Furthermore, increasing the energy security index by the additional refinery development might bring negative impact especially to the cost impact such as increasing of government spending, fuel oil price, fuel oil price per GDP per capita, and fuel subsidy. The Government Spending comparison between each case and base case indicates that case 1 with a higher additional refinery rate will increase the government spending with an 8.83% difference. Case 2 with higher GDP will produce the highest government spending by 15.94% due to higher fuel oil consumption. Only Case 4 with higher increasing oil production shows a decreasing rate of government spending by 3.06% because of lower crude import. The least impact on government spending is Case 5 with a higher population growth rate.



Case Name	Result	Difference Yearly Ave rage Rate
Case 1 Additional Refinery	Increasing	8.83%
Case 2 GDP	Increasing	15.94%
Case 3 Oil Price	Increasing	1.22%
Case 4 Oil Product ion	Decreasing	-3.06%
Case 5 Population	No Impact	0.00%

Figure 33. Government Spending Difference of each case with Base Case

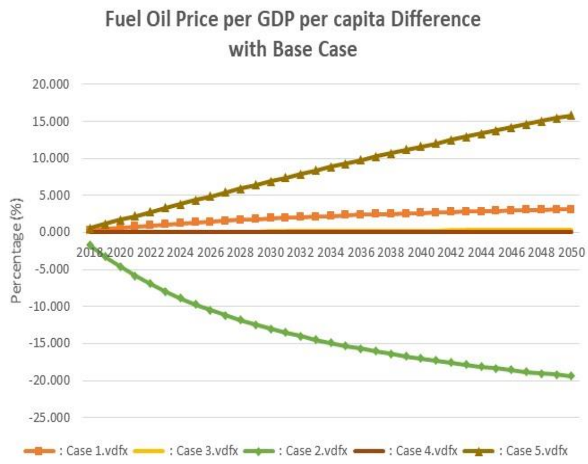
Fuel Oil Price has impacted by the global oil price and additional refinery investment. The fuel oil price between each case and base case indicates that case 1 with a higher additional refinery rate will increase fuel oil price with a 2.05% difference. Case 3 with higher crude oil price will produce increased fuel oil price by 0.19%. The least impact to fuel oil price is Case 2, Case 4, and Case 5.



Case Name	Result	Difference Yearly Average Rate
Case 1 Additional Refinery	Increasing	2.05%
Case 2 GDP	No Impact	0.00%
Case 3 Oil Price	Increasing	0.19%
Case 4 Oil Production	No Impact	0.00%
Case 5 Population	No Impact	0.00%

Figure 34. Fuel Oil Price difference of each case with Base Case

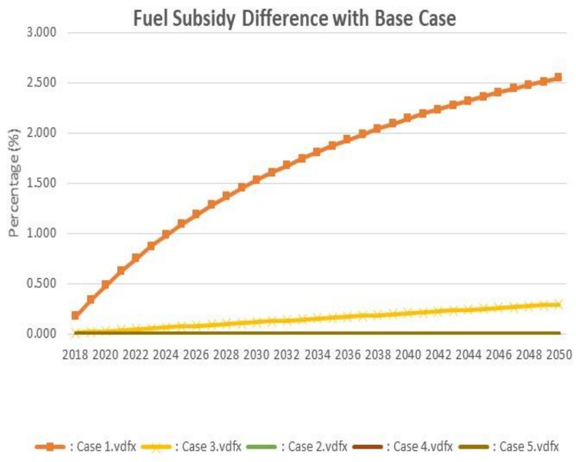
The Fuel Oil Price per GDP per capita between each case and base case indicates that case 1 with a higher additional refinery rate will create an increasing fuel oil price per GDP per capita ratio with a 2.05% difference. Case 5 higher population growth will produce the highest fuel oil price per GDP per capita ratio by 8.61% difference. Case 2 with higher GDP will produce lower fuel oil price per GDP per capita ratio by 13.52% due to higher fuel oil consumption. The least impact to fuel oil price per GDP per capita ratio in the Case 4 Oil production.



Case Name	Result	Difference Yearly Average Rate
Case 1 Additional Refinery	Increasing	2.05%
Case 2 GDP	Decreasing	-13.52%
Case 3 Oil Price	Increasing	0.19%
Case 4 Oil Producti on	No Impact	0.00%
Case 5 Population	Increasing	8.61%

Figure 35. Fuel Oil Price per GDP per capita difference of each case with Base Case

The Fuel subsidy comparison between each case and base case indicates that case 1 with a higher additional refinery rate will create the highest fuel subsidy with a 1.66% difference. Case 2 with higher GDP will also produce higher fuel subsidy by 0.15% due to higher fuel oil consumption. The least impact to fuel subsidy is the Case 3 Oil price, Case 4 Oil production, and Case 5 population growth rate.



Case Name	Result	Difference Yearly Average Rate
Case 1 Additional Refinery	Increasing	1.66%
Case 2 GDP	Increasing	0.15%
Case 3 Oil Price	No Impact	0.00%
Case 4 Oil Production	No Impact	0.00%
Case 5 Population	No Impact	0.00%

Figure 36. Fuel Subsidy difference of each case with Base Case

The increasing energy security from the higher additional rate of refinery may bring negative impact to the increasing government spending, fuel price, fuel price per GDP per capita ratio and fuel subsidy. The finding in this analysis shows that the energy security index in Indonesia will get higher value in several conditions as follows:

a. Optimized Refinery Capacity

b. Lower Fuel Oil Consumption

c. Higher rate of additional oil reserves

On the other hand, the energy security index will get lower value through several conditions: higher oil production (decrease crude oil import but also decrease the oil reserves), higher GDP (increase petroleum product consumption), higher population growth and global oil price

3.2.4 Government Support for Oil Refinery Development

According to (Keuangan, 2017), Indonesia's government budget in the period of 2007-2017 indicates that the total budget is in the range of 82-160 Billion USD. The highest share of the budget is allocated to the transfer to local government and rural development. The second highest is the subsidy, both oil and non-oil subsidy (electricity). The yearly capital cost from the government budget is in the range of 8.2-18.8 Billion USD for all government projects and infrastructure. The average capital expenditure in Indonesia's government budget is about 13.81 Billion USD per year.

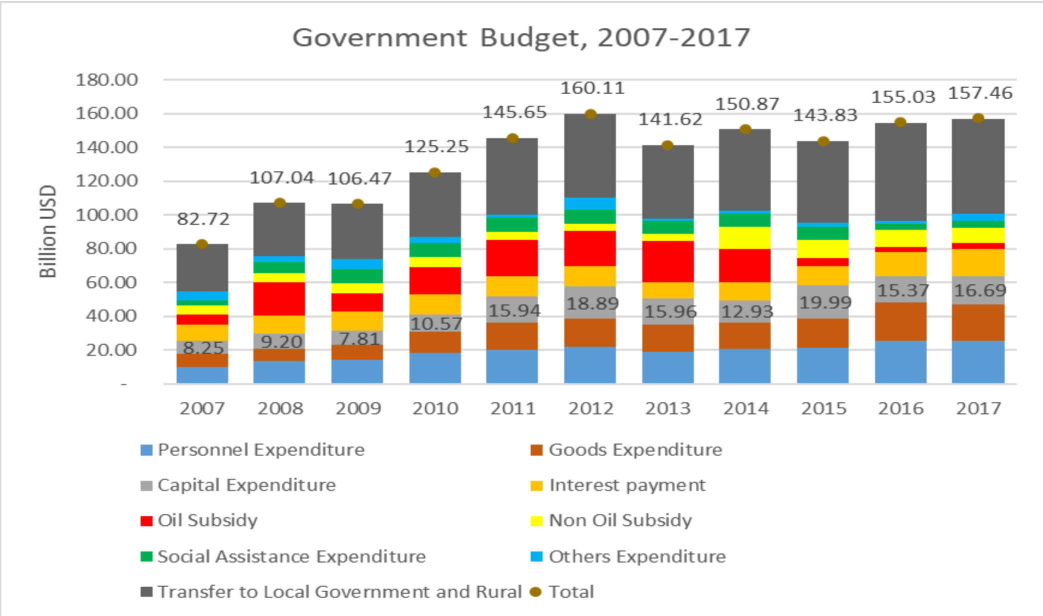


Figure 37. Indonesia Government Budget, 2007-2017

Source: (Keuangan, 2017)

An additional refinery development will require 90.86 Billion USD during the 2018-2050 period with the yearly average budget requirement is about 2.84 Billion USD per year. It is shown that the additional refinery development will require about 20.56% of average capital expenditure in the government budget only for oil refinery project. The percentage can be increased to 37.68% with the current government plan to build new oil refinery with capacity of 906 kbopd in 2021-2024 through Grass Root Refinery Project (GRR) and 302 kbopd in 2019-2023 through Refinery Development Masterplan (RDMP) Project. The optimized refinery development will need an additional 24.99 Billion USD for 1st 10-year development, 11.40 Billion USD for 2nd 10-year development, and 54.47 Billion USD for the last 3rd 12-year development. The total oil refinery development cost might be a burden for government budget. This fact shows that the government can't rely on its budget for additional refinery development.

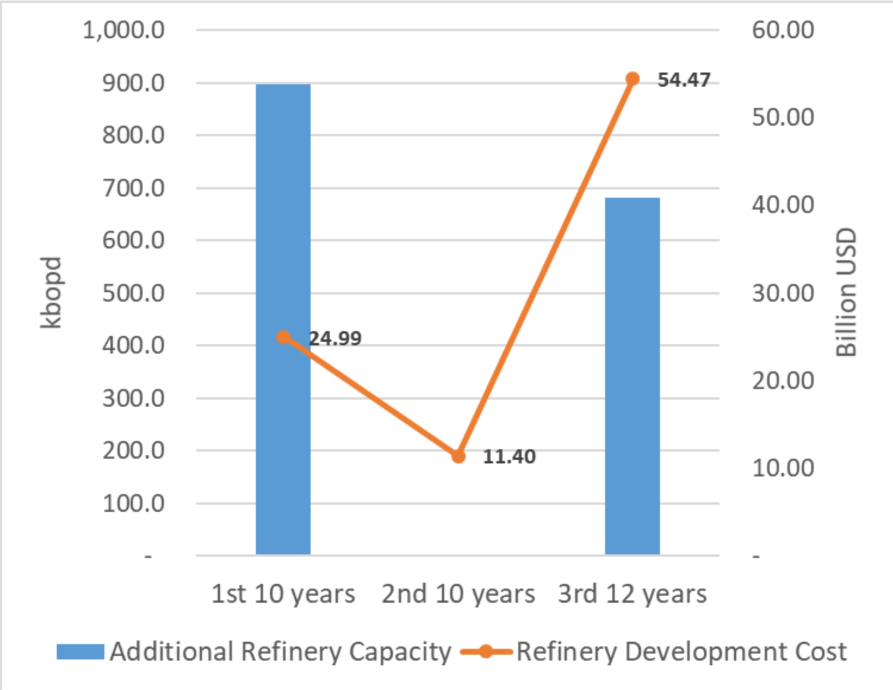


Figure 38. Additional Refinery Capacity and Development Cost

To support Indonesia's economic growth and social life, the current government initiate rapid development of basic infrastructure, including transportation, telecommunication, sanitation, and energy. However, the development of infrastructure in Indonesia will face many challenges, especially in the financial capabilities and land acquisition issues. Geographical conditions of Indonesia that consist of 17,540 islands will also threaten the development of these infrastructures. The government has limited financial capabilities so that government funds cannot fully support infrastructure development. The role of the private sector from the local and international corporations shall be encouraged to accelerate the development of infrastructure in Indonesia.

Traditionally, the infrastructure in one country is supported and owned by the government or executed by the State-Owned Enterprise (SOE). However, the introduction of the private sector in the development of infrastructure has been initiated due to the reduction of a financial burden for the government and encouragement of more efficient execution by the private sector(Kirkpatrick et al., 2004). Then, the participation of the private sector has increased in infrastructure development of developing countries by about 2500 projects in 2001(Izaguirre, 2003).

Foreign direct investment (FDI) is one way to solve the government's limited financial capabilities on oil refinery development. FDI can be conducted when a private sector in one country would like to establish their business operation in another country through some cooperation methods such as a new wholly-owned affiliate, acquiring a local private company, or forming a joint venture with the private cooperation in the destination country(Moran, 2012). FDI can be flowing to the destination country in the form of supporting infrastructure. FDI in developing countries will offer strong financial sources to support the transfer technology, organizational and managerial practices, and access to the international market (Alfaro et al., 2004). With the stable economic growth and political situation, the number of FDI in Indonesia has increased in recent years with the average annual inflow FDI in Indonesia is about 8 Billion USD since 2005(Moccero, 2008). This condition is the result of simplified policy and procedure for foreign investment, better coordination among government institutions, and tax incentives.

A previous study shows that higher infrastructure development would increase the FDI inflows in Indonesia(Fitriandi et al., 2014). The development of infrastructure, especially in the energy sector is crucial for the Indonesian government. The recent government emphasizes attracting FDI inflows by introducing a Public-Private Partnership (PPP) scheme[1]. Ambitious infrastructure plans could not be supported by government funding and local private investment and foreign investment through FDI inflows.

One of FDI forms to develop infrastructure through is by conducting a Public-Private Partnership (PPP) mechanism. PPP or Public-Private Partnership is a specific relationship between the government and private sector in the development of infrastructure generally and energy and technology specifically(Felsinger, 2008). The basic idea is to develop a corporation in a particular project between government or public sector authorities (local government, city councils, municipalities) and parties that operate outside public sectors. The responsibility of these parties is to set service standards, price, monitoring process, and get financial benefit during the project's operations(Sovacool, 2013). Furthermore, the recent PPP model has involved the participation of other entities instead of private companies such as multilateral development banks, microfinance institutions, and nonprofit organizations.

This policy was under the supervision of the Indonesia National Agency of Planning and Development(Indra, 2011). The objective of this policy is to encourage the

[1] https://www.fdiintelligence.com/article/75303 accessed on November 19, 2020

active participation of the private sector in Indonesia's infrastructure development. The projected risk in this partnership will be shared between the government and the private sector. Most PPP project in Indonesia was established through BOT (Build, Operate, Transfer) and BOO (Build, Own, Operate) scheme and the selection of private company shall be conducted on an open tender process(Kim et al., 2018). The government of Indonesia will support the implementation of the PPP project through direct support such as additional capital cost or operating subsidies, land acquisition, government guarantee support, tax incentives, and guarantee fund for infrastructure development(Bappenas, 2018). The Government of Indonesia (GOI) has taken a series of major steps to refine the PPP Policies and regulatory framework to improve the attractiveness and competitiveness of the government's PPP program.

These are the following regulations that were introduced by the government, including:

1. Presidential Regulation Number 38 the Year 2015 establishing the cross-sector regulation framework for implementing PPPs in the provision of infrastructure. it includes detailed stipulations about the unsolicited proposal, cooperation agreement, return on investment with the payment by the user in the form of tariffs (user charge) or availability payment, government support and guarantee to project;
2. Presidential Regulation Number 78 the year 2010 regarding government guarantee on PPP infrastructure project;

The implementation of financing alternatives on the PPP scheme in Indonesia are classified into three groups that divided by the project feasibility aspect and scheme aspect as follows:

A hybrid financing scheme is strongly recommended if the project feasibility is economically viable but financially not viable. The corporation will involve the government role in the construction stage and the private sector role in the operation and maintenance stage. PPP with government support is strongly recommended if the project feasibility is economically viable but financially marginal. The corporation will involve government role and private role in the construction stage and private sector role in the operation and maintenance stage. A regular PPP scheme is strongly recommended if the project is economically and financially viable. The construction, operation, and maintenance stage will be the responsibility of the private sector only.

The implementation of Oil Refinery Development in the PPP scheme will involve the role of the central government, private sector, and international development bank. Each of them will have the responsibility to ensure that this scheme is developed and operated well. High capital cost, technical limitations, social acceptance of local communities, and land acquisition issues will stimulate difficulties in the development of oil refineries. Based on these reasons, the PPP scheme of Oil Refinery development in Indonesia may utilize the scheme of a PPP project with government support. The proposed responsibility of each stakeholder in the implementation of oil refinery can be illustrated in Figure 39.

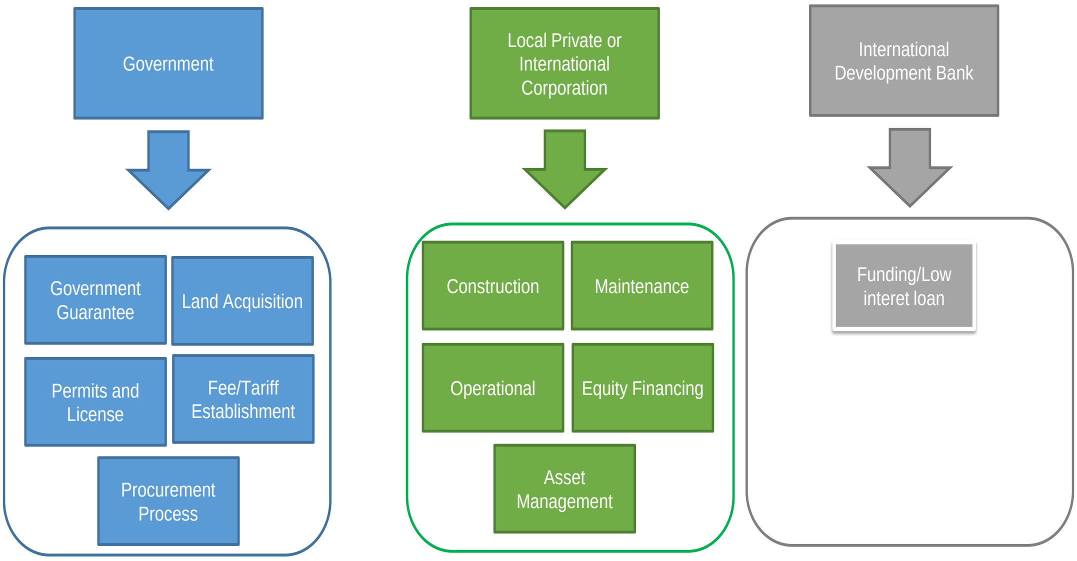


Figure 39. Responsibility of Stakeholders in Oil Refinery Development

The responsibility of the government will include the issuance of government guarantees, issuance of business permits and licenses, establishment of fee and tariff structure that will adapt by the user, procurement process of each refinery, and land acquisition process. The procurement process will choose the selected bidder who has the rights to construct and operate a particular refinery. Land acquisition is believed as the most difficult issues in infrastructure construction in Indonesia. If a private company conducts the land acquisition process, then the price of the land will be very expensive and the local communities stricter to give their land. The role of the government in the land acquisition process is to make sure that the local people will be easier to be persuaded due to this project will be conducted for national and social benefits(Suhadi, 2018).

The responsibility of the private sector will include construction works, operational and maintenance works, conduct equity financing, and asset management. The private sector will establish the Special Purpose Company (SPC) as a business entity that will have an agreement with the other stakeholders. After the Private company is selected by the government in the procurement process, SPC will have a PPP agreement with a government agency. The private sector will give certain investments from their equity as capital to conduct the construction process. The private sector through their SPC may select the EPC contractors for the construction phase and O&M operator for the operation phase. All of the refinery assets will be managed by the SPC before the transfer process to the government after the PPP agreement is finished.

The responsibility of the International Development Bank will include the initial preliminary study funding and low-interest loan financing for SPC. As we know that Refinery Development will require high investment and the payback of the investment will take a long period, just stated in the PPP agreement. The role of an international financial entity like the International Development Bank in this project is very important to assist, with their low-interest loan. Each project may be funded by mixed financing between private equity and a bank loan with the ratio is 30:70 or 20:80. The repayment period of the loan will be expected in 8-15 years of refinery operation.

The proposed implementation process of Oil Refinery Development in Indonesia is explained as follows:

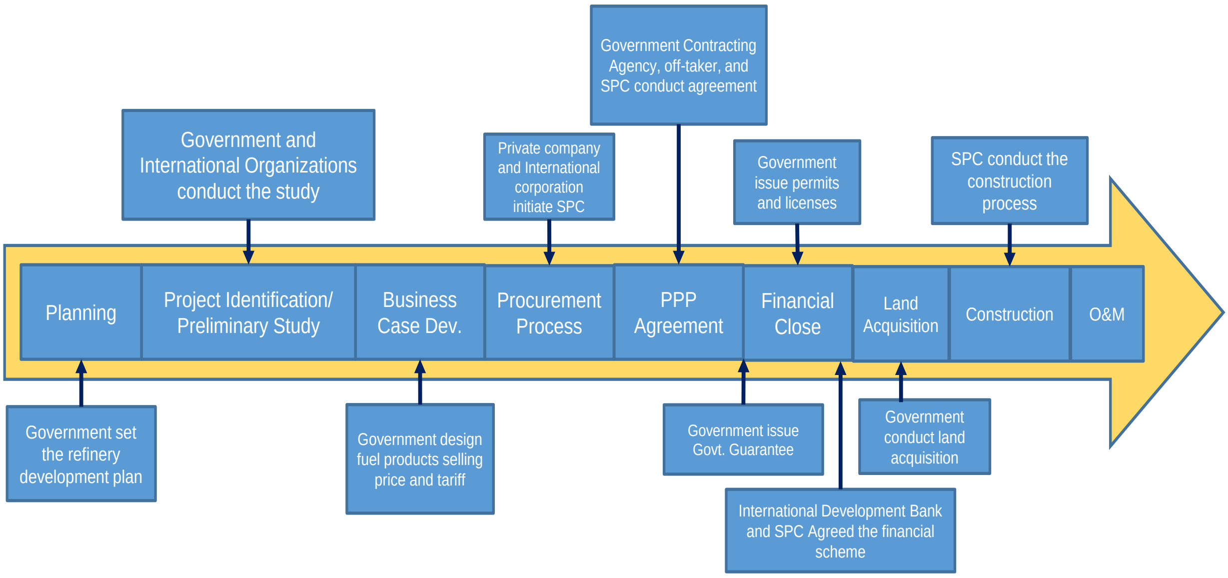


Figure 40. Implementation Process of Indonesia Refinery Development

Source: (Bappenas, 2018)

An initial preliminary study is also important to identify the technical and economic feasibility of oil refinery development. With the corporation between the government, International Organizations, and International Development banks, the study result may produce a comprehensive perspective about this concept and propose the most suitable process that needs to be done.

The implementation process starts with the planning stages, where the government initiates the national refinery development plan. This planning will include the grand design of the oil refinery construction plan every year, required capacity, technology, and specification plan. Then, the planning will be derived into several project identifications. Each project will be decided based on the location priority, demand profile, technology selection, and transportation constraint. To get a comprehensive approach to each project, the government and international organizations may conduct the preliminary feasibility study, including the analysis of site identification, existing fuel supply and demand, legal and regulatory framework, general technology selection and design, implementation plan, and financial analysis. After the preliminary study, the government will discuss business case development. In this phase, the government will also design the fee or tariff establishment to ensure that the selected business entity will get a proper return on their investment. All of the possible risks shall be analyzed in this phase and the government may put some risk into the contract in the PPP agreement for risk mitigation. The procurement process of the refinery developer will be conducted by the government. It will select the most suitable bidders from the consortium of a local private company and international corporation who have capabilities in providing the best option based on the technical and economic judgment of each refinery project. In this phase, the private company shall initiate the Special Purpose Company (SPC) establishment to conduct all of the legal and business activity in this project. SPC from selected bidders will make a PPP agreement with the Government Contracting Agency that will include the fee/tariff, the right and obligation of each party, force Majeure issue, implementation plan, contract term, and any other legal issue.

Commonly, SPC will get one year of financial close period, and during this period, the SPC will get business permits and license from the government. The financing source and disbursement method will also be discussed between SPC and the International Development Bank or any financial institutions that provide loans for the project. The land acquisition process will be conducted by the government to ensure a faster and safer process. Land prices will be lower if the initiator is the government. After the land acquisition process is over, SPC can conduct engineering, equipment procurement, and construction work. Commonly, this phase took 7-8 years of work depending on the technical and social complexity of the project. SPC will also conduct the operation and maintenance process after the refinery was built to ensure it will work properly during the PPP agreement period. The asset ownership and management will be transferred to the government after the contract period is finished.

This study will also propose the Return on Investment (ROI) method for the implementation of the PPP scheme in oil refinery development. SPC will get the payment from GCA through availability payment. Availability payment is a long-term agreement with fixed periodic payments to a private sector partner for grid facilities and services(KPMG, 2009). GCA will ensure the payment with the contribution of user tariff payment and government budget allocation. This mechanism will be stated in the PPP agreement.

The financial benefit from availability payment will be used by the SPC to give back the equity allocation from the private mother company and credit from the lender or bank. The equity allocation from the private sector will be guaranteed by a certain percentage to get back their initial equity investment. On the other hand, the loan allocation from the Bank will be guaranteed by the payment of principal loan payment and interest loan payment. The capital investment for the lender or private mother company will be used to conduct construction works that started in the EPC contract and operation and maintenance works that stated in the O&M contract. Uganda is now executing PPP mechanism in oil refinery development by the development of 60 Kbopd Uganda Oil Refinery in 2018[2]. Indonesia is now offering an oil refinery project under the PPP scheme in Bontang with the expected capacity of 300 Kbopd in 2024[3].

This study will also propose the Return on Investment (ROI) method for the implementation of Oil Refinery development. SPC will get the payment from GCA through availability payment. Availability payment is a long-term agreement with fixed periodic payments to private sector partners for grid facilities and services(KPMG, 2009). GCA will ensure the payment with the contribution of user tariff payment and government budget allocation. This mechanism will be stated in the PPP agreement.

The financial benefit from availability payment will be used by the SPC to give back the equity allocation from the private mother company and credit from the lender or bank. The private sector's equity allocation will be guaranteed by a certain percentage to get back their initial equity investment. On the other hand, the loan allocation from the Bank will be guaranteed by the payment of principal loan payment and interest loan payment. The capital investment for the lender or private mother company will be used to conduct construction works in the EPC contract and operation and maintenance works

[2] Biryabarema, Elias (10 April 2018). *"Uganda signs agreement with investors to build oil refinery"*. Reuters.com. accessed on November 19, 2020
[3]https://www.world-today-news.com/pertamina-is-looking-for-new-partners-in-the-bontang-refinery-project/ accessed on November 19, 2020

stated in the O&M contract. The proposed return of investment methods will be explained in Figure 41.

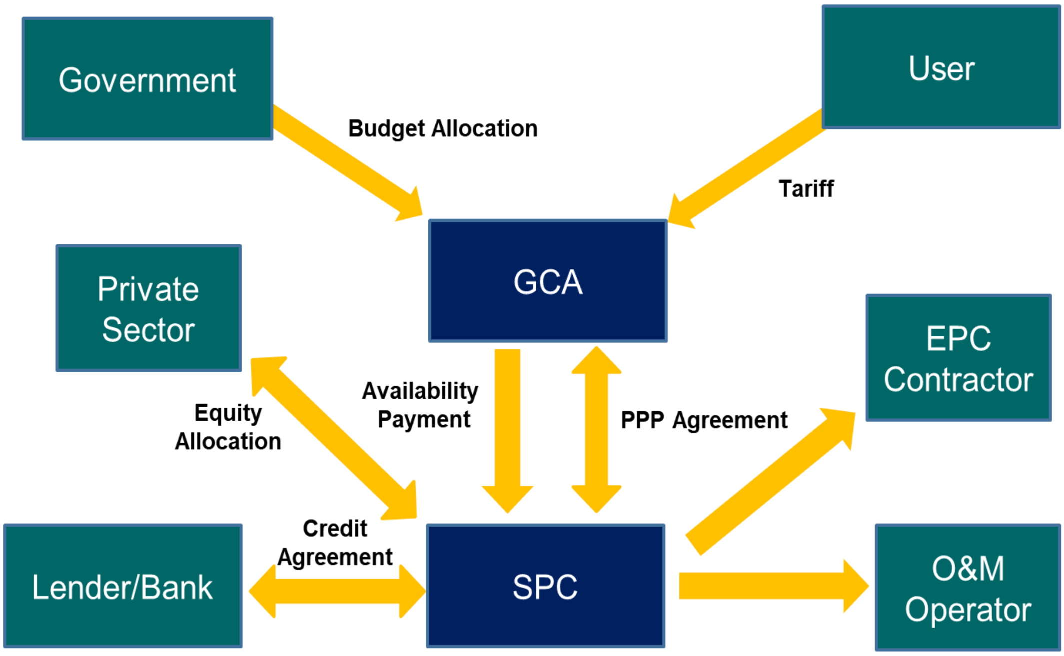


Figure 41. Proposed Return on Investment Method

Source: (Bappenas, 2018)

3.3 Conclusions

To support the oil refinery development in Indonesia, this study recommends some conclusions and recommendations for the Government of Indonesia, in the terms of optimization capacity of refinery, the potential of financing source, the reduction of fuel oil import, impact on energy security index, and system dynamic analysis and the introduction of electric vehicle analysis with details as follows:

1. The proposed refinery development in Indonesia will be divided into three periods of development, which are the 1st 10-year period (2018-2027), 2nd 10-year period (2028-2037), 3rd the 12 years (2038-2050). The optimization result shows that Indonesia needs an additional refinery with 898 kbopd (1st period) and 682 kbopd (3rd period). There is no need to build additional refinery development in the 2nd period (2028-2037) due to 900 kbopd additional new refinery will be added as stated in the government plan in 2021-2024. Cumulative additional refinery development from 2018-2050 by 1,580 kbopd or equal to 135.4% of the existing capacity in 2017 with 1,166 kbopd. This result shows that Indonesia has to double its refinery development for 2018-2050 to reduce fuel oil import dependence.
2. To reduce the fuel oil import dependence in Indonesia, the required refinery development cost from 2018-2050 is 90.86 Billion USD. This paper encourages the Indonesian government to seek an alternative source of financing for refinery development through crude export revenue or increasing the petroleum product price as a part of the effort to secure its energy security. The analysis results show that the

percentage of crude export revenue that needs to be collected every year as a source of refinery development financing is about 157.91% of total crude oil export revenue, which means that the government cannot consider this option. On the other hand, the percentage of petroleum prices that need to be added every year as refinery financing source is about 2.46%.

3. The additional refinery development will decrease the fuel oil import from 711.48 Billion USD to 311.59 Billion USD. It will save 399.89 Billion USD or 56.2% cost saving.
4. Refinery development Optimization impact to the energy security dimension:
    a. It will increase the availability dimension due to improving fuel oil production and decreasing fuel import dependence
    b. It will decrease the acceptability dimension due to increasing emission from the oil refinery
    c. It will increase the affordability dimension due to the decreasing share of subsidy per government spending (higher refinery investment)
    d. There will be no difference between two cases for intensity dimension
    e. It will increase the energy security index from 2018 to 2050 due to improvement of availability and affordability dimension but the decrease acceptability dimension

5. The system dynamic analysis shows several results as follows:
   a. Case 1 Additional Refinery is the only case that increases the energy security index by 15.81% on average
   b. Case 2 Higher GDP will decrease the energy security index by decreasing 1.20% on average
   c. Case 3 Higher Oil Price will decrease the energy security index by decreasing 0.01% on average
   d. Case 4 Higher Oil Production will decrease the energy security index by decreasing 27.40% on average
   e. Case 5 Higher Population will decrease the energy security index by increasing 0.68% on average
6. The Energy Security index in the oil sector is not only influenced by the development of oil refinery but also several parameters need to be considered by the government policy such as additional oil reserves, oil production rates, and fuel oil consumption.
7. Energy Security index from the perspective of oil refinery development will get higher value in several conditions which are a higher rate of additional oil reserves, optimized Refinery Capacity, and lower Fuel Oil Consumption through the introduction of electric vehicle on passenger vehicle and motorcycle
8. On the other hand, the energy security index will get lower value through several conditions:

a. Higher Oil Production (decrease crude oil import and oil reserves)
b. Higher GDP (increase petroleum product consumption)
c. Higher Population
d. Higher Global Oil Price

9. The increasing energy security from the higher additional rate of refinery may bring negative impact to the increasing government spending, fuel price, fuel price per GDP per capita ratio and fuel subsidy
10. Due to the limited government budget, the development of additional oil refineries can be encouraged by introducing the Foreign Direct Investment (FDI) through the Public-Private Partnership (PPP) scheme. The international corporation can form a joint venture with a local private company and have a PPP agreement with the Government Contracting Agency for the operation period of the oil refinery to guarantee its return of investment.
11. The Government of Indonesia can use this research as useful information in improving the domestic refinery capacity and support this plan with new mechanism and policy to engage public contribution in reducing import fuel dependence through the increasing the price of petroleum products;
12. This study results can be used as supporting information to justify increasing refinery capacity project in Indonesia to improve its energy security level. This research can also be the starting point for the government to solve the fuel import dependence and start appropriate investment in increasing refinery capacity.

Chapter 4. The Development of Power Generation in Indonesia: Optimization and System Dynamic

4.1 Introduction

The availability of energy is a crucial parameter to support economic growth and human well-being. Human life depends on the energy supply as the energy grows to support all human activity. The need for flexible and environment-friendly energy supply is increasing, especially from electricity provision. Electricity can be produced by various of primary energy such as coal, natural gas, oil, nuclear and renewable energy. Electricity provision is usually based on the optimal utilization of domestic energy potential and technology to generate electricity. Recently, the requirement of low emission electricity has been widely introduced in the agenda to reduce the impact of climate change and pollution. Clean, affordable, easy to access and adequate quality of electricity is needed in terms to improve energy security from the power generation perspective.

The energy security concept indicates one country's effort to deliver uninterrupted availability of energy sources at affordable prices. In the beginning, the concern of energy security is the quantity of energy and its affordability issue. The concept is then growing over time, depending on the dynamic global energy situation and political economy trends. Energy security has been the crucial parameter for energy policy. Many countries get a direction to do energy transition from heavily dependent on fossil fuel to diversify energy sources with renewable energy to reduce the emission or low carbon transition.

The transition also needs to consider the system's level of reserve margin when fossil fuels are replaced by renewable energy. Electricity has not been looked quite important, like oil and natural gas provision at the beginning. However, the utilization of electricity with progressive, growing consumption all over the world has made electricity one of the parameters to be considered in energy security. Electricity is one of the largest sources of greenhouse gases. Environmental concern is now heavily linked to the energy security concept. Electricity provision shall pay more attention to reducing the emission, especially in the power generation sector.

Indonesia has declared its commitment to reduce the CO_2 emission and climate change impact by putting 23% of renewable energy share target for energy mix in 2025 and 31% in 2050. However, this country is heavily relied on the utilization of coal to generate cheap electricity. This decision impacts the high CO_2 emission from the burning of coal in the powerplant, especially the coal for domestic use is categorized as low-rank coal. With the same amount of electricity, it takes more low-rank coal to be burned for Indonesia's coal powerplant. The decision on using coal as a backbone of power generation is coming from an economic perspective, and the clean energy transition target put coal as the lowest option for power generation. It will be difficult for Indonesia to reach a clean energy transition target if they have to minimize coal's role in power generation. The power generation sector couldn't rely on other fossil energy options such as oil and natural gas due to its depleted resources.

Indonesia located on the equator and consists of myriad islands, has abundant renewable energy sources such as geothermal, biomass, hydro, wind, and solar. The total power generation capacity in 2018 is 61.99 GW, with the electrification rate reach almost 97.1%. Recent conditions show that Indonesia's electricity consumption has increased almost 2.5 times from 2000-2017, while power generation also grew in a similar trend. Total electricity consumption in 2018 is 267 TWh.

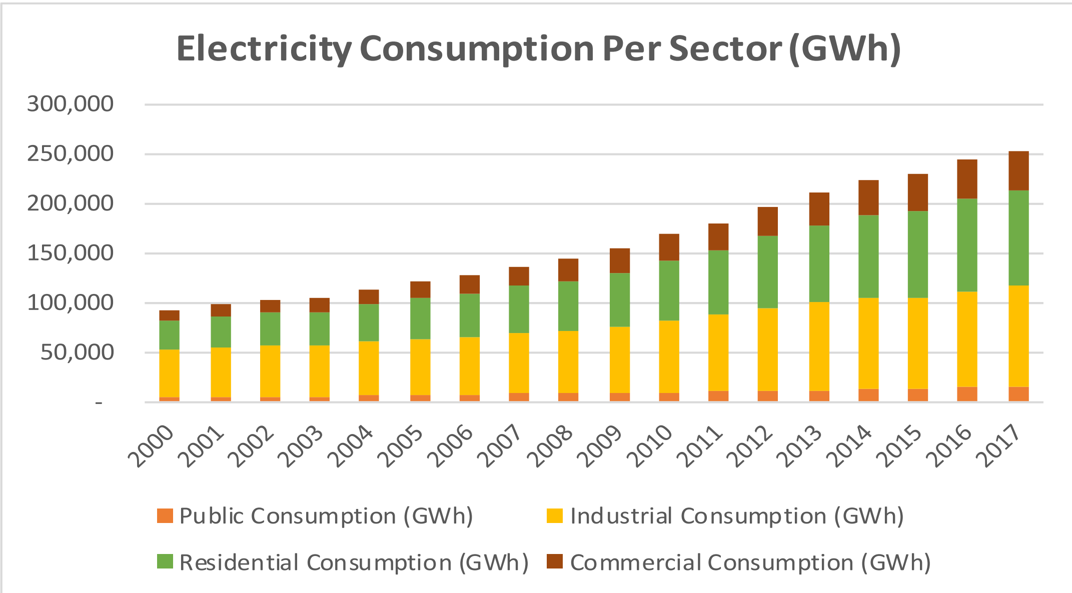


Figure 42. Electricity consumption per sector in Indonesia in 2000-2017

Source: (Ketenagalistrikan, 2018)

The highest share of electricity consumption is coming from the industrial sector by 44%, followed by the Household sector (35%), Commercial sector (15%), and Public sector (6%). The electricity consumption per capita reached 1,021 kWh per capita in 2018. Most of Indonesia's part has electricity access with low access is now only occurring on the eastern side of the country especially Maluku, Papua, and Nusa Tenggara Island. The major concern is the quality of electricity, where many areas in Indonesia still can't enjoy 24 hours of adequate electricity. Electricity customer in Indonesia has increased from 28 million customers in 2000 to 68 Million in 2017. It was dominated by the Household customer (90%) followed by Industrial customers (5%).

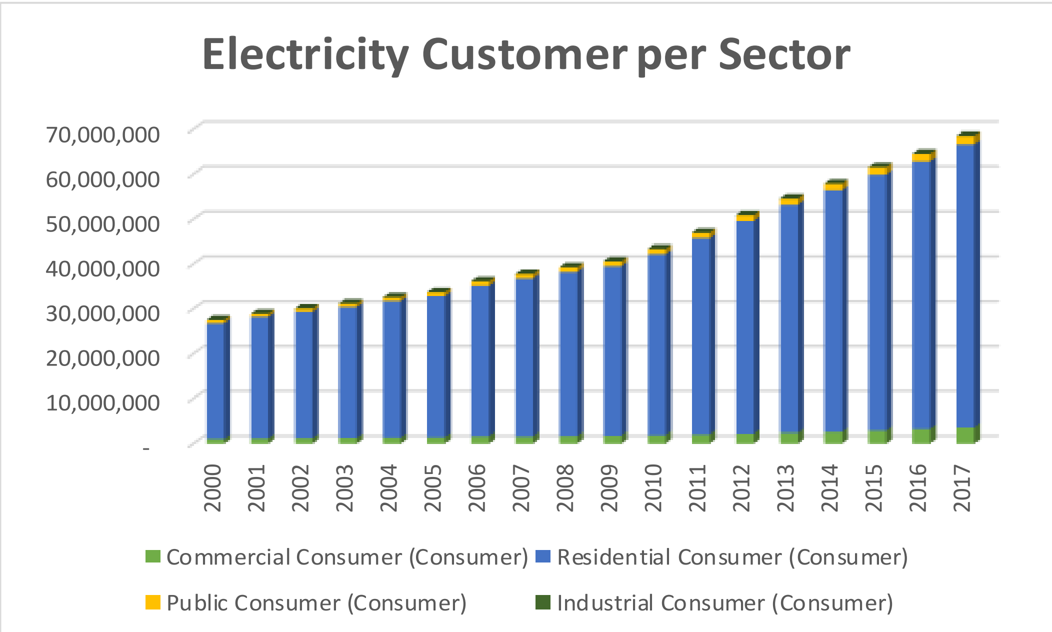


Figure 43. Electricity customer in Indonesia, 2000-2017

Source: (Ketenagalistrikan, 2018)

The electricity tariff in Indonesia also provides a subsidy mechanism from the government for underdeveloped and low-income families. The number of electricity subsidies in 2018 is about 3.84 Billion USD. High electricity consumption with low quality of electricity, high subsidy, coal-dependent power system will make it difficult for Indonesia to improve its energy security through low carbon energy transition mechanisms and renewable energy sources. Indonesia's highest average electricity tariff is the commercial sector for 980 IDR/kWh (6.5 cUSD/kWh), and the lowest one is the residential sector for 650 IDR/kWh (4.3 cUSD/kWh).

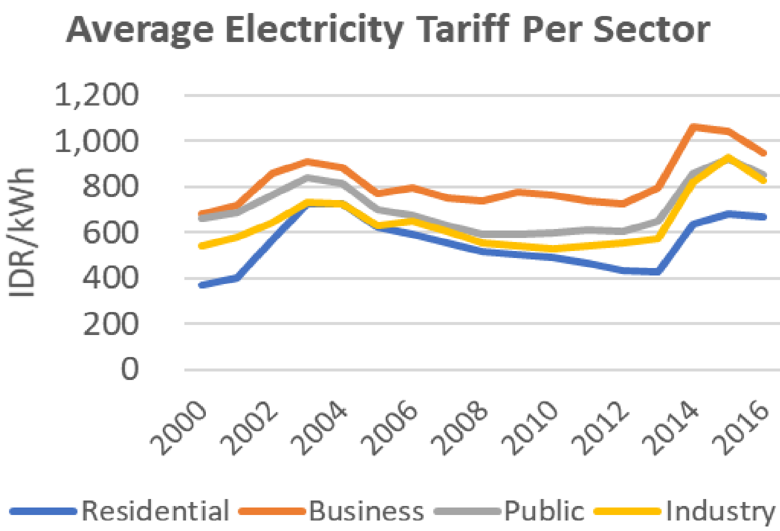


Figure 44. Average electricity tariff in Indonesia, 2000-2016

Source: (Ketenagalistrikan, 2018)

To generate a solution for this problem, it is necessary and important for the Indonesian government to consider the optimization of power generation capacity in the future with the increasing target of renewable energy sources to reduce CO_2 emission and global climate change impact. However, it may increase the Levelized Cost of Electricity (LCOE) due to the high utilization of intermittent renewable energy. This study aims to investigate the optimized capacity of power generation to secure electricity supply with an affordable, diversified energy source, low carbon transition, and minimize environmental impact in Indonesia during the period 2018-2050, analyze the impact of power generation development on the energy security index. This research will also elaborate the energy security from the perspective of power generation development through a system dynamic model to understand the correlation of several input factors that impact the electricity consumption and production. Furthermore, the introduction of an electric vehicle policy will be conducted through the sensitivity analysis process to identify whether this policy impacts the power generation development process.

4.1.1 Research Questions

Research questions in this study are as follows:

1. How to optimize the required capacity of reliable power generation to secure electricity supply in Indonesia?
2. How to analyze power generation development's effect on the energy security index in the system dynamic model?

3. What policies and strategies implications are required to overcome future electricity consumption in Indonesia?

4.1.2 Research Objectives

This study aims to analyze the optimal power generation development to increase the diversification of primary energy, especially renewable energy sources in Indonesia, and its impact on the energy security index. The other objective is to elaborate on the introduction of electric vehicle policy in the transportation sector and its impact on the power generation development and energy security index.

4.1.3 Expected Research Result

The expected result of this part are as follows:

1. The optimization of power generation development in Indonesia for 2018-2050;
2. Analysis of power generation development impact to energy security index in the system dynamic model;
3. Policy Recommendation framework to support power generation development in Indonesia.

4.1.4 Research Methodology

The research steps and methodology in this part will be determined as follows:

1. LEAP and OSEMOSYS as an optimization model of power generation development for the period of 2018-2050;
2. System dynamic model analyzes the correlation of each input factor, both from oil demand and supply side to the energy security index in power generation development.

4.2 Research Design and Methodology

4.2.1 Optimization Model of Power Generation Development

This paper will utilize the Long-Range Energy Alternative Planning (LEAP) model with data processing from the historical data of electricity consumption and existing power generation capacity. The implementation of the LEAP model has been widely used to analyze the optimization of the power generation sector. The objective of this method is to find the optimal solution for power generation to meet the electricity demand within several required constraints. LEAP was developed to integrate energy modeling systems for policy analysis, especially to support environmental concerns such as climate change and emission reduction. This model will analyze the process behind energy consumption, energy transformation, and energy supply within several macroeconomic or demographic parameters such as population, GDP, or income. LEAP model has a flexible data structure and user-friendly interface to develop the future impact of specific energy policy. The optimization for power generation will require the specific condition of load shape on an hourly basis that can be facilitated in LEAP. The load shape will be based on the 8760 hours demand in a year. This requirement will decide which powerplant priority and characteristics can fulfill the load shape. This study found that the LEAP model has been widely used as a model to optimize the power generation mix (Ataei & Ebadi, 2015; Bhuvanesh et al., 2017; Chang et al., 2017; Emodi et al., 2017; Gresat et al., 2018; Shahinzadeh et al., 2016; Utama et al., 2012; Wang et al., 2018). LEAP model facilitates the development of load shape in the module. We can generate the load shape of the system based on the current condition. According to (Handayani et al., 2017), the LEAP model usage can simulate capacity expansion in large power systems, wide options of power generation technologies, calculate the cost and CO_2 emission, and a long period of future projection (more than ten years). The structure of the LEAP model is described as follows:

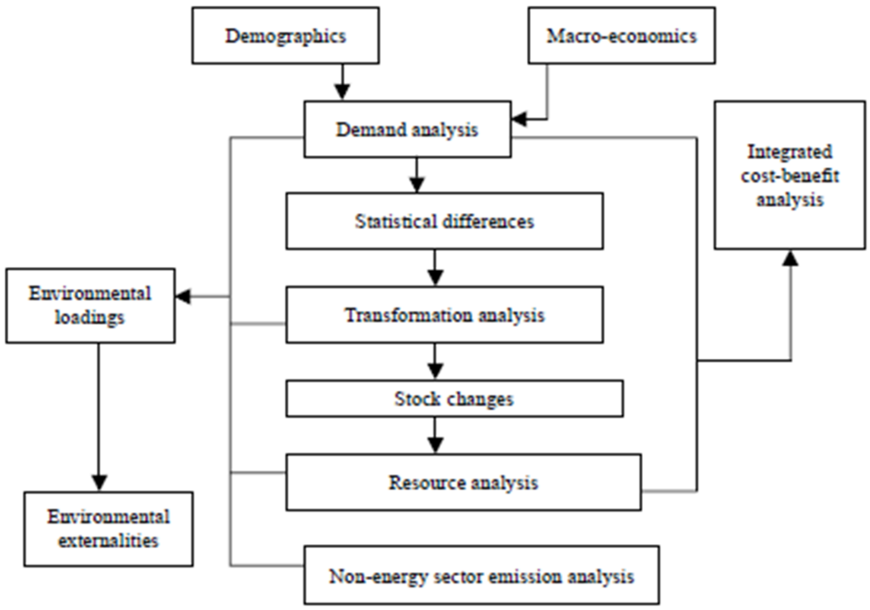


Figure 45. LEAP Model Structure

Source: (Heaps, 2016)

Specifically, for the power generation sector, the LEAP model uses a technical framework to analyze electricity consumption, power generation, energy mix, and environmental impact (emission). The electricity consumption is calculated with the equation as follows:

$$EC_n = \sum_i \sum_j AL_{n,i,j} \times EI_{n,i,j} \tag{28}$$

EC is the aggregate electricity consumption in a specific sector. AL is the activity level of each sector and EI is the energy intensity for n fuel type of equipment j in the sector i. The energy intensity will calculate the annual final consumption of electricity per unit of activity level. Especially in the transportation sector, such as the utilization of an electric vehicle, the energy consumption will be calculated by the equations as follows:

$$EV_n = \sum_c s \times \frac{m}{fe} \tag{29}$$

EV is the electricity consumption for the electric vehicle in the transportation sector, *s* is the number of vehicles, *m* is the mileage of the vehicle, and *fe* is the fuel economy of *n* type and *c* vehicle type. For an electric vehicle, the fuel economy is represented by the number of electricity consumption that one electric vehicle needed in the one-kilometer distance (mileage). In the transformation sector, electricity consumption will be supplied by the power generation with the equation as follows:

$$ET_s = \sum_m \sum_i ETP_{t,m} \times \left(\frac{1}{f_{t,m,s}} - 1 \right) \tag{30}$$

ET is the required energy for transformation. *ETP* is the energy transformation product, which is electricity from the power generation sector. *f* is the energy efficiency in the transformation sector, where the output product will be divided by the input product from the feedstock fuels. *s* is the primary energy, *m* is the equipment, and *t* is the type of secondary energy.

LEAP will also calculate the total cost of the transformation system. The cost will include the fixed, variable, and fuel cost with the equation as follows:

$$C = \sum_i \sum_j \left\{ \left[\sum_n (e_{n,j,k} \times ep_n) + \sum_k (m_{i,j,k} \times mp_k) + fc_{j,i} \right] \right\} \tag{31}$$

C is the total cost, *e* is the required fuel, *ep* is the unit price of fuel type *n*, *m* is the required raw material *k* to develop power plant, *mp* is the unit price of the raw material *k*, and *fc* is the fixed cost of the power plant operation. This study will focus on electricity production costs from the transformation sector (power generation). This study's optimization objective is to minimize the electricity production cost including the fuel cost, operation, maintenance cost, and the capital cost for the future additional power plant capacity within several constraints such as the requirement of reserve margin and certain renewable energy target.

LEAP can conduct optimization to get the least-cost capacity expansion and dispatch of the supply side of the transformation module (power generation) based on the linear programming-based optimization framework named OSEMOSYS (The Open Source Energy Modelling System) developed by several EU organization and academic institutions. OSEMOSYS is an integral part of LEAP. Optimization by using OSEMOSYS has been used in some energy research (Al Hasibi et al., 2013; Emodi et al., 2019; Gardumi et al., 2019; Howells et al., 2011; Lavigne, 2017; Löffler, Hainsch, Burandt, Oei, Kemfert, & Von Hirschhausen, 2017; Löffler, Hainsch, Burandt, Oei, Kemfert, & von Hirschhausen, 2017; Rogan et al., 2014; Welsch et al., 2012).

The objective function of OSEMOSYS is to find the minimum net present value of total powerplant cost in the entire calculation period including capital cost, fixed and variable operating and maintenance cost, fuel cost, and environmental externality values (pollution damage cost) as explained in the following equation.

Objective Function:

$$\min, v_{obj} = \sum_{c,r,a,g,t} (C^{fuel}_{a,g,t} + C^{fixedO\&M}_{a,g,t} + C^{VarO\&M}_{a,r,g,t} + C^{inv}_{a,r,g,t}) \quad (32)$$

$C^{fuel}_{a,g,t}$: Feedstock fuel costs for generation technology (g) in area (a) at time (t)

$C^{fixedO\&M}_{a,g,t}$: Fixed O&M cost for generation technology (g) in area (a) at time (t)

$C^{fixedO\&M}_{a,g,t}$: Variable O&M cost for generation technology (g) in area (a) at time (t)

$C^{inv}_{a,r,g,t}$: Investment cost in the new generation technology (g) in area (a) at time (t)

The least cost from the objective function shall also consider several optimization constraints, including as follows:

a. Planning reserve margin;

b. Minimum or maximum capacity;

c. Maximum annual levels of emission (CO_2, SOx, NOx, PM10)

d. Percentage of renewable energy penetration

Meanwhile, the optimization model will have several constraints: the planning reserve margin shall be 30% and the renewable energy share in the power generation shall be more than 30%, as described below.

Constraints:

1. Planning Reserve Margin shall be 30% (33)

$$RM = 100 \times \frac{(\sum Capacity - Peak\ Load)}{Peak\ Load} = 30\%$$

2. Renewable Energy Share in Power Generation Mix shall be more than 30% (34)

$$RES = 100 \times \frac{(\sum \text{Renewable Electricity Production})}{\sum \text{Electricity Production}} > 30\%$$

The flow diagram of the optimization process in LEAP and OSEMOSYS is explained in Figure 46.

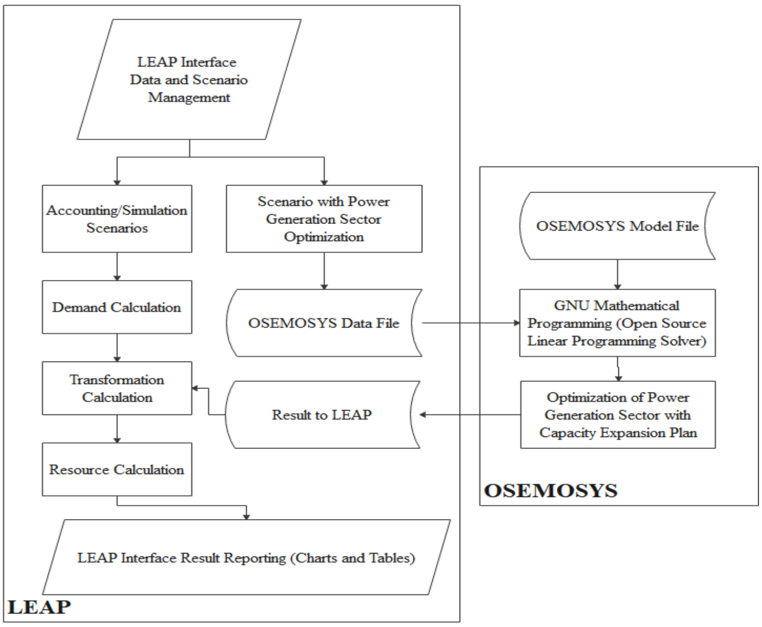


Figure 46. Optimization Flowchart in LEAP and OSEMOSYS

Source: (Al Hasibi et al., 2013)

The process in LEAP started by the collection of related powerplant technology and characteristics. It is important to decide how the powerplant will be operated in dispatch rule and merit order. The baseload powerplant (CFPP, CCPP, Renewable Energy Powerplant) will be prioritized over the peak load powerplant (Gas Turbine powerplant or diesel powerplant). The other required data are powerplant efficiency, exogenous capacity, maximum availability, capital cost, fixed and variable O&M cost, simulation year, capacity credit, historical production, and salvage value (if necessary). Then, the process continues with the determination of system load shape and reserve margin. The powerplant configuration will be organized according to the load shape. All of this data will be considered as an input for OSEMOSYS optimization.

OSEMOSYS will calculate the possible way to minimize the electricity production cost and generate the configuration in each particular year. The optimization result will send it back as an input for the LEAP transformation module of power generation. The data input in the LEAP model will include the annual demand growth, transmission and distribution losses, system load shape, required reserve margin, existing capacity of power generation, power plant characteristic and operation priority, capacity factor, discount rate, unit of capital cost and operational cost, and emission factor as explained in Table 7.

Table 7. Data input for LEAP model

Input Data	Value	Sources
Annual Demand Growth	2018: 204 TWh	PLN Statistics
Transmission and Distribution Losses	9.7-11.6%	PLN Statistics
System Load Shape	Typical Load Shape in Indonesia	MEMR
Reserve Margin	30%	National General Electricity Planning (RUKN)
Existing Capacity	2018: 54.6 GW	MEMR
Powerplant Operation Priority: Baseload Powerplant Intermediate Powerplant Peak Load powerplant	 CFPP, PV, Geothermal CCPP, Hydro PP GTPP, Diesel PP	MEMR
Capacity Factor	Vary depend on the Powerplant type	MEMR
Discount Rate	10%	PLN
Capital Cost of each powerplant type	Vary depend on the Powerplant type	PLN, MEMR, IEA, (Handayani,2017)
Operation Cost of each powerplant type	Vary depend on the Powerplant type	PLN, MEMR, IEA, (Handayani,2017)
Emission Factor	Vary depend on the Powerplant type	IPCC Emission Factor

The power generation analysis will be supported by the powerplant characteristics data from a relevant source such as IEA, ASEAN Center for Energy, Ministry of Energy and Mineral Resources (MEMR), and the national utility company data (PLN). The powerplant characteristics will include the powerplant type, lifetime, efficiency, availability factor, capacity credit, capital cost, fixed operation and maintenance cost, and fuel cost. The powerplant characteristic is described in Table 8.

Table 8. Powerplant characteristic data for the LEAP model

Power plant Type	Lifetime (years)	Efficiency (%)	Availability(%)	Capacity Credit(%)	Capital Cost (USD/kW)	Fixed O&M Cost (USD/kW)	Variable O&M Cost (USD/MWh)	Fuel Cost
Coal	25	57	80	100	817	24	3.8	51.8 USD/Ton
Natural Gas Combined Cycle	25	38	80	100	439	21	3.8	7.6 USD/MMBTU
Natural Gas Open Cycle	35	100	41	51	2200	56	3.8	7.6 USD/MMBTU
Hydro	35	100	46	58	3350	67	3.8	-
Hydro Pumped Storage	35	95	20	25	1050	54	3.8	-
Geothermal	20	10	80	100	2675	53	0.7	-
Solar PV	20	100	17	22	1953	20	0.4	-
Wind Power	20	100	28	35	1756	44	0.8	-
Nuclear	40	33	85	100	3967	164	8.6	9.33 USD/MWh
Biomass	20	35	80	100	2228	78	6.5	11.67 USD/Ton

For the resource analysis, there is an energy resource potential data of both fossil and renewable energy, as stated in Government Regulation No 22 the Year 2017 on the national general energy plan. The fossil energy will include oil, natural gas, and coal as described in Table 9.

Table 9. Fossil Energy Potential data for LEAP model

No	Energy	Resources	Proven Reserve	Production	Expected Lifetime
1	Oil	151 Billion Barrels	3.6 Billion Barrels	288 Million Barrels	12 Years
2	Natural Gas	487 TCF	98 TCF	3 TCF	33 Years
3	Coal	120 Billion Tonnes	32.4 Billion Tonnes	393 Million Tonnes	82 Years

Renewable energy potential comes from geothermal, hydropower, bioenergy, solar, and wind, as shown in Table 10.

Table 10. Renewable Energy Potential data for LEAP model

No	Energy	Potential	Existing Capacity
1	Geothermal	29,544 MW	1,438 MW
2	Hydro	75,091 MW	4,826 MW
3	Mini hydro	19,385 MW	197 MW
4	Bioenergy	32,654 MW	1,671 MW
5	Solar	207,898 MW	78 MW
6	Wind	60,647 MW	3,1 MW

The assumption that has been used in this analysis is coming from the assumption of national general energy plan modeling with the required data are GDP, expected economic growth, GDP per capita, population, and the number of households.

There will be a scenario analysis in this study to analyze the impact of the optimization result. There will be a business as usual (BAU) scenario where the power generation development will be developed in a normal condition. In contrast, the optimization scenario (OPT) will be equipped with optimization. Moreover, the electric vehicle introduction policy will be introduced in the optimization scenario, to generate the difference in power generation development after electric vehicle penetration in the transportation sector. The detail of the scenario is explained as follows:

1. Business As Usual based on Indonesia National Energy Plan (RUEN) without optimization
2. Optimization Scenario

Each scenario will generate the power generation mix to see which energy source is dominant in electricity production. Both scenarios will then be assessed by the result of the energy security indicator in the power generation sector including availability, affordability, acceptability, accessibility, and intensity indicator. Several indicators will be analyzed in the availability dimensions: electricity production per capita, electricity consumption per capita, self-sufficiency of electricity, increased utilization of new and renewable energy reserves and resources, and the share of renewable energy in total primary energy supply. For the affordability dimension, the energy security will be assessed by electricity price per GDP per capita ratio, cost of the subsidy, and overall system cost (LCOE). Similar to oil refinery energy security assessment, the acceptability indicators will include emission per electricity consumption, CO_2 emission, and emission intensity. The intensity indicator will be measured by the electricity intensity to see the efficiency of electricity consumption in generating economic benefit to GDP. Two indicators will define the accessibility dimension: electrification rate and reserve margin of generation capacity.

4.2.2 Power Generation Development Optimization Result

4.2.2.1 Business as Usual Scenario (BAU)

Based on National Energy General Plan (Presidential Regulation No. 22/2017), Indonesia's projected demand for electricity is expected to reach 440 TWh by 2025 and 2,984 TWh. The household sector still dominant, with 258 TWh (58.6%) by 2025 and 1,996 TWh (66.8%) by 2050. The second highest electricity consumption comes from the industrial sector with 99 TWh (22.2%) by 2025, but the share decreases in 2050 with 475 TWh (14.3%). The commercial sector electricity consumption increase to 63 TWh (22.2%) by 2025, but the share is increasing in 2050 by 450 TWh (15.1%). The lowest electricity consumption is the public sector with 18 TWh (4.0%) by 2025, but the share decreases in 2050 with 62 TWh (2%).

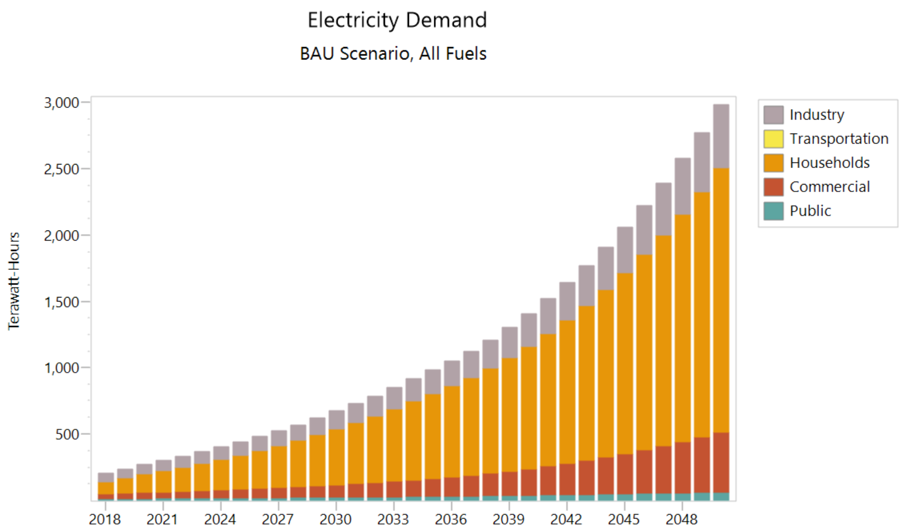


Figure 47. Electricity Consumption Projection

The result shows that GDP has increased seven times from 1056 Billion USD in 2018 to 7224 Billion USD in 2050, the electricity intensity shows a slight increase two times from 193 kWh/USD to 406 kWh/USD. The electricity production and electricity production per capita has increased in a similar trend. Electricity production has increased from 204 TWh in 2018 to 2934 in 2050. Electricity production per capita has increased from 798 MWh/capita in 2018 to 8751 MWh/capita in 2050

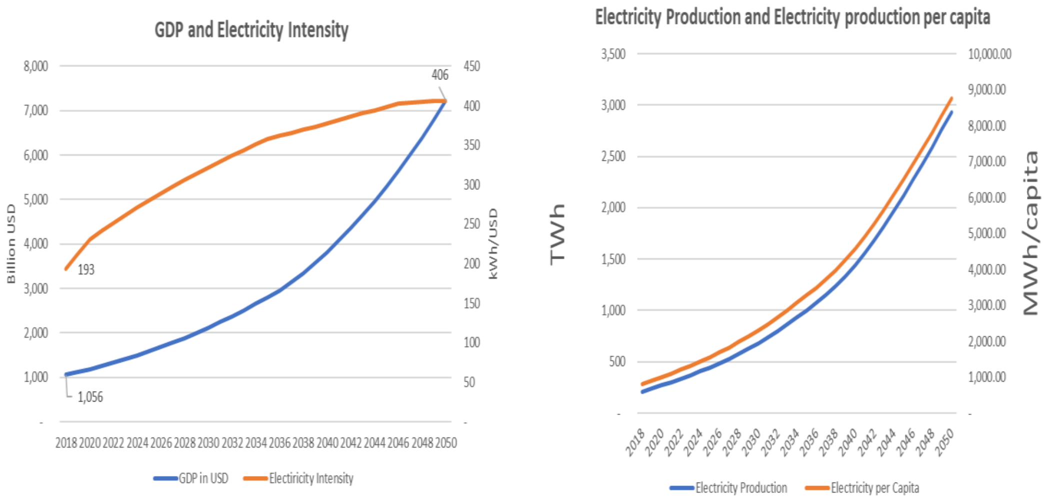


Figure 48. GDP, Electricity Intensity, and Electricity Production Projection

The power generation in the BAU scenario will grow with the historical generation data's average growth rate. The projected power generation will produce electricity for 440 TWh by 2025 and 2,889 TWh by 2050. In 2025, the power generation mix will be dominated by the coal-fired powerplant/CFPP (220 TWh) and Combined Cycle powerplant/CCPP (71 TWh). The dominant share in 2050 stays the same by the existence of CFPP (1,706 TWh) and CCPP (453 TWh). Intermittent renewable energy such as solar will increase from 9.7 TWh by 2025 to 54.7 TWh by 2050. Wind Turbines also increase from 8.9 TWh by 2025 to 52 TWh by 2050. The utilization of a diesel-fueled power plant will be stopped in 2023. Large-scale hydro powerplant and mini-hydro got 29TWh and 5 TWh by 2025, respectively. Then, large hydro only increased dramatically to 143 TWh, and mini-hydro increased rapidly by 40 TWh by 2050.

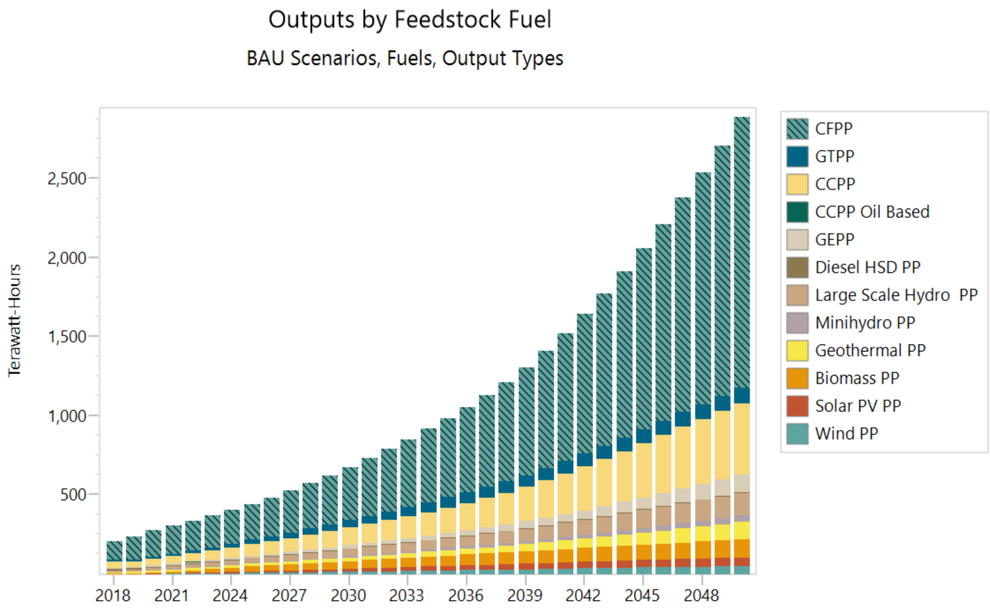


Figure 49. The output of Feedstock Fuel for the BAU scenario

Electricity production will increase by 8.2% each year. The highest yearly average growth was shown by Minihydro, Solar PV, and Windpower with about 11%. For fossil power generation (CFPP, GEPP, GTPP, and CCPP), the average growth is in the range of 7.4%-9.0%. However, the oil-based power generation (CCPP Oil Based and Diesel PP) is in decreasing trends due to the policy to restrict the utilization of fuel oil in the power generation. Renewable energy power generation shows an 8.8% yearly growth rate, which is higher than fossil energy power generation (8.1% per year), as shown in Table 11.

Table 11. Electricity Production Result for BAU Scenario

Powerplant	Electricity Production (TWh)							Yearly Average Growth	Yearly Average Share
	2020	2025	2030	2035	2040	2045	2050		
CFPP	161	220	331	495	736	1,136	1,707	8.2%	53.1%
GTPP	12	29	46	68	76	89	98	7.4%	5.5%
CCPP	41	72	111	158	237	344	453	8.3%	16.3%
CCPP Oil Based	1	0	0	0	0	0	0	-100.0%	0.1%
GEPP	9	12	19	30	47	75	112	9.0%	3.2%
Diesel HSD PP	8	4	5	5	5	5	4	-1.8%	0.9%
Large Scale Hydro PP	15	29	44	60	82	113	143	7.8%	5.9%
Minihydro PP	2	5	9	15	21	31	40	11.0%	1.3%
Geothermal PP	11	17	24	34	50	75	110	8.1%	3.7%
Biomass PP	9	33	49	66	82	98	114	9.0%	5.7%
Solar PV PP	2	10	19	29	38	46	55	11.1%	2.2%
Wind PP	2	9	16	25	34	44	53	11.3%	2.0%
Total	273	440	674	984	1,407	2,056	2,889	8.2%	100%
Renewable Energy Including Hydro	41	103	161	228	307	408	515	8.8%	
Renewable Energy Share	15%	23%	24%	23%	22%	20%	18%		
Fossil Energy	232	338	513	756	1,101	1,649	2,374	8.1%	
Fossil Energy Share	85%	77%	76%	77%	78%	80%	82%		

The power generation mix in the BAU scenario will be dominated by the CFPP with the yearly average share is about 53.1%, followed by CCPP (16.3%). On the other hand, the renewable power generation will be influenced by Large Scale Hydro PP with the yearly average share is about 5.9% and Biomass PP (5.7%). The BAU scenario emphasizes each power generation's growth based on its historical data, which the CFPP is keeping its dominant share from 58.9% in 2018 to 59.0% in 2050. This scenario didn't consider the externalities of CFPP and the possibility of CO_2 emission reduction from Indonesia's commitment to the climate change issue. The domination of CFPP in the power generation mix may bring lower LCOE due to CFPP feedstock fuel cost is considered the cheapest among the other fuels. Electricity production shall focus not only on the least cost approach but also on the potential of environmental issues such as undesirable emission and environmental effects known as externalities. The study about externalities in the energy sector was started in 1991 with the European Commission cooperation and the US Department of Energy(Krewitt, 2002). The result of the study is the introduction of energy technologies external cost assessment known as ExternE. ExternE indicates the monetary cost of a greenhouse, health, and environmental impact of power sector emission. It shows that black and brown coal externalities are about 41 €/MWh and 58 €/MWh, respectively(Biegler & Zhang, 2009). Another study conducted by (Wijaya & Limmeechokchai, 2010) shows several considerations of externalities in Indonesia's power generation sector, which are the direct emission of CO_2, SO_2, NO_x, and PM_{10}. Each of the pollutants will generate damage cost in a unit of cents USD/kWh.

Especially for CO_2 emission, the highest damage cost will be occurred by the operation of Coal Fired Steam Powerplant (2.45 cUSD/kWh) and Diesel Generators (2.05 cUSD/kWh). The least damage cost of CO_2 emission will be produced by Combined Cycle Powerplant (1.08 cUSD/kWh) as shown in Table 12.

Table 12. Measured externalities from CO2 direct emission and damage cost

Source: (Wijaya & Limmeechokchai, 2010)

Powerplant	**CO_2(kg/kWh)**	**Damage Cost (cUSD/kWh)**
Coal Fired Steam	922	2.45
Oil Fired Steam	735	1.96
Natural Gas Fired Steam	503	1.34
Oil Combined Cycle	620	1.65
Natural Gas Combined Cycle	407	1.08
Gas Turbine (Natural Gas)	726	1.93
Gas Turbine (Diesel)	1,230	3.27
Diesel Generator	772	2.05

There is a difference in the external cost of coal-fired powerplant (CFPP) between ExternE with 4.86-6.88 cUSD/kWh and (Wijaya & Limmeechokchai, 2010) with 2.45 cUSD/kWh or about 2.43-4.43 cUSD/kWh. This number may be affected by the difference in the exchange rate, tax, and healthcare cost.

If the utilization of CFPP adds the consideration of its externalities, then it might increase the LCOE of the system or reduce CFPP share in the power generation mix. Indonesia's government needs to consider the externalities of its CFPP, especially its high contribution to the CO_2 emission in the power generation sector. CFPP contribution in CO_2 emission is about 201 $MtCO_2$ or 84% of total CO_2 emission in 2020 and 1,514 $MtCO_2$ or 83.8% in 2050. CFPP also produces air pollutants such as SO_2. NO_x, and PM_{10}, which now has limited allowable production from the power generation sector by the government environmental regulation(Kementerian, 2019). The contribution of CO_2 emission in the BAU scenario is shown in Table 13.

Table 13. CO_2 emission (Non-Biogenic) for BAU Scenario (Million Tonnes)

Branches	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
CFPP	201.5	272.2	379.1	528.7	736.0	1,068.2	1,514.1
GTPP	7.4	17.0	26.6	37.5	40.9	46.3	49.3
CCPP	19.2	32.3	48.9	68.0	99.6	141.7	183.0
CCPP Oil Based	0.9	-	-	-	-	-	-
GEPP	4.7	6.8	10.4	16.0	24.3	38.3	56.7
Diesel HSD PP	6.0	3.3	3.5	3.8	3.7	3.8	3.5
Total	239.7	331.5	468.5	653.9	904.6	1,298.3	1,806.5

There is a difference in the external cost of coal-fired powerplant (CFPP) between ExternE with 4.86-6.88 cUSD/kWh and (Wijaya & Limmeechokchai, 2010) with 2.45 cUSD/kWh or about 2.43-4.43 cUSD/kWh. This number may be affected by the difference in the exchange rate, tax, and healthcare cost.

If the utilization of CFPP adds the consideration of its externalities, then it might increase the LCOE of the system or reduce CFPP share in the power generation mix.

Indonesia's government needs to consider the externalities of its CFPP, especially its high contribution to the CO_2 emission in the power generation sector. CFPP contribution in CO_2 emission is about 201 $MtCO_2$ or 84% of total CO_2 emission in 2020 and 1,514 $MtCO_2$ or 83.8% in 2050. CFPP also produces air pollutants such as SO_2. NO_x, and PM10, which now has limited allowable production from the power generation sector by the government environmental regulation(Kementerian, 2019). The contribution of CO_2 emission in the BAU scenario is shown in Table 14.

Table 14. Emission (Non Biogenic) for BAU Scenario (Million Tonnes)

Branches	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
CFPP	201.5	272.2	379.1	528.7	736.0	1,068.2	1,514.1
GTPP	7.4	17.0	26.6	37.5	40.9	46.3	49.3
CCPP	19.2	32.3	48.9	68.0	99.6	141.7	183.0
CCPP Oil Based	0.9	-	-	-	-	-	-
GEPP	4.7	6.8	10.4	16.0	24.3	38.3	56.7
Diesel HSD PP	6.0	3.3	3.5	3.8	3.7	3.8	3.5
Total	239.7	331.5	468.5	653.9	904.6	1,298.3	1,806.5

If the BAU scenario added the externalities cost from CFPP based on ExternE and (Wijaya & Limmeechokchai, 2010), then the LCOE of the system will be increased, as shown in Figure 50.

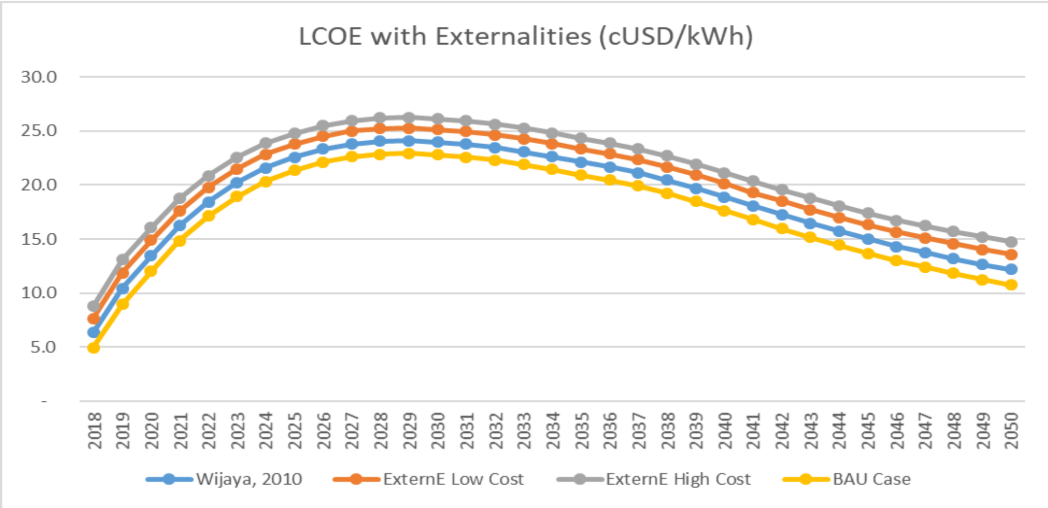


Figure 50. LCOE with Externalities cost from CFPP in BAU scenario

The externalities cost will come from three cases: (Wijaya & Limmeechokchai, 2010), ExternE Low Cost and ExternE high cost. The average LCOE in the BAU scenario will be increased from average LCOE with 17.3 cUSD/kWh to 18.6 cUSD/kWh in Case Wijaya, 19.9 cUSD/kWh in Case ExternE Low Cost, and 20.9 cUSD/kWh in Case ExternE High Cost.

Unmet Requirement will be occurred from 2045 by 5 TWh to 2050 by 95 TWh, which means that there will be a possibility of electricity shortage during that period. The reserve margin in the BAU scenario has decreased by years from 80% in 2018 to a negative value (-10%) in 2050, which means that electricity production is insufficient to supply the demand.

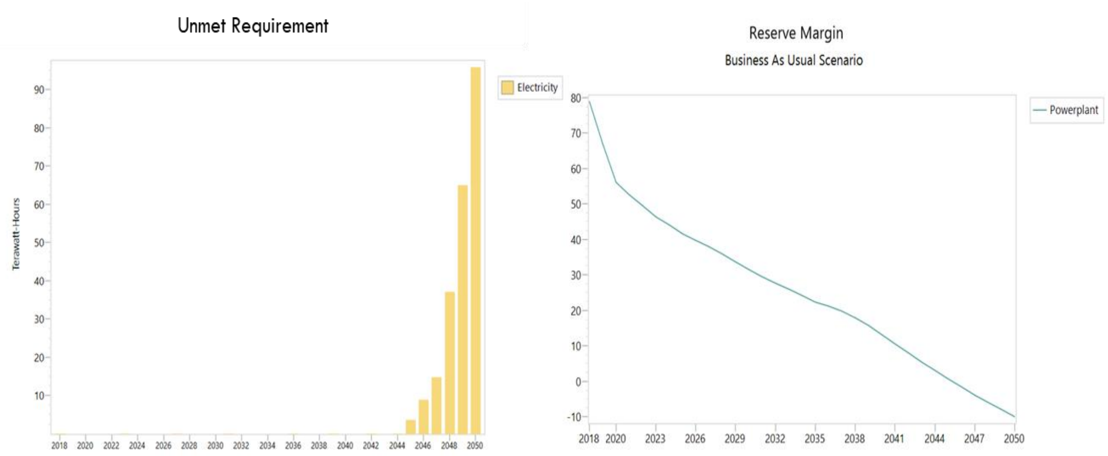
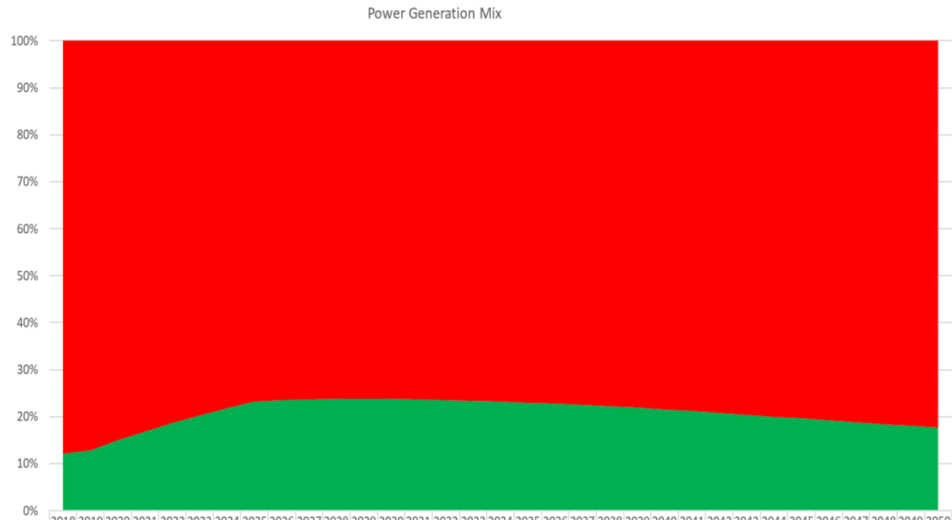


Figure 51. Unmet requirement and reserve margin for BAU scenario

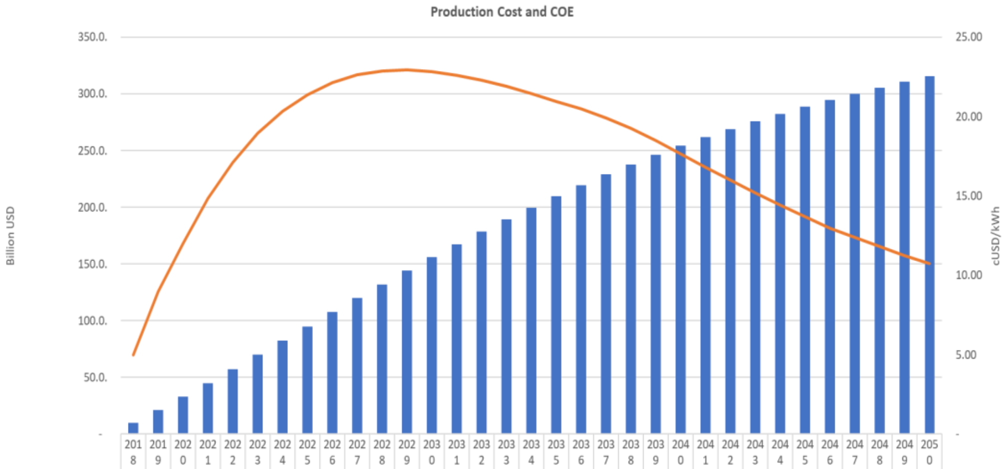
The actual Availability of Fossil Energy Powerplant has reached more than 60% by 2050 (CFPP, GTPP, GEPP, and CCPP). On the other hand, Geothermal (95%) and Biomass Powerplant AF (65%) could exceed 50% in the renewable energy category. Most renewable energy can only reach below 50%, such as Wind(45%), Solar (23%), Hydro (49%). Fossil energy power generation has been decreased from 88% in 2018 to 76% in 2032. However, it has increased again to 82% in 2050. Renewable energy power generation has been increased steadily from 12% in 2018 to 24% in 2032 and then decreased to 18% until 2050.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Fossil Energy PP	88%	87%	85%	83%	81%	80%	78%	77%	76%	76%	76%	76%	76%	76%	76%	77%	77%	77%	77%	77%	78%	78%	78%	79%	79%	80%	80%	80%	81%	81%	82%	82%	82%
Renewable Energy PP	12%	13%	15%	17%	19%	20%	22%	23%	24%	24%	24%	24%	24%	24%	24%	23%	23%	23%	23%	23%	22%	22%	22%	21%	21%	20%	20%	20%	19%	19%	18%	18%	18%

Figure 52. Power generation mix for BAU scenario

Production cost has been increased steadily from 10.1 Billion USD in 2018 to 315 Billion USD in 2050. The cost of electricity has been increased from 4.97 cUSD/kWh in 2018 to 22.9 cUSD/kWh because of increasing renewable energy in 2029 and then decreased to 10.7 cUSD/kWh until 2050 due to increasing fossil power share in the generation mix.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Production Cost	10.	21.	32.	45.	57.	69.	82.	95.	107	119	132	144	155	167	178	189	199
Cost Of Electricity	4.9	8.9	12.	14.	17.	18.	20.	21.	22.	22.	22.	22.	22.	22.	22.	21.	21.

	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Production Cost	209	219	228	237	246	254	261	269	275	282	288	294	300	305	310	315
Cost Of Electricity	20.	20.	19.	19.	18.	17.	16.	15.	15.	14.	13.	12.	12.	11.	11.	10.

Figure 53. COE and production cost for BAU scenario

Sankey Diagram in 2018 indicates that the Power Generation sector will require 409 TWh of Coal Production, 141 TWh of Natural Gas Production, 49 TWh of Hydropower, 26 TWh of Distillate Fuel Oil, 24 TWh of Geothermal, and 10 TWh of Biomass. Wind Power and Solar Power will only contribute 0.8 TWh and 0.5 TWh, respectively. 465 TWh will be considered as losses, including power generation and transmission and distribution losses. 204 TWh will be produced as electricity to the end-user sector. Electricity production will supply 88 TWh (43.1%) to the household sector, 65 TWh (31.8%) to Industrial Sector, 37 TWh (18.1%) to the commercial sector, and 13 TWh (6.3%) to the public sector.

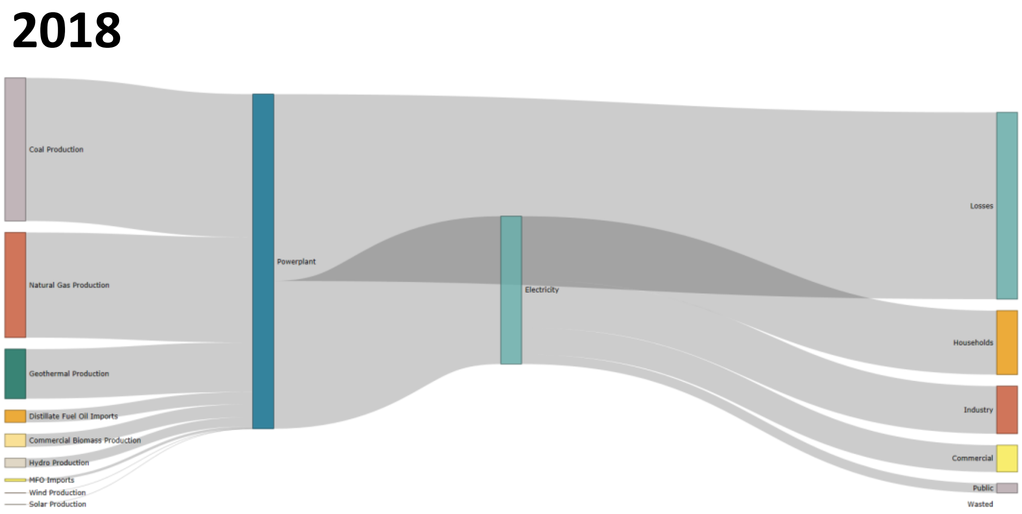


Figure 54. Sankey Diagram in 2018 for BAU scenario

Sankey Diagram in 2050 indicates that the Power Generation sector will require 4376 TWh of Coal Production, 1430 TWh of Natural Gas Production, 610 TWh of Hydropower, 551 TWh of Geothermal, and 379 TWh of Biomass. Wind Power and Solar Power have increased their contribution to 175 TWh and 219 TWh, respectively. 4867 TWh will be considered as losses, including power generation and transmission and distribution losses. 2934 TWh will be produced as electricity to the end-user sector. Electricity production will supply 1996 TWh (66.8%) to the household sector, 475 TWh (15.9%) to Industrial Sector, 450 TWh (15.1%) to the commercial sector, and 62 TWh (2.0%) to the public sector.

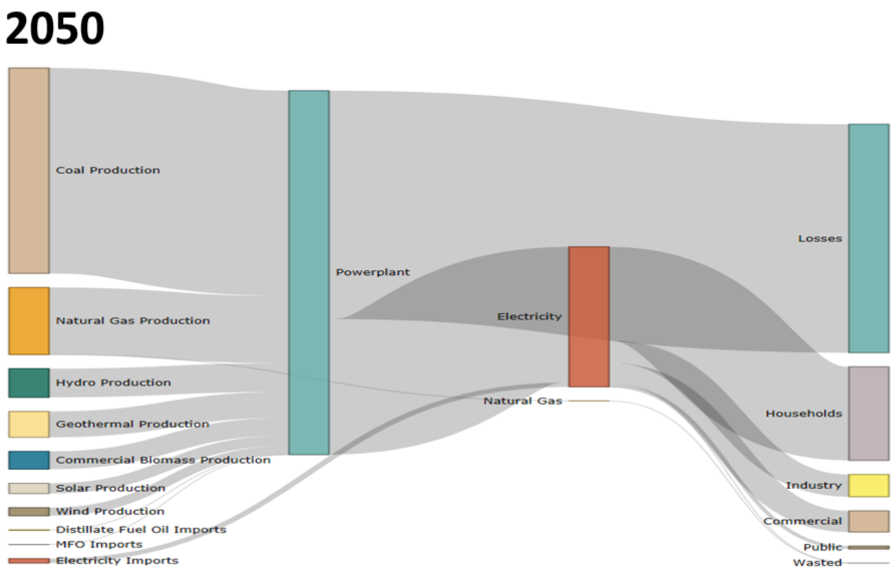


Figure 55. Sankey Diagram in 2050 for BAU scenario

From the energy security indicator perspective, the BAU scenario will increase electricity production per capita, Electricity Consumption per capita, Increased utilization of New and Renewable energy reserves and resources, Share of renewable energy in total primary energy supply in the availability dimension.For the affordability dimension, the BAU scenario will decrease the electricity price per GDP per capita and the cost of the subsidy. However, it will increase the overall system cost until 2050. BAU scenario will increase the entire acceptability indicator, including CO_2 emission, emission intensity, and emission per electricity consumption. The electrification ratio will increase and reached 100% in 2022, while the reserve margin will decrease to a negative value in 2050. Electricity intensity will increase two times, from 0.2 in 2018 to 0.4 in 2050.

Table 15. Energy security indicator for BAU scenario

Dimension	Indicator	Information	2018	2028	2038	2048	2050	Trend
Availability	Electricity production per capita	Electricity Production per population	0.80	1.96	3.88	7.59	8.49	Increasing
	Electricity Consumption per capita	Electricity Consumption per population	0.80	1.96	3.88	7.78	8.90	Increasing
	Self Sufficiency of Electricity	Share of domestic electricity production over total consumption	1.00	1.00	1.00	1.00	1.00	-
	Increased utilization of New and Renewable energy reserves and resources	Rate of electricity production from renewable energy by year	0.00	0.09	0.06	0.04	0.04	Decreasing
	Share of renewable energy in total primary energy supply	Share of electricity production from renewable energy over total electricity production	0.22	0.35	0.35	0.31	0.30	Increasing
Affordability	Electricity Price per GDP per capita ratio	Electricity price per GDP per capita	1.14	0.99	0.58	0.29	0.25	Decreasing
	Cost of Subsidy	Expenditure in electricity subsidy per total government spending	0.43	0.17	0.11	0.08	0.07	Decreasing
	Overall System Cost (LCOE)	Levellized cost of electricity in the system	4.97	22.87	19.24	11.82	10.75	Increasing
Acceptability	Emission per electricity consumption	Total Emission of the powerplant per electricity consumption	0.51	0.65	0.60	0.57	0.56	Increasing
	Emission Intensity	CO2 emission related to refinery development per GDP	0.10	0.18	0.20	0.22	0.23	Increasing
	CO2 Emission	Total CO2 emission	103.09	372.80	721.21	1465.98	1658.66	Increasing
Intensity	Electricity Intensity	Total electricity consumption per GDP	0.20	0.27	0.33	0.39	0.41	Increasing
Accessibility	Electrification Ratio	The number of households with electricity access per total households	99.00	100.00	100.00	100.00	100.00	Increasing
	Reserve Margin of generation capacity	Percentage of power generation reserve capacity to the electricity consumption	78.90	35.86	17.99	-5.92	-9.97	Decreasing

Business As Usual (BAU) Scenario will have some indication in the energy security dimensions. For the affordability dimension, the BAU scenario will decrease the electricity price per GDP per capita and the cost of the subsidy. However, it will increase the overall system cost until 2050. BAU scenario will increase the entire acceptability indicator, including CO_2 emission, emission intensity, and emission per electricity consumption. The electrification ratio will increase and reached 100% in 2022, while the reserve margin will decrease to a negative value in 2050. Electricity intensity will increase two times, from 0.2 in 2018 to 0.4 in 2050.

Table 16. Energy security dimension for BAU scenario

Energy Security Dimension	2018	2028	2038	2048	2050
Availability	0.43	0.53	0.62	0.87	0.95
Affordability	0.67	0.43	0.38	0.39	0.39
Acceptability	0.67	0.63	0.61	0.56	0.55
Intensity	1.00	0.68	0.39	0.06	0.00
Accessibility	0.50	0.63	0.55	0.50	0.50
Energy Security Indicator	0.65	0.58	0.51	0.48	0.48

Business As Usual (BAU) Scenario will generate several impacts in energy security dimension as follows:

a. It will increase the availability dimension due to increasing electricity production

b. It will decrease the acceptability dimension due to increasing emission from the fossil power generation
c. It will decrease the affordability dimension from 2018-2038 due to the increasing production cost and cost of electricity. But it will increase again until 2050.
d. It will decrease the intensity dimension due to increasing electricity intensity (higher electricity consumption per GDP)
e. It will increase the accessibility dimension due to the increasing electrification rate, but the lower reserve margin of power generation contributes to the decreasing trend until 2050.

BAU scenario will decrease the energy security index from 0.65 in 2018 to 0.48 in 2050 due to the decreasing trend of acceptability, accessibility, affordability, and intensity dimension. However, the availability dimension will be increased.

4.2.2.2 Optimization Scenario (OPT)

The power generation in the Optimization scenario (OPT) will grow with the average growth rate from the historical generation data. The projected power generation will produce electricity for 440 TWh by 2025 and 2,984 TWh by 2050. In 2025, the power generation mix will be dominated by the CFPP or Coal Fired powerplant (163TWh) and Combined Cycle powerplant (111 TWh). The dominant share in 2050 is still with the existence of CFPP (1,231 TWh) and CCPP (588 TWh). The highest share of renewable energy in 2025 is Large scale Hydro powerplant (48 TWh), followed by geothermal powerplant (46 TWh). The situation changed in 2050. The Windpower has been dominant with 354 TWh and followed by the geothermal powerplant (176 TWh). Intermittent renewable energy such as Solar power will increase from 9.6 TWh by 2025 to 54 TWh by 2050. Biomass increase almost five times from 28 TWh by 2025 to 113 TWh by 2050. The utilization of a diesel-fueled power plant will be stopped in 2025. There is no significant increasing capacity for gas turbine and gas engine powerplant while only a combined cycle power plant is dominant in the natural gas-fueled powerplant category. Coal-Fired Power plant (CFPP) will generate more electricity from 163 TWh by 2025 to 1,231 TWh by 2050. Large-scale hydro powerplant and mini-hydro got 48 TWh and 7 TWh by 2025, respectively. Then, large hydro increased three times to 153 TWh, and mini-hydro increased six times, with 42 TWh by 2050.

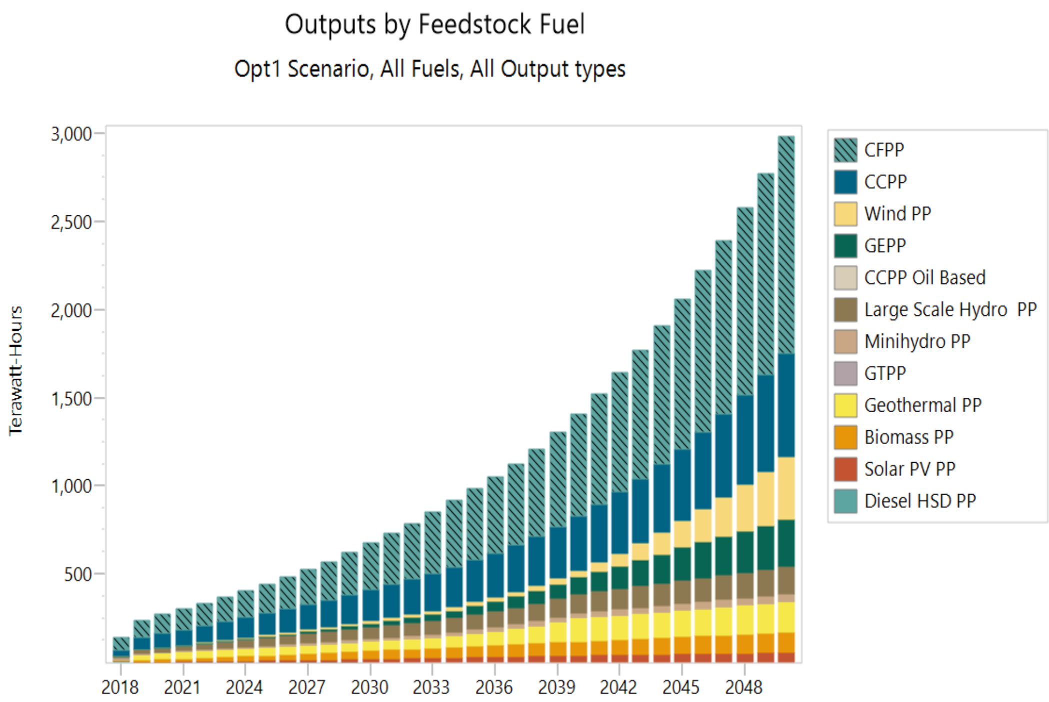


Figure 56. The output of Feedstock Fuel for OPT scenario

Electricity production will increase by 8.2% each year. The highest yearly average growth was shown by Minihydro, Solar PV, and Windpower with about 11%. For fossil power generation (CFPP, GEPP, GTPP, and CCPP), the average growth is in the range of 7.4%-9.0%.

Table 17. Electricity Production Result for OPT Scenario

Powerplant	Electricity Production (TWh)							Yearly Average Growth	Yearly Average Share	Share Difference with BAU
	2020	2025	2030	2035	2040	2045	2050			
CFPP	111	164	264	406	581	850	1,231	8.4%	**27.4%**	**-25.7%**
CCPP	76	122	174	236	308	406	588	7.0%	**34.5%**	**18.2%**
Wind PP	3	9	16	25	34	154	354	17.9%	2.0%	-
GEPP	2	4	19	47	96	186	269	17.8%	2.8%	-.0.4%
CCPP Oil Based	0	-	-	-	-	-	-	0%	0.0%	-0.1%
Large Scale Hydro PP	24	48	67	86	109	133	153	6.4%	**8.3%**	**2.4%**
Minihydro PP	6	8	14	21	28	36	43	7.0%	1.9%	0.6%
GTPP	0	0	0	0	1	0	0	5.6%	0.1%	-5.4%
Geothermal PP	35	47	54	72	134	152	177	5.5%	**14.9%**	**11.2%**
Biomass PP	14	29	46	63	80	97	114	7.3%	5.7%	-
Solar PV PP	2	10	18	29	38	46	55	10.9%	2.2%	-
Diesel HSD PP	0	0	-	-	-	-	-	0%	0.1%	-0.8%
Total	273	440	674	984	1,407	2,060	2,985	8.3%	100%	
Renewable Energy Including Hydro	83	150	216	295	422	618	895	8.2%		
Renewable Energy Share	31%	34%	32%	30%	30%	30%	30%			
Fossil Energy	189	290	457	689	985	1,442	2,089	8.3%		
Fossil Energy Share	69%	66%	68%	70%	70%	70%	70%			

However, the oil-based power generation (CCPP Oil Based and Diesel PP) is in decreasing trends due to the policy to restrict the utilization of fuel oil in the power generation. Renewable energy power generation shows an 8.2% yearly growth rate shows a slightly lower value than fossil energy power generation (8.3% per year), as shown in

Table 17. Unmet Requirement occurred in 2018 when the optimization has not been started. It will not occur from 2019-2050 when the optimization is conducted, which means there will be no electricity shortage during that period. The reserve margin in the OPT scenario is stable at 30% value as the constraint of the optimization process, which means that electricity production has sufficient reserve to handle unexpected outages.

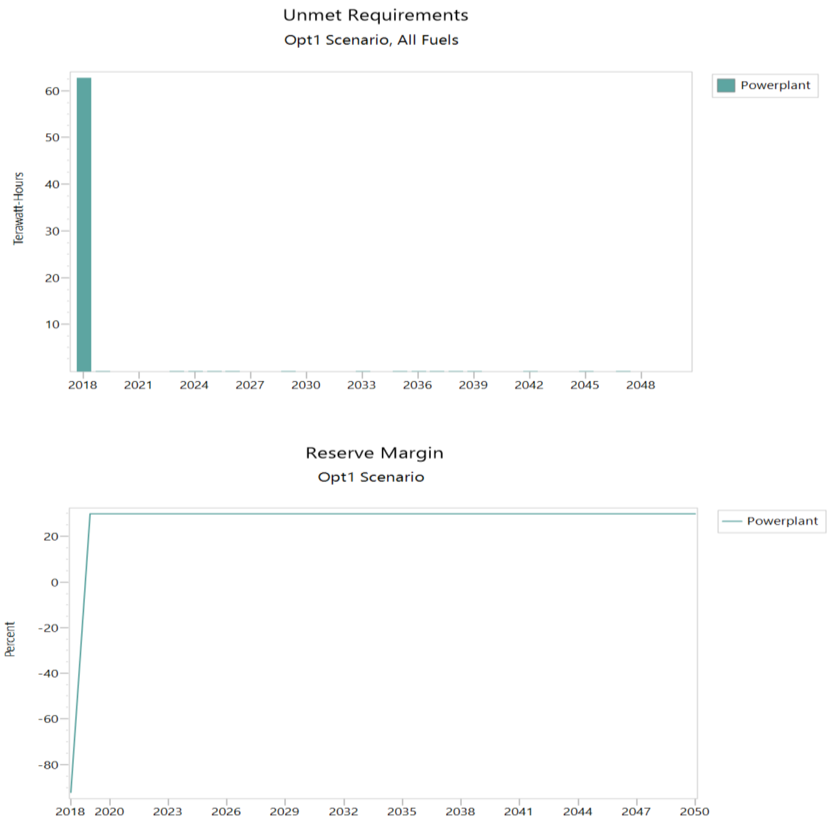
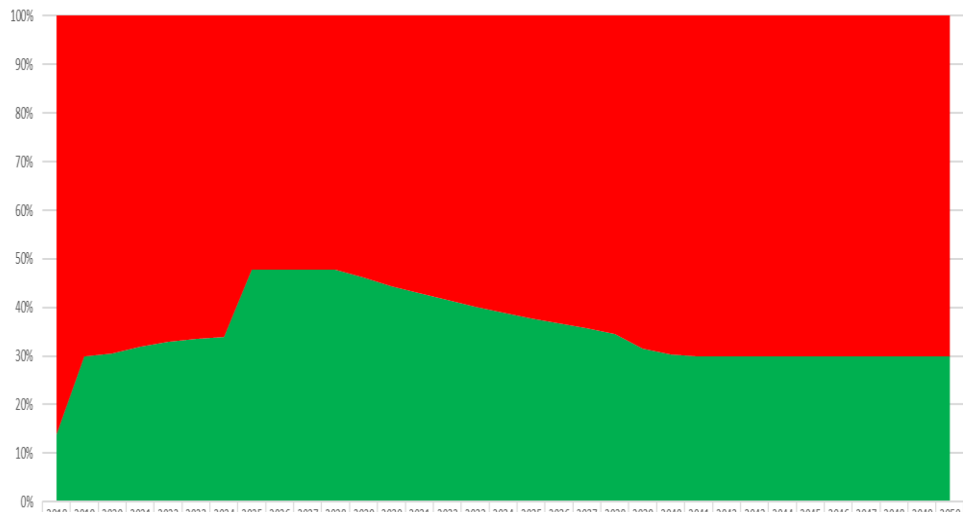


Figure 57. Unmet requirement and reserve margin for OPT scenario

The renewable power generation share in the OPT scenario has increased to 48% in 2025 but then decreased to 30% in 2050. This result fulfills the share of renewable constraint that shall be at least 30% of the total power generation mix. On the other hand, fossil power generation has reached 70% in 2019, then decreased to 52% in 2025. It comes again to 70% in 2050.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Fossil Energy PP	86%	70%	69%	68%	67%	66%	66%	52%	52%	52%	52%	54%	56%	57%	58%	60%
Renewable Energy PP	14%	30%	31%	32%	33%	34%	34%	48%	48%	48%	48%	46%	44%	43%	42%	40%

	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Fossil Energy PP	61%	62%	63%	64%	65%	69%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Renewable Energy PP	39%	38%	37%	36%	35%	31%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%

Figure 58. Power generation mix for OPT scenario

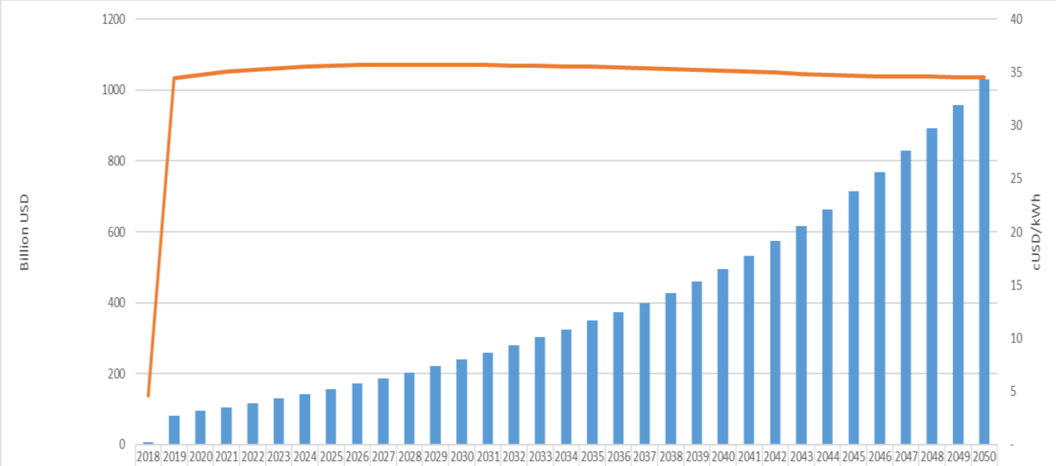
The OPT scenario's electricity production cost has been increased dramatically from only 95 Billion USD in 2020 to 1,030 Billion USD in 2050. High production cost has occurred in the Natural gas-fueled powerplant such as Combined Cycle powerplant (CCPP) with 74 Billion USD (77%) in 2020 to 320 Billion USD (31%) in 2050 and Gas

Engine powerplant (GEPP) with 11 Billion USD (14%) in 2020 to 580 Billion USD (56%) in 2050 (Table 18). This condition may be affected by the share of renewable energy and reserve margin as optimization constraints.

Table 18. Electricity Production Cost for OPT Scenario

	Electricity Production Cost in Billion USD						
Powerplant	2020	2025	2030	2035	2040	2045	2050
CFPP	6	11	18	28	41	61	88
CCPP	74	115	150	181	205	221	320
Wind PP	0	1	1	2	2	6	13
GEPP	11	23	59	121	223	400	580
CCPP Oil Based	0	0	0	0	0	0	0
Large Scale Hydro PP	1	2	4	5	7	8	10
Minihydro PP	0	0	1	1	2	2	3
GTPP	0	1	2	2	2	2	2
Geothermal PP	1	2	2	3	5	6	7
Biomass PP	1	2	3	4	5	5	6
Solar PV PP	0	1	2	3	3	3	2
Diesel HSD PP	0	0	0	0	0	0	0
Total	95	157	240	349	494	714	1030

Cost of electricity has increased from 5 cUSD/kWh in 2018 to 34.5 cUSD/kWh in 2050 because of optimization start in 2019 then stable in the range 34-35 cUSD/kWh until 2050 due to increasing renewable power share in the generation mix. Along with the cost of electricity, the production cost also dramatically increasing from 6.38 Billion USD in 2018 to 1,030 Billion USD in 2050.



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Production Cost	7	81	95	106	117	130	143	157	172	187	204	222	240	260	281	302	325
Cost of Electricity	5	34	35	35	35	35	36	36	36	36	36	36	36	36	36	36	36

	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Production Cost	349	373	398	427	459	494	533	573	617	664	714	769	828	891	958	1030
Cost of Electricity	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35

Figure 59. COE and production cost for OPT scenario

From the energy security indicator perspective, the OPT scenario will increase electricity production per capita, Electricity Consumption per capita, Increased utilization of New and Renewable energy reserves and resources, Share of renewable energy in total primary energy supply in the availability dimension. For the affordability dimension, the OPT scenario will decrease the cost of the subsidy. However, it will increase electricity price per GDP per capita and the overall system cost until 2050. OPT scenario will increase the entire acceptability indicator, including CO_2 emission, emission intensity, and emission per electricity consumption. The electrification ratio will also increase and reached 100% in 2022, while the reserve margin will stay at 30% until 2050. Electricity intensity shows a similar result with the BAU scenario.

Table 19. Energy security indicator for OPT scenario

Dimension	Indicator	Information	2018	2028	2038	2048	2050	Trend
Availability	Electricity production per capita	Electricity Production per population	0.55	1.96	3.93	7.86	9.00	Increasing
	Electricity Consumption per capita	Electricity Consumption per population	0.80	1.96	3.88	7.78	8.90	Increasing
	Self Sufficiency of Electricity	Share of domestic electricity production over total consumption	1.00	1.00	1.00	1.00	1.00	-
	Increased utilization of New and Renewable energy reserves and resources	Rate of electricity production from renewable energy by year	-	0.05	0.06	0.07	0.07	Increasing
	Share of renewable energy in total primary energy supply	Share of electricity production from renewable energy over total electricity production	0.23	0.65	0.63	0.61	0.61	Increasing
Affordability	Electricity Price per GDP per capita ratio	Electricity price per GDP per capita	1.24	5.00	3.03	1.79	1.61	Increasing
	Cost of Subsidy	Expenditure in electricity subsidy per total government spending	0.51	0.04	0.02	0.01	0.01	Decreasing
	Overall System Cost (LCOE)	Levellized cost of electricity in the system	4.51	33.83	33.51	32.92	32.85	Increasing
Acceptability	Emission per electricity consumption	Total Emission of the powerplant per electricity consumption	0.51	0.83	0.76	0.65	0.63	Increasing
	Emission Intensity	CO2 emission related to refinery development per GDP	0.51	0.83	0.76	0.65	0.63	Increasing
	CO2 Emission	Total CO2 emission	103.09	472.75	914.58	1,685.01	1,888.54	Increasing
Intensity	Electricity Intensity	Total electricity consumption per GDP	0.20	0.27	0.33	0.39	0.41	Increasing
Accessibility	Electrification Ratio	The number of households with electricity access per total households	99.00	100.00	100.00	100.00	100.00	Increasing
	Reserve Margin of generation capacity	Percentage of power generation reserve capacity to the electricity consumption	(92.24)	30.00	30.00	30.00	30.00	Increasing

A comparison between the BAU scenario and OPT scenario has been conducted to see the difference in each energy security dimension impact. OPT scenario is higher than the BAU scenario for availability, acceptability, and accessibility dimension. However, the BAU scenario is higher in terms of affordability than the OPT scenario.

Table 20. Energy security indicator comparison for BAU and OPT scenario

Business As Usual (BAU) Scenario

Energy Security Dimension	2019	2028	2038	2048	2050	Result
Availability	0.46	0.42	0.54	0.79	0.86	Lower
Affordability	0.65	0.52	0.47	0.53	0.54	Higher
Acceptability	0.98	0.48	0.45	0.27	0.24	Lower
Intensity	1.00	0.68	0.39	0.06	0.00	No change
Accessibility	0.93	0.26	0.16	0.02	0.00	Lower
Energy Security Indicator	0.81	0.47	0.40	0.34	0.33	Lower

Optimization (OPT) Scenario

Energy Security Dimension	2019	2028	2038	2048	2050	Result
Availability	0.41	0.62	0.70	0.89	0.94	Higher
Affordability	0.64	0.51	0.42	0.37	0.36	Lower
Acceptability	1.00	0.47	0.40	0.30	0.27	Higher
Intensity	1.00	0.68	0.39	0.06	0.00	No change
Accessibility	0.50	1.00	1.00	1.00	1.00	Higher
Energy Security Indicator	0.71	0.65	0.58	0.52	0.51	Higher

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The overall energy security index indicates that the optimization scenario (OPT) improves the energy security index than the BAU scenario despite the lower affordability dimension result. The energy security index in the BAU scenario without optimization will be decreased from 0.81 in 2019 to 0.33 in 2050. In the OPT scenario, the energy security index has increased to 0.80 in 2020 after the optimization result and decreased to 0.51 in 2050.

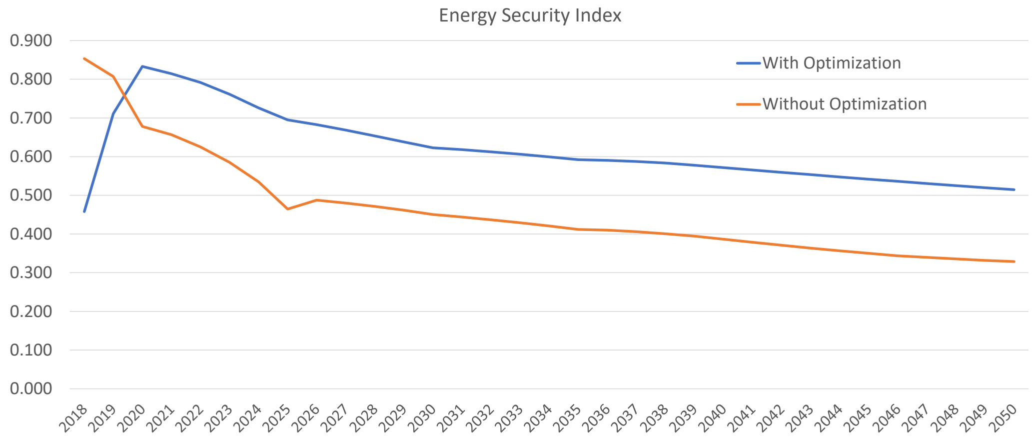


Figure 60. Energy security Index comparison for BAU and OPT scenario

Furthermore, there is a consequence in the improvement of energy security index in OPT scenario with the increasing trend of Levelized Cost of Electricity (LCOE). Business As Usual Scenario is based on the Indonesia National Energy Planning. This planning set a target of renewable energy in 2025 by 23%. The renewable energy shares then still increasing until 2032 with 24% shares. However, the shares are decreasing to 18% until 2050. The graph of LCOE in the BAU scenario is mostly affected by the share of renewable energy. A higher share of renewable energy might increase the LCOE, although the capital cost has been set into a decreasing rate from 2018-2050.

Hence, the LCOE graph in the optimization scenario is based on the constraint of 30% renewable energy penetration in the power generation mix from 2019 (optimization start period). The increasing share of renewable energy will increase the utilization of geothermal powerplant, Large Hydro powerplant, and Combined Cycle powerplant, and Gas Engine powerplant which fueled by natural gas. The increasing CCPP and GEPP has contributed significantly to the increasing electricity production cost and LCOE in the optimization scenario (OPT).

4.2.3 Power Generation System Dynamic Model in Indonesia

The system dynamic model in power generation will analyze the interaction among the input and output parameters in the electricity sector, especially power generation development perspective. The power generation sector system dynamic model in the Thesis has been developed following Powerplant Investment Planning conducted by (APERC, 2016) as shown in Figure 61.

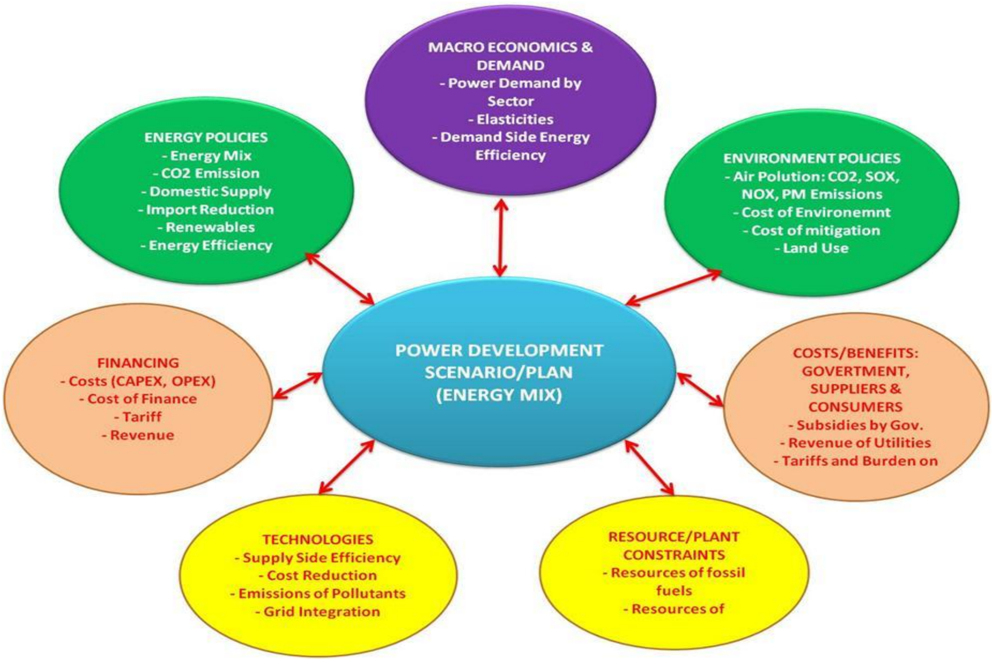


Figure 61. Powerplant Investment Planning

Source: (APERC, 2016)

The power development plan will be divided into several blocks, including macroeconomic, electricity demand, energy and environmental (emission), Cost and Tariff, technologies and resources, and plant constraints. Due to the focus and limitation of the optimization and system dynamic analysis in this Thesis is the total and share of the power generation mix in the system and not the operational constraint of the power generation system, then the requirement of Battery Energy Storage System (BESS) is not crucial to be analyzed in the system dynamic model

The system dynamic model input will be divided from the electricity demand and supply-side (Figure 62). Input from the electricity demand side will be represented by the GDP, global oil price, coal price, population, and electrification rate. Normally, higher GDP, population, and electrification rate will bring higher electricity consumption. On the other hand, higher global oil prices and coal prices will decrease electricity consumption. Historically, the fluctuation of global oil prices didn't significantly impact electricity consumption due to the electricity tariff in Indonesia still be covered by the electricity subsidy, although the power generation cost was increasing.

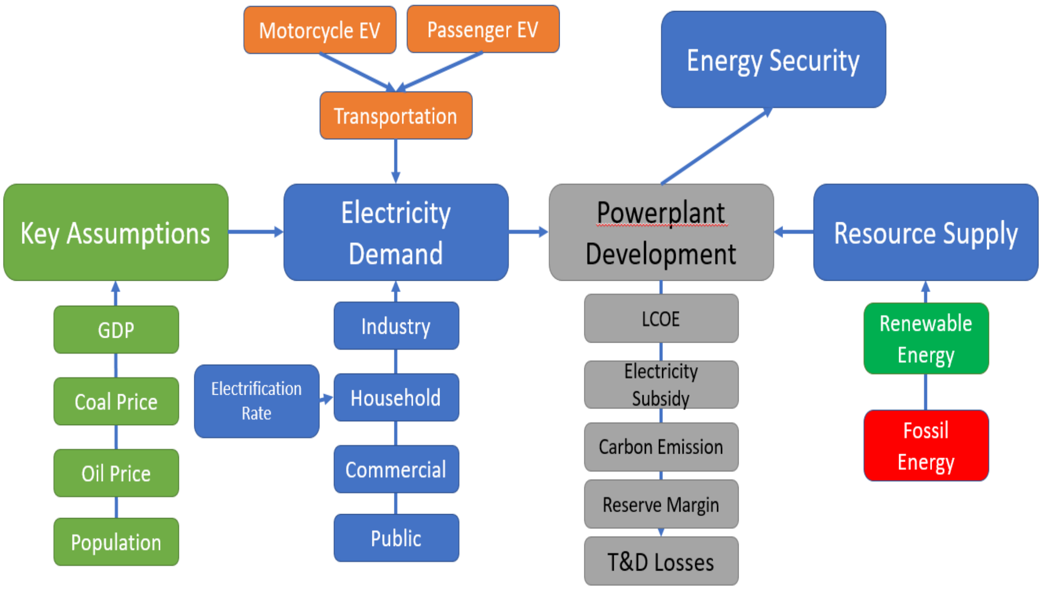


Figure 62. Structure of electricity sector system dynamic model

This study will use GDP, population, global oil price, and coal price as key assumptions that will impact the electricity demand. The electricity demand in Indonesia is divided into four sectors, which are industrial, commercial, household, and Public sector. The electrification rate is the parameter to measure electricity's accessibility where the number of electrified households per total households. The electrification rate increased significantly from 70% in 2000 to 97.1% in 2018 due to the government and national utility company efforts on providing electricity access to underdeveloped communities. The coal price is included in the key assumption to generate electricity consumption due to 60% of existing power generation is coming from the coal-fired powerplant. Historically, coal price has a significant impact on the industrial and public sector electricity consumption, while oil prices impact the public and commercial sectors. The increasing economic growth or GDP solely influences residential sector electricity consumption. The input from the electricity supply side will include fossil power generation and renewable power generation. Higher fossil and renewable power generation will increase electricity production in the country. In Indonesia, power generation development has several constraints to be considered such as the Levelized cost of electricity (LCOE), electricity subsidy, reserve margin, carbon emission, and transmission and distribution losses.

LCOE is the parameter to measure the Levelized value of the power generation cost in IDR/kWh or cUSD/kWh. In 2017, the LCOE of Indonesia was about 1,025 IDR/kWh or 7.6 cUSD/kWh. The government of Indonesia put a subsidy policy to get an affordable electricity tariff for the underdeveloped communities in Indonesia. The electricity subsidy in Indonesia is for 450 VA customers and a partial 900 VA customers. The electricity subsidy is in Indonesia has varied from 30-100 Billion IDR in the last decade. Reserve margin is available generating capacity in the power system as a reserve to handle the unexpected or scheduled outage from the other running powerplant. From the planning perspective, Indonesia's number of reserve margins is about 30-35% of net generating capacity.

System dynamic model of power generation development will be derived with the following structure:

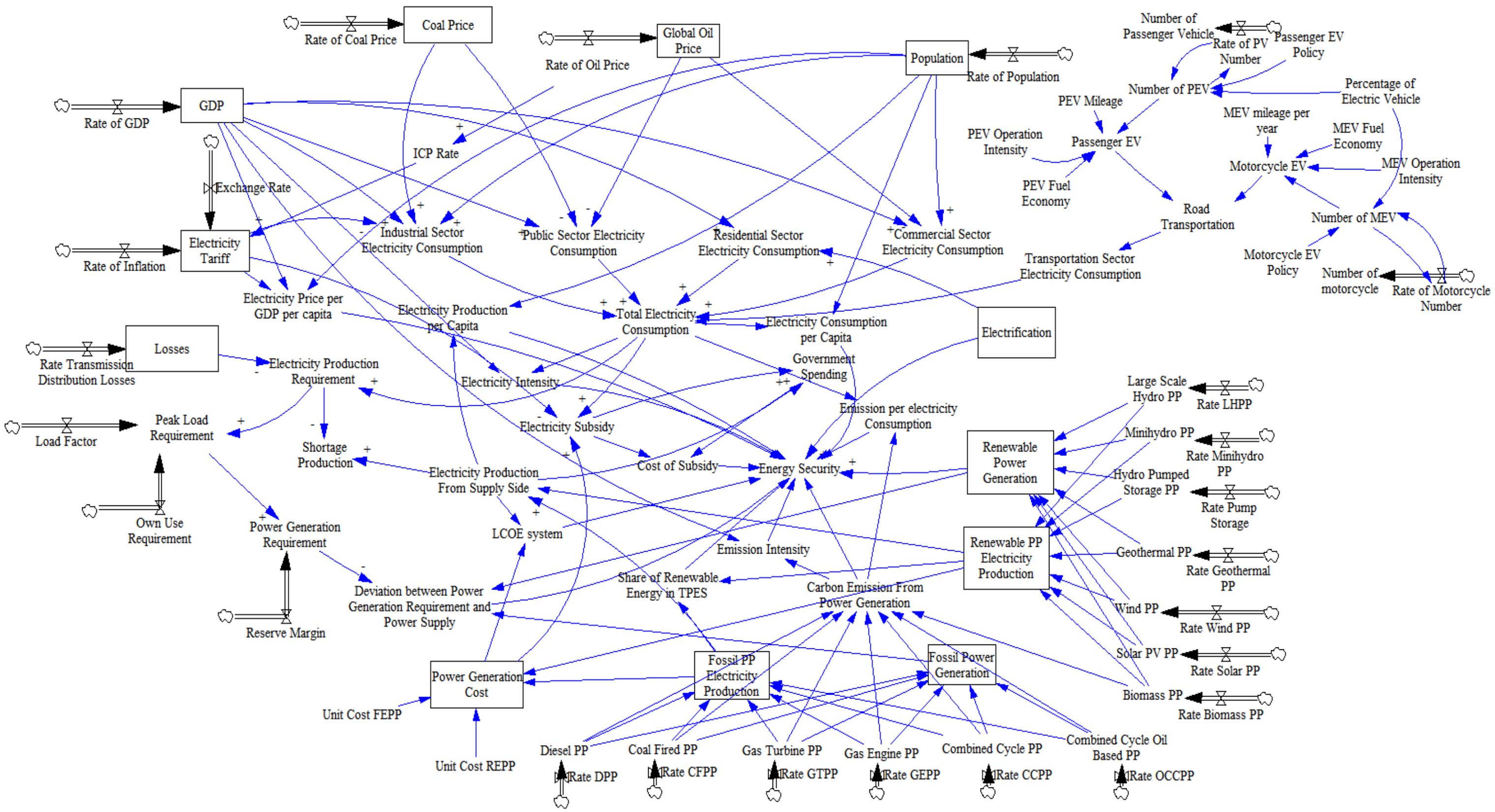


Figure 63. System dynamic model structure in power generation development

There will be some scenarios to analyze the impact of changing the input parameter on the energy security level and other parameters in the power generation sector. The scenarios will be divided into five scenarios which are Base scenario where there is no change in the input parameter, scenario 1 with higher GDP growth rate, scenario 2 with higher oil price rate, scenario 3 with a higher population growth rate, scenario 4 with higher additional fossil power generation rate, and scenario 5 with higher additional renewable power generation rate. The parameter change in the scenario analysis is explained in Table 21.

Table 21. Scenario analysis in system dynamic model

Scenario	GDP Growth Rate	Global Oil Price Rate	Population Gr. Rate	Additional Fossil PG Rate	Add. RE PG Rate
Base	5%	0.08%	1.5%	Average Rate	Average Rate
Scenario 1 Higher GDP	7%	0.08%	1.5%	Average Rate	Average Rate
Scenario 2 Higher Oil Price	5%	0.16%	1.5%	Average Rate	Average Rate
Scenario 3 Higher Population Growth	5%	0.08%	3.0%	Average Rate	Average Rate
Scenario 4 Additional Fossil Power Generation	5%	0.08%	1.5%	2 times Average Rate	Average Rate
Scenario 5 Higher Additional RE Power Generation	5%	0.08%	1.5%	Average Rate	2 times Average Rate

The system dynamic analysis for power generation development will be based on several equations as follows:

Electricity consumption equations:

$$IEC_t = C_1 GDP_t + C_2 ET_t + C_3 CP_t + C_4 POP_t + \varepsilon_{dt} \qquad (35)$$

IEC_t : Industrial Electricity Consumption at year t

GDP_t : GDP at year t; ET_t : Electricity tariff at year t
CP_t : Coal Price at year t; POP_t : Population at year t

$$PEC_t = C_1 GDP_t + C_2 OP_t + C_3 CP_t + \varepsilon_{dt} \qquad (36)$$

PEC_t : Public Electricity Consumption at year t

OP_t : Oil Price at year t

$$REC_t = C_1 GDP_t + C_2 ER_t + \varepsilon_{dt} \qquad (37)$$

REC_t : Residential Electricity Consumption at year t

ER_t : Electrification Rate at year t

$$CEC_t = C_1 GDP_t + C_2 OP_t + C_3 POP_t + \varepsilon_{dt} \qquad (38)$$

CEC_t : Commercial Electricity Consumption at year t

$$TEC_t = IEC_t + PEC_t + REC_t + CEC_t \qquad (39)$$

TEC_t : Total Electricity Consumption at year t

Electricity tariff equations:

$$RET_t = C_1 RI_t + C_2 RX_t + C_3 ROP_t + \varepsilon_{dt} \qquad (40)$$

RX_t : Exchange Rate at year t ; RI_t : Inflation Rate at year t

ROP_t : Indonesia Crude Oil Price Rate at year t

Electricity production requirement equations:

$$REP_t = \frac{TEC_t}{(1-L_t)} \qquad (41)$$

; L_t : T&D Losses at year t

Peak load requirement equations:

$$RPL_t = REP_t \times \frac{(1+OU_t)}{(LF \times 8760)} \quad ; \text{OU}_t : \text{Own Use at year t} ; \text{LF:Load Factor} \tag{42}$$

Power generation requirement equations:

$$RPG_t = RPL_t \times (1+RM_t) \quad ; \text{RM}_t : \text{Reserve Margin at year t} \tag{43}$$

Deviation of power generation requirement and supply equations:

$$\Delta RPG_t = (FEP + REP_t) - RPG_t \tag{44}$$

FEP_t : Fossil Power Generation at year t

REP_t : Renewable Power Generation at year t

Electricity production from supply-side equations:

$$FEP_t = DEP_t + CFP_t + GTP_t + GEP_t + CCP_t \tag{45}$$

$$REP_t = LHP_t + MHP_t + HPP_t + GOP_t + WTP_t + SPP_t + BPP_t \tag{46}$$

DEP_t : Diesel Power Generation at year t
CFP_t : Coal Power Generation at year t
GTP_t : Gas Turbine Power Generation at year t
GEP_t : Gas Engine Generation at year t
CCP_t : Combined Cycle Generation at year t
LHP_t : Large Hydro Power Generation at year t
MHP_t : Minihydro Power Generation at year t
HPP_t : Pump-storage Power Generation at year t
GOP_t : Geothermal Power Generation at year t
WTP_t : Wind Power Generation at year t
SPP_t : Solar Power Generation at year t
BPP_t : Biomass Power Generation at year t

Power generation cost equations:

$$PGC_t = FEP_t \times FUC_t + REP_t \times RUC_t \tag{47}$$

FUC_t : Fossil Power Generation Unit Cost at year t
RUC_t : Renewable Power Generation Unit Cost at year t

Electricity Subsidy equations:

$$ES_t = PGC_t - (TEC_t \times RET_t) \quad (48)$$

Emission from power generation equations:

$$CE_t = (\sum_{plant} FEP_t \times FEF) + BPP_t \times BEF \quad (49)$$

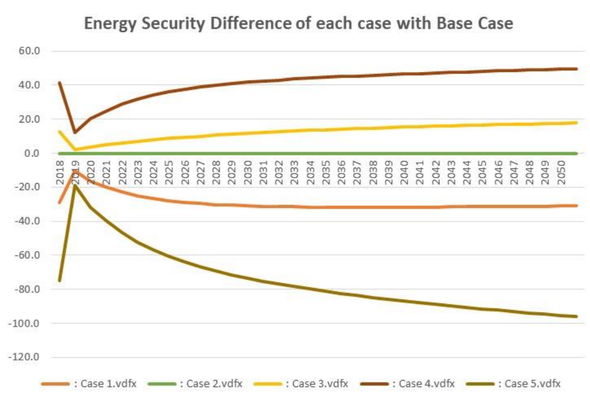
FEF_t : Fossil Power Generation Emission Factor at year t
BEF_t : Biomass Power Generation Emission Factor at year t

Total electricity consumption will consist of the Industrial sector (IEC), Public sector (PEC), Residential sector (REC), and Commercial sector (CEC) electricity consumption. Industrial sector consumption will be derived from the linear model of GDP, Electricity Tariff (ET), Coal Price (CP), and population (POP). Public sector electricity consumption will be based on the linear model of GDP, Oil price (OP), and Coal price (CP). Commercial electricity consumption will be based on GDP, Oil price (OP), and population (POP).

The result of the system dynamic model shows the difference of each scenario with Base Case scenario with the details are as follows:

- Scenario 5 Higher Additional Renewable Energy Power Generation shows the highest energy security index among the other scenario while Scenario 4 shows the lowest one. (Higher RE means higher ESI),
- Scenario 4 with high additional fossil power generation will decrease energy security index by decreasing 41.4% on average

- Scenario 1 Higher GDP will increase the energy security index by increasing 29.1% on average
- Scenario 2 Higher Oil Price will decrease the energy security index by decreasing 0.01% on average
- Scenario 3 Higher Population Growth doesn't show a significant impact on energy security



Case Name	Energy Security Result	Difference Yearly Average Rate
Case 1 GDP	Increasing	29.1%
Case 2 Oil Price	Decreasing	-0.01%
Case 3 Population	Decreasing	-12.6%
Case 4 Additional Fossil Power Generation	Decreasing	-41.4%
Case 5 Additional Renewable Power Generation	Increasing	75.1%

Figure 64. Energy Security Difference of each case with Base Case in power generation

The other result of the system dynamic model identifies Scenario 1 Higher GDP shows the highest total electricity consumption which means electricity consumption is significantly affected by the fluctuation of GDP. Scenario 1 with higher GDP has 1.7 times higher for total electricity consumption as shown in Figure 65.

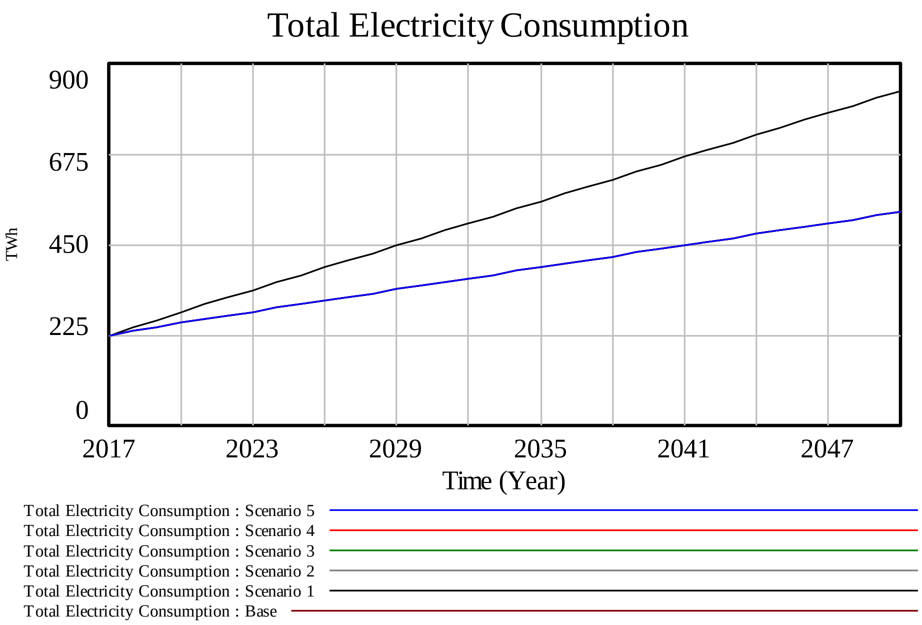


Figure 65. Total electricity consumption result

Scenario 4 Higher additional Fossil Power Generation shows the highest electricity production per capita and Scenario 3 higher population growth shows the lowest one. Scenario 4 will produce the electricity production per capita with 6.500 kWh/capita or increasing for almost 4 times from 2018-2050. Scenario 3 higher population growth will decrease the increasing rate of electricity production per capita with only reach 4.200 kWh/capita in 2050 while scenario 5 higher renewable energy penetration will have higher electricity production per capita around 4.500 kWh/capita as shown in Figure 66. Scenario 4 also shows the carbon emission due to high fossil energy utilization.

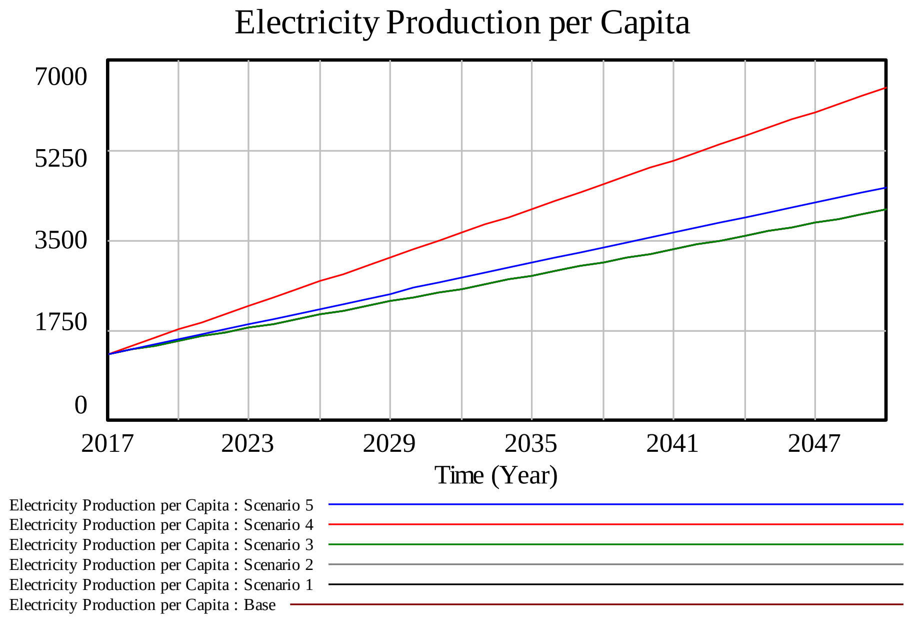


Figure 66. Electricity production per capita result

The comparison of LCOE, reserve margin, renewable energy share, and emission intensity among each scenario has been conducted to see the impact of each scenario on these parameters. The findings in this analysis are as follows:

- Scenario 4 Higher Additional Fossil Energy Power Generation shows the highest LCOE system among the other scenario, while Scenario 5 shows the lowest one. (Higher Fossil Power Generation means higher LCOE)

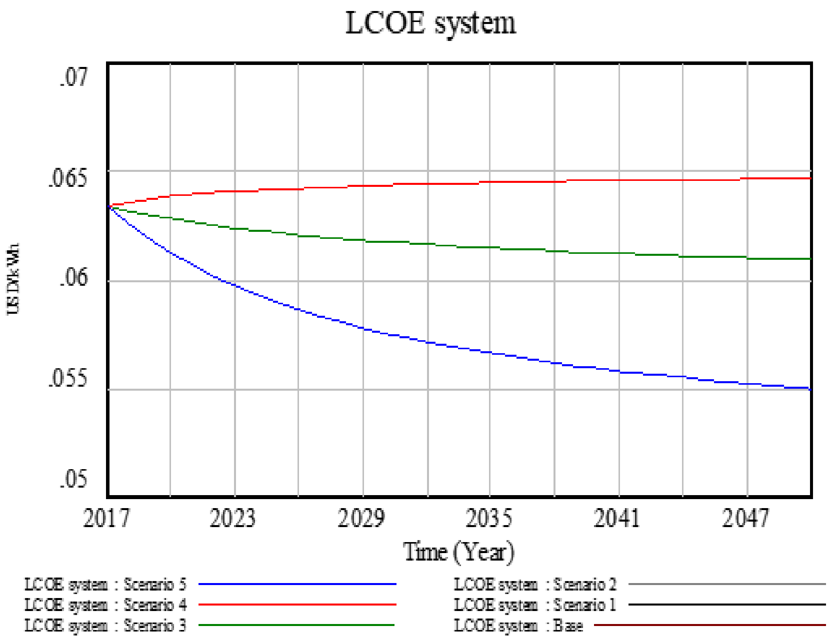


Figure 67. The difference of LCOE for each case with Base Case

- Scenario 4 Higher Additional Fossil Energy Power Generation shows the highest reserve margin in the system among the other scenario while Scenario 1 Higher GDP shows the lowest one. (Higher Fossil Power Generation means higher reserve margin)

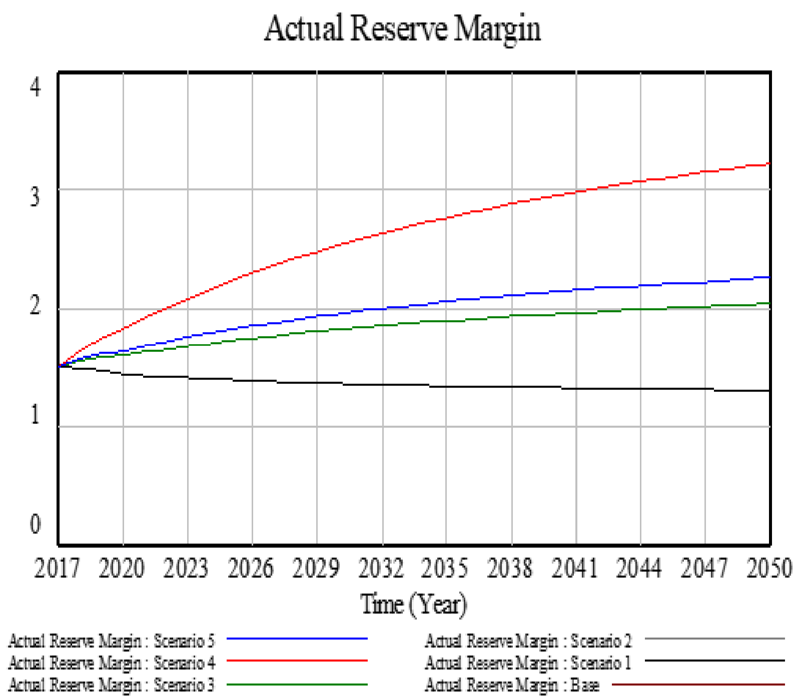


Figure 68. The difference of reserve margin for each case with Base Case

- Scenario 4 Higher Additional Fossil Energy Power Generation shows the highest emission intensity among the other scenario while Scenario 1 shows the lowest one. (Higher Fossil Power Generation means higher emission intensity)

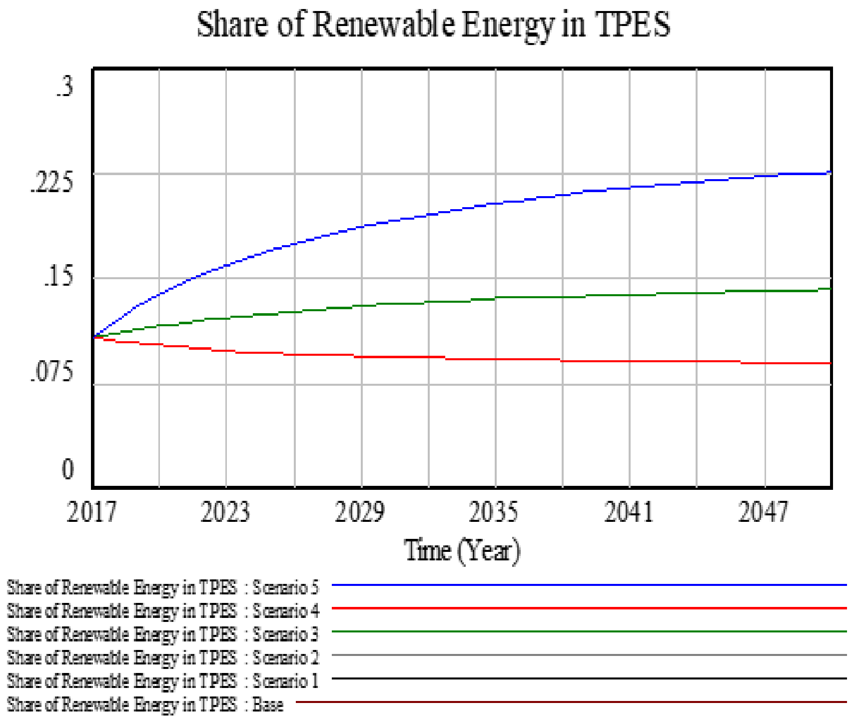


Figure 69. The difference of renewable energy share for each case with Base Case

- Scenario 5 Higher Additional Renewable Energy Power Generation shows the highest share of RE in TPES among the other scenario, while Scenario 5 shows the lowest one.

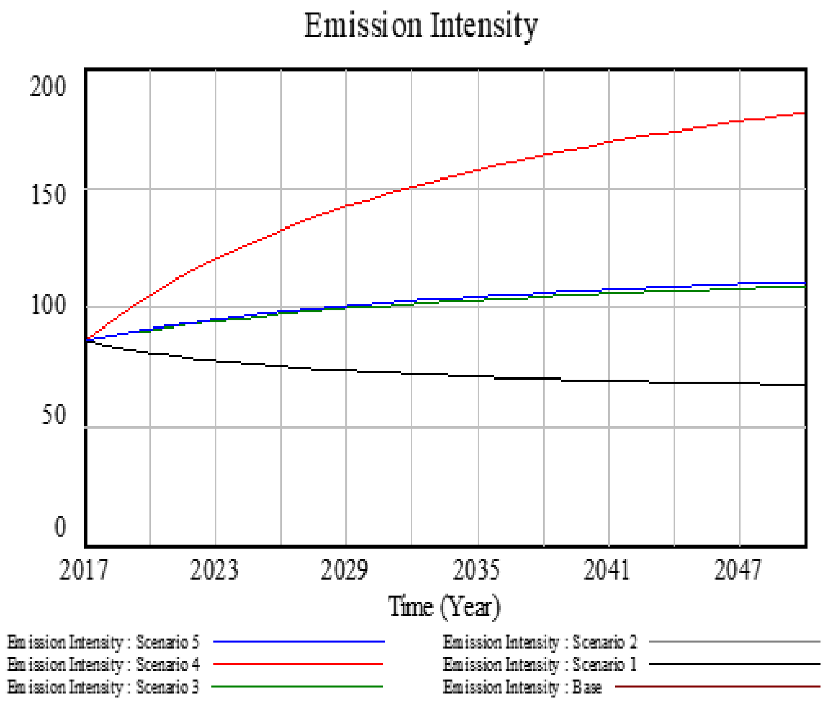


Figure 70. The difference of emission intensity for each case with Base Case

System dynamic analysis on the power generation development indicated that the energy security index in the electricity sector is not only influenced by the development of power generation but several parameters need to be considered by the government which is the share of fossil power generation, the share of renewable power generation and higher electricity consumption.

A higher rate of fossil power generation will increase electricity production per capita, emission per electricity consumption, emission intensity, CO_2 emission, and reserve margin. A higher renewable energy production rate will increase electricity production per capita, the share of renewable energy in TPES, higher utilization of renewable energy, LCOE, and reserve margin. On the other hand, it also decreases emission per electricity consumption and emission intensity, which increases the acceptability dimension of energy security. The higher electricity consumption will increase electricity consumption per capita and electricity intensity while reducing emission per electricity consumption. The other impact is a lower reserve margin of generation capacity and higher electricity production. Indonesia government may consider these three-parameter to increase the energy security index level by increasing the share of renewable energy with the cautious consideration of increasing LCOE, reducing fossil power generation ultimately diesel power due to high cost and high emission of CO_2. They might also consider the introduction of an electric vehicle to increase electricity consumption.

The finding in this analysis shows that the Energy Security index in Indonesia will get higher value in several conditions:

a. Higher rate of additional fossil power generation
b. Higher rate of additional renewable power generation
c. Higher GDP
d. Higher electricity consumption

On the other hand, the energy security index will get a lower value through higher Oil Prices. The higher population growth rate didn't show a significant impact on energy security from power generation development.

4.3 Conclusions

To support the power generation development to increase energy security in Indonesia, this study recommends some conclusions and recommendations for the Government of Indonesia, in the terms of optimization capacity of power generation, impact to energy security index, and system dynamic analysis, and the introduction of electric vehicle analysis with details as follows:

1. A comparison between the BAU scenario and OPT scenario has been conducted to see the difference in each energy security dimension. OPT scenario is higher than the BAU scenario for availability, acceptability, and accessibility dimension. However, the BAU scenario is higher in terms of affordability than the OPT scenario.
2. The overall energy security index indicates that the optimization scenario (OPT) improves the energy security index than the BAU scenario despite the lower affordability dimension result.
3. Power Generation Optimization impact to the energy security dimension:
   a. It will increase the availability dimension due to improving electricity production and renewable energy share in total primary energy supply;
   b. It will increase the acceptability dimension due to decreasing emissions from the power generation sector.
   c. It will decrease the affordability dimension due to the increasing overall system cost and cost of the subsidy.

d. There will be no difference between two cases for intensity dimension

4. The system dynamic analysis shows several results as follows:
    a. Scenario 5, Higher Additional Renewable Energy Power Generation, shows the highest energy security index among the other scenario, while Scenario 4 shows the lowest one. (Higher RE means higher ESI)
    b. Scenario 1 Higher GDP will increase the energy security index by increasing 21% on average
    c. Scenario 2 Higher Oil Price will decrease the energy security index by decreasing 0.008% on average
    d. Scenario 3 Higher Population Growth doesn't show a significant impact on energy security
5. The Energy Security index in the power generation sector will be influenced by the higher fossil power generation, higher renewable power generation, and higher electricity consumption;
6. The Energy Security index of power generation development in Indonesia will get higher value in several conditions, which are a higher rate of additional fossil power generation, a higher rate of additional renewable power generation, higher GDP, and higher electricity consumption that can be conducted through the introduction of electric vehicle on passenger vehicle and motorcycle;

7. On the other hand, the energy security index will get a lower value because of the higher oil price. The higher population growth rate didn't show a significant impact on energy security;
8. The Government of Indonesia can use this research as useful information in improving power generation development to increase energy security by improving the renewable energy share;
9. This paper result can be used as supporting information to justify renewable energy project development in Indonesia's power generation sector to improve its energy security level.

Chapter 5. Discussions: Energy Security in Oil Refinery and Power Generation Development Perspective in Indonesia

5.1 Energy Security Index Evaluation

Energy Security Index formulation can be processed by several steps such as the dimension and indicator formulation, data collection process, indicator normalization, weighting, and aggregation as the final process. Energy security is a multi-dimension evaluation parameter. The energy security dimension can be determined by its indicators(Erahman et al., 2016). Some dimensions and indicators were evaluated to develop energy security. The choice of dimensions and indicators will be chosen based on the energy security assessment objective, so there are no rigid indicators over time(Narula & Reddy, 2016). Several published research has introduced the four-energy security dimension: availability, affordability, acceptability, and accessibility. Other research adds one more dimension in intensity. Out of 83 energy security research, the discussion mainly focused on energy availability (99%), energy accessibility with the supported infrastructure(72%), energy affordability (71%), environmental acceptability (71%), and energy efficiency (22%)(Ang et al., 2015).

Moreover, the discussion about the energy security issue is changing with each dimension. The discussion about energy availability and accessibility has slightly decreased from 2001-2013, while the discussion of energy affordability, acceptability, and intensity is dramatically increasing. However, the main discussion is still the energy availability dimension, which focuses on how a country can provide an uninterruptable energy supply in a certain period.

Energy security indicators are divided into two groups, which are simple and complex indicators. A simple indicator can be captured by fast and momentary assessment, while the complex indicator needs a more comprehensive evaluation by the aggregate of multiple variables in the assessment (Sovacool & Mukherjee, 2011). (Kruyt et al., 2009b) found that energy security could be assessed from the simple energy supply indicator and other relevant indicators related to energy security. Hence, the selection of energy security indicators has a common indicator that will be used and other new indicators that have been modified from the other reference(Erahman et al., 2016).

5.2 Energy Security Dimension

5.2.1 Availability Dimension

Recent research has developed some indicators in the availability dimension from both Indonesia or other country energy security index discussions. Some research indicates that diversification and the geopolitical parameter is a key issue in energy availability. Diversification can be defined by several factors, which are the capability of a country to diversify the supply of energy source, while reduce and mitigate the risk for the energy importer country (source diversity), the capability of a country to get a higher potential of energy source especially renewable energy in their area (spatial diversity), the capability to reach a balance in the energy mix (energy mix diversity), and how a county can find an optimal way to transport the energy import from various source (transport route diversity) (Ang et al., 2015). The other consideration in availability is the development of energy infrastructure to provide a stable energy supply, including energy transformation facilities such as oil refinery, power generation, and the energy transmission infrastructure such as oil and gas pipeline and transmission line and substation network. The capability of this infrastructure to provide energy supply without shortage is vital for energy supply reliability.

A country shall provide sufficient investment to ensure that this facility can generate energy in a short and long term period. The energy infrastructure shall be robust and provided with enough reserve margin. Indonesia National Energy Commission in 2014 indicates that the availability indicators can be expressed into several indicators such as oil and gas reserve and resources, energy buffer reserve, the domestic market obligation of gas and coal, import of crude oil and fuel oil/LPG, and national fuel oil/LPG Reserves. One year later, they issued a new Indonesia energy security analysis in 2015 with the availability dimension has changed some of its indicator with decreased in fuel oil/LPG import, decreased in crude oil import, increased utilization of oil, natural gas, coal, new and renewable energy reserves, and resources and compliance of domestic market obligation of gas and coal.

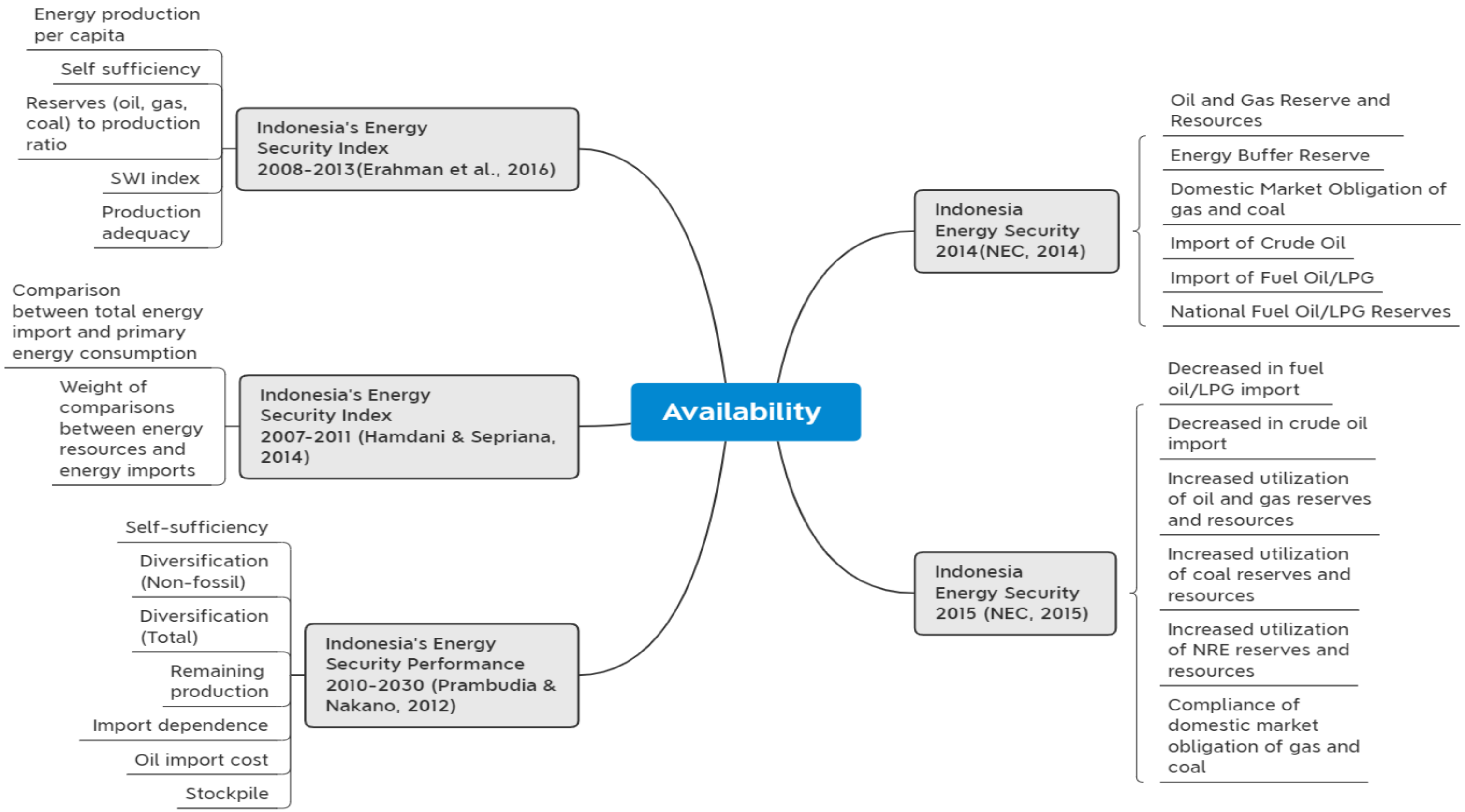


Figure 71. Availability dimension indicators from existing Indonesia case references

(Erahman et al., 2016) shows that the availability dimension in Indonesia can be represented by the energy production per capita, self-sufficiency, reserve of oil, natural gas, and coal to production ratio, SWI Index, production adequacy. The other research shows that the comparison between total energy import and primary energy consumption and the weight of this comparison can evaluate the availability dimension(Hamdani & Sepriana, 2014). (Prambudia & Nakano, 2012) focused on self-sufficiency, diversification, remaining production, import dependence, oil import cost, and stockpile as availability dimension measurement.

For international reference, the availability dimension can be investigated by measuring resource estimates, reserves to production ratios, and demand-side indicators (Kruyt et al., 2009b). The analysis in Thailand availability dimension can be estimated from resource estimates, reserves/production ratio, diversity indices (SWI index), energy import, net energy, import, dependency, geopolitical market concentration risk, market liquidity, geopolitical energy security, oil vulnerability indicator, the share of the transport sector, and the share of oil used in the transport sector(Martchamadol & Kumar, 2012). In China, the availability is measured by coal reserve-to-production (R/P) ratio, oil import dependence ratio, natural gas reserve-to consumption ratio, availability factor of conventional thermal electricity, availability factor of nonthermal electricity(Yao & Chang, 2014).

Energy Security in ASEAN member countries assessment indicates that the availability dimension indicators are primary energy mix, electricity generation by source, sectoral energy consumption, total primary energy supply per capita, final energy, consumption per capita, energy self-sufficiency, coal/crude oil/natural gas self-sufficiency, coal/crude oil/natural gas r/p ratio, refining capacity, energy import dependency, reliance on middle east crude oil/natural gas/refined oil imports, and coal/crude oil/natural/gas/refined oil export destination/import source diversification (Kanchana & Unesaki, 2014). (Narula & Reddy, 2016) decide to put the energy indicator per capita as a crucial factor to identify availability. (Sovacool et al., 2011) express the availability for 18 countries assessment through total primary energy supply per capita, the average reserve-to-production ratio for the three primary energy fuels (coal, natural gas, and oil), self-sufficiency, and the share of renewable energy in total primary energy supply. The availability dimension indicator assessment is shown in Figure 72.

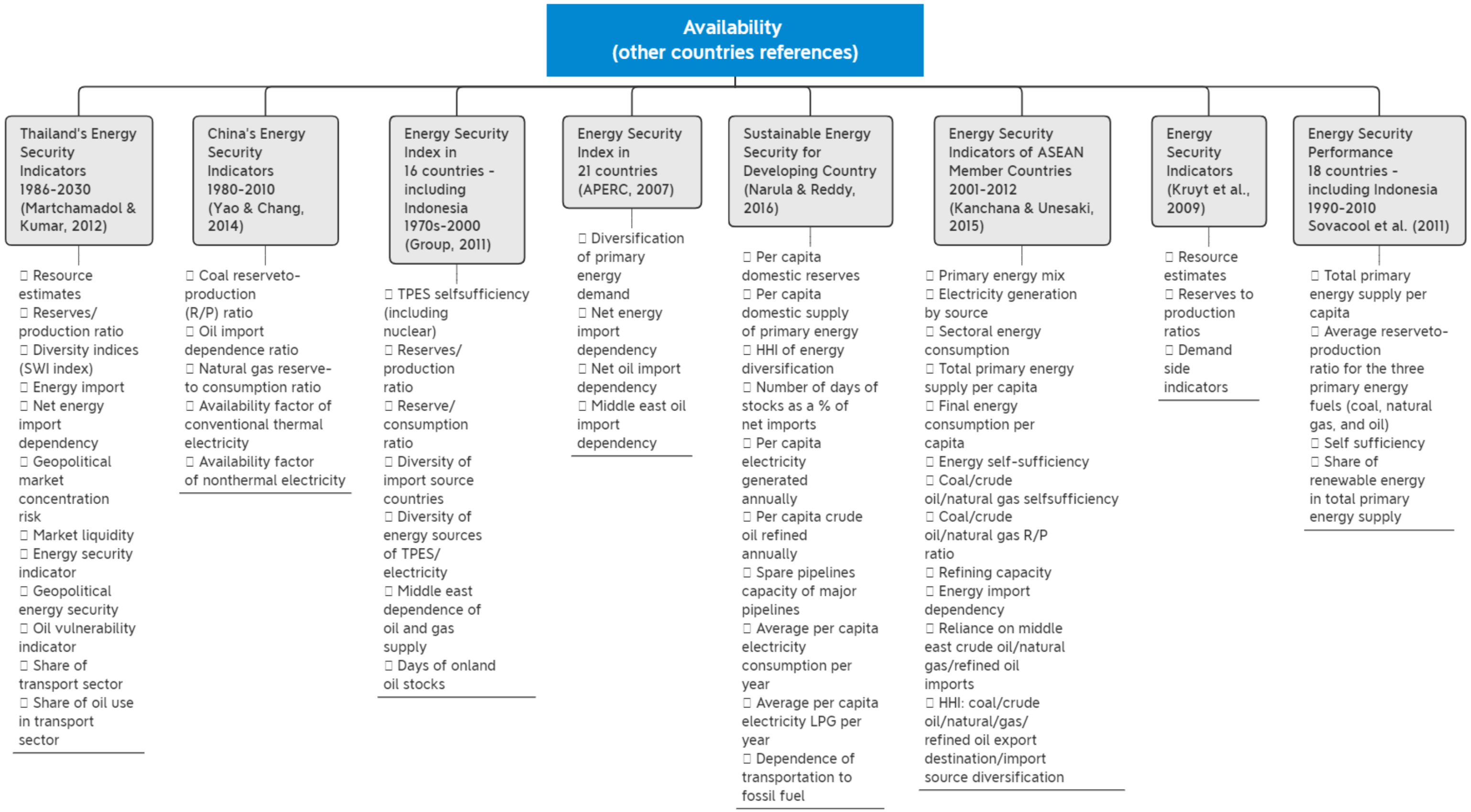


Figure 72. Availability dimension indicators from other countries case references

5.2.2 Accessibility Dimension

For accessibility dimension indicators in the energy security index, Indonesia National Energy Commission in 2014 identified that the availability indicators could be expressed by the provision of fuel oil/LPG and electricity, and natural gas distribution services. It has changed to an increased in fuel oil/LPG and electricity supply and the provision of natural gas and coal supply. (Erahman et al., 2016) put electrification ratio, percentage of people relying on traditional biomass, and electric vehicle ownership as an accessibility indicator. (Hamdani & Sepriana, 2014) also agreed to choose the electrification ratio indicator for accessibility.

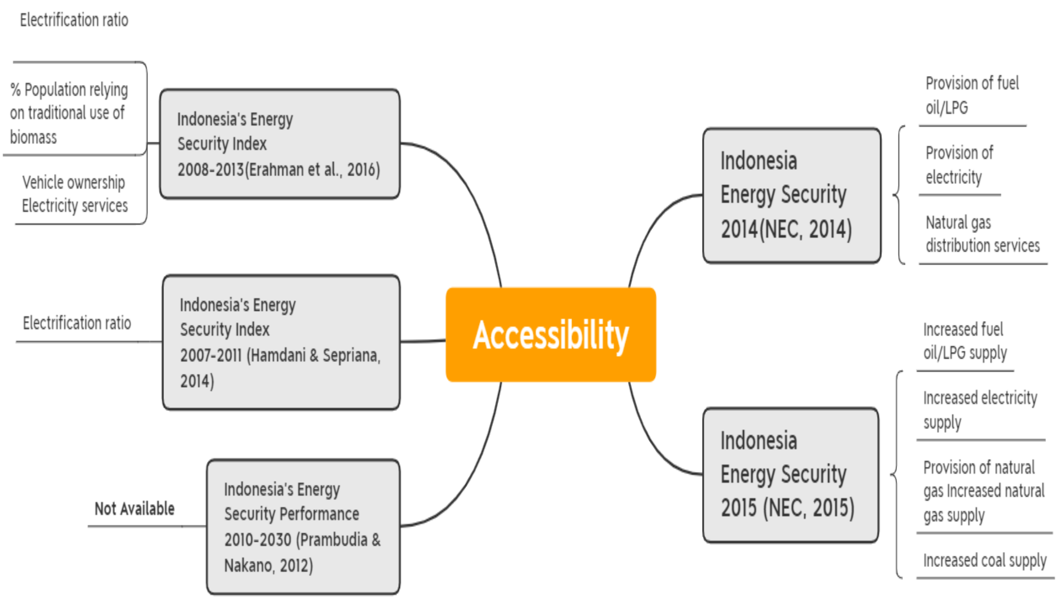


Figure 73. Accessibility dimension indicators from existing Indonesia case reference

For international reference, the accessibility dimension can be investigated by measuring diversity indices, import dependence, supply-demand index, oil vulnerability index, and Shannon index (Kruyt et al., 2009b). The energy security analysis for 16 countries from 1970-2000 shows that the accessibility dimension can be estimated from reserve margin of generation capacity, power outage frequency/duration, commercial energy access ratio (Quantitative Assessment of Energy Security Working Group, 2011).

In China, the accessibility dimension is measured by coal reserve-to-production (R/P) ratio, oil import dependence ratio, natural gas reserve-to consumption ratio, availability factor of conventional thermal electricity, availability factor of non-thermal electricity(Yao & Chang, 2014). Energy Security in ASEAN member countries' assessment indicates that the accessibility dimension indicators are access to electricity and electricity consumption per capita(Kanchana & Unesaki, 2014).

(Narula & Reddy, 2016) put the percentage of the population with access to electricity and the percentage of the population using LPG/PNG for cooking purposes. The accessibility dimension indicator assessment is shown in Figure 74.

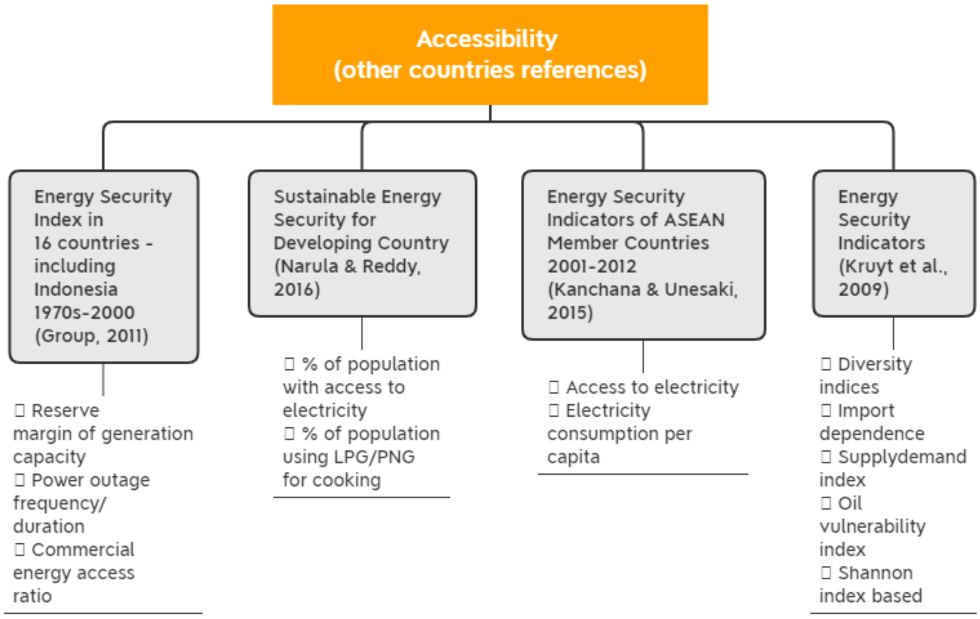


Figure 74. Accessibility dimension indicators from other countries case reference

5.2.3 Affordability Dimension

For affordability dimension indicators in the energy security index, energy security concern are on the energy price level, the price volatility, and the competition of the energy market. However, Indonesia has a different structure of energy policy with the other energy market-oriented countries. The energy policy in Indonesia is still fully dominated by government decisions. Hence, consideration is a bit different. The people in Indonesia may not be heavily affected by energy price volatility because the government will cover the price deviation with energy subsidies. Recently, Indonesia has three kinds of energy subsidies: motor gasoline subsidy, LPG subsidy, and electricity subsidy. The Indonesia National Energy Commission in 2014 found that the affordability dimension indicator could be expressed by Energy productivity, Price of fuel oil/LPG and electricity, and provision of natural gas supply. It was then modified to energy efficiency, affordability of fuel oil /LPG prices, electricity prices, and natural gas prices. (Erahman et al., 2016) explained petroleum product price to GDP per capita ratio and electricity price to GDP per capita ratio. (Hamdani & Sepriana, 2014) indicates overall system cost can represent the affordability dimension. On the other hand, (Prambudia & Nakano, 2012) focuses on the number of subsidies and the ratio cost of subsidy per total government spending.

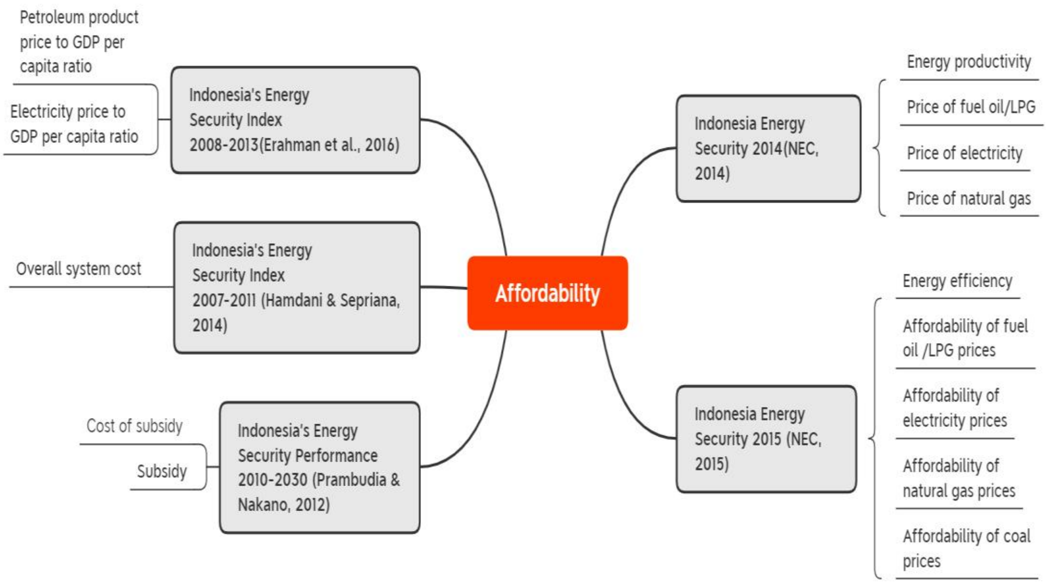


Figure 75. Affordability dimension indicators from existing Indonesia case reference

For other countries' reference, the affordability dimension can be identified by measuring energy price, mean-variance portfolio, market liquidity, willingness to pay, IEA's energy security index, diversity indices, and oil vulnerability index (Kruyt et al., 2009b). The energy security analysis for 18 countries from 1990-2010 shows that the affordability dimension can be estimated from the stability of energy prices, percentage of the population with high-quality connections to the electricity grid, households dependent on traditional fuels, and the retail price of gasoline/ petrol(Sovacool et al., 2011). In China, affordability was measured by a growth rate of the ex-factory price index for coal, petroleum, and electricity, the volatility of coal prices, and energy consumption per capita(Yao & Chang, 2014). While in Thailand, affordability is stated by oil expenditure, retail fuel oil prices, and world oil prices (Martchamadol & Kumar, 2012). Energy Security in ASEAN member countries' assessment indicates that the accessibility dimension indicator is energy trade per GDP(Kanchana & Unesaki, 2014). (Narula & Reddy, 2016) put the import cost of primary energy, energy import bill per GDP, technical and commercial losses, gross refining margin, and fuel expenditure by the households. The affordability dimension indicator assessment is shown in Figure 76.

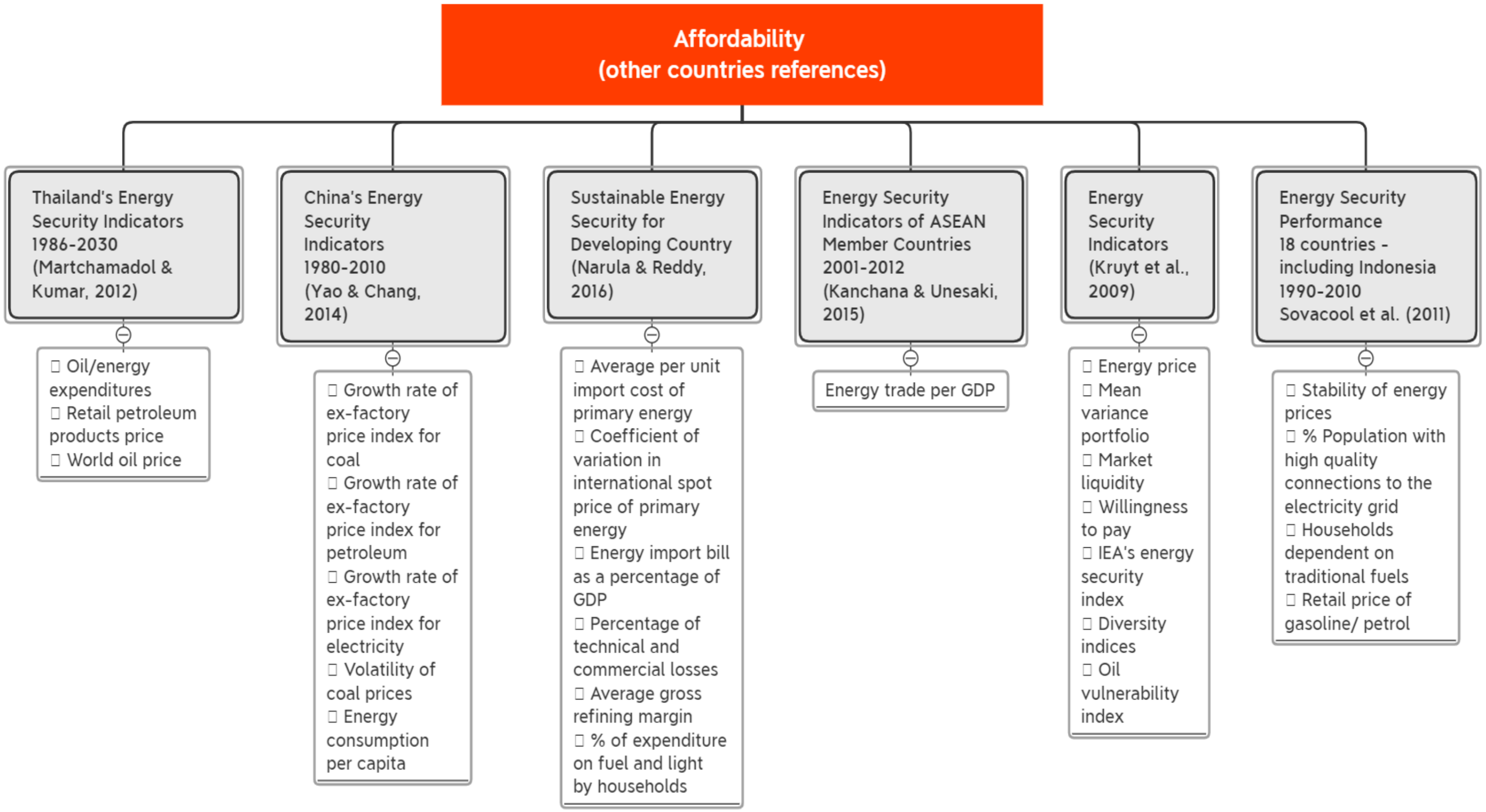


Figure 76. Affordability dimension indicators from other countries case reference

5.2.4 Acceptability Dimension

The discussion on the acceptability dimension focuses on the environmental impact of the energy sector. The environmental impact measurement is calculated by the number of emissions and any other pollutions from energy sector's production. The other environmental damage can be occurred by the loss of forest area for the hydropower project, leak of oil in the sea after oil exploration activity, or natural damage from coal mining activities. Indonesia National Energy Commission in 2014 analyzed that the acceptability dimension indicator could be expressed by energy efficiency, NRE role, and intensity of greenhouse gas emission. It was then developed to the achievement of the energy mix, reduction of emission gas, and public acceptance of energy infrastructure development. (Erahman et al., 2016) explained that emission per energy consumption and emission intensity could represent the acceptability dimension. (Hamdani & Sepriana, 2014) indicates energy intensity, CO_2 emission, and energy elasticity are the indicator of acceptability. (Prambudia & Nakano, 2012) decides that the emission intensity both from energy-wise and economy-wise can explain the acceptability dimension.

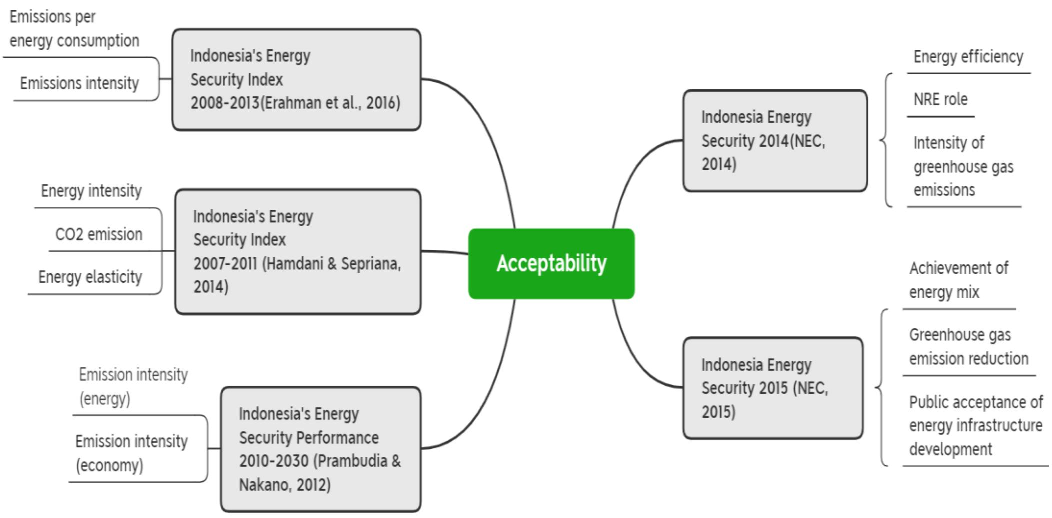


Figure 77. Acceptability dimension indicators from existing Indonesia case reference

By the reference of other countries, the acceptability dimension can be identified by measuring the share of zero-carbon fuels (Kruyt et al., 2009b) and non-carbon fuel portfolio(APERC, 2007). The energy security analysis for Thailand shows a Non-carbon incentive fuel portfolio and CO_2 emission(Martchamadol & Kumar, 2012). (Sovacool et al., 2011) indicates forest cover, water availability, carbon dioxide, and sulfur oxide emission from energy-related activities as the acceptability indicators. In China, acceptability was measured by CO_2, Sulfur Oxide, and Soot emission and the share of renewable energy per electricity production (Yao & Chang, 2014). (Narula & Reddy, 2016) put CO_2 emission, land use, and water consumption as their concern in acceptability indicators. The affordability dimension indicator assessment is shown in Figure 78.

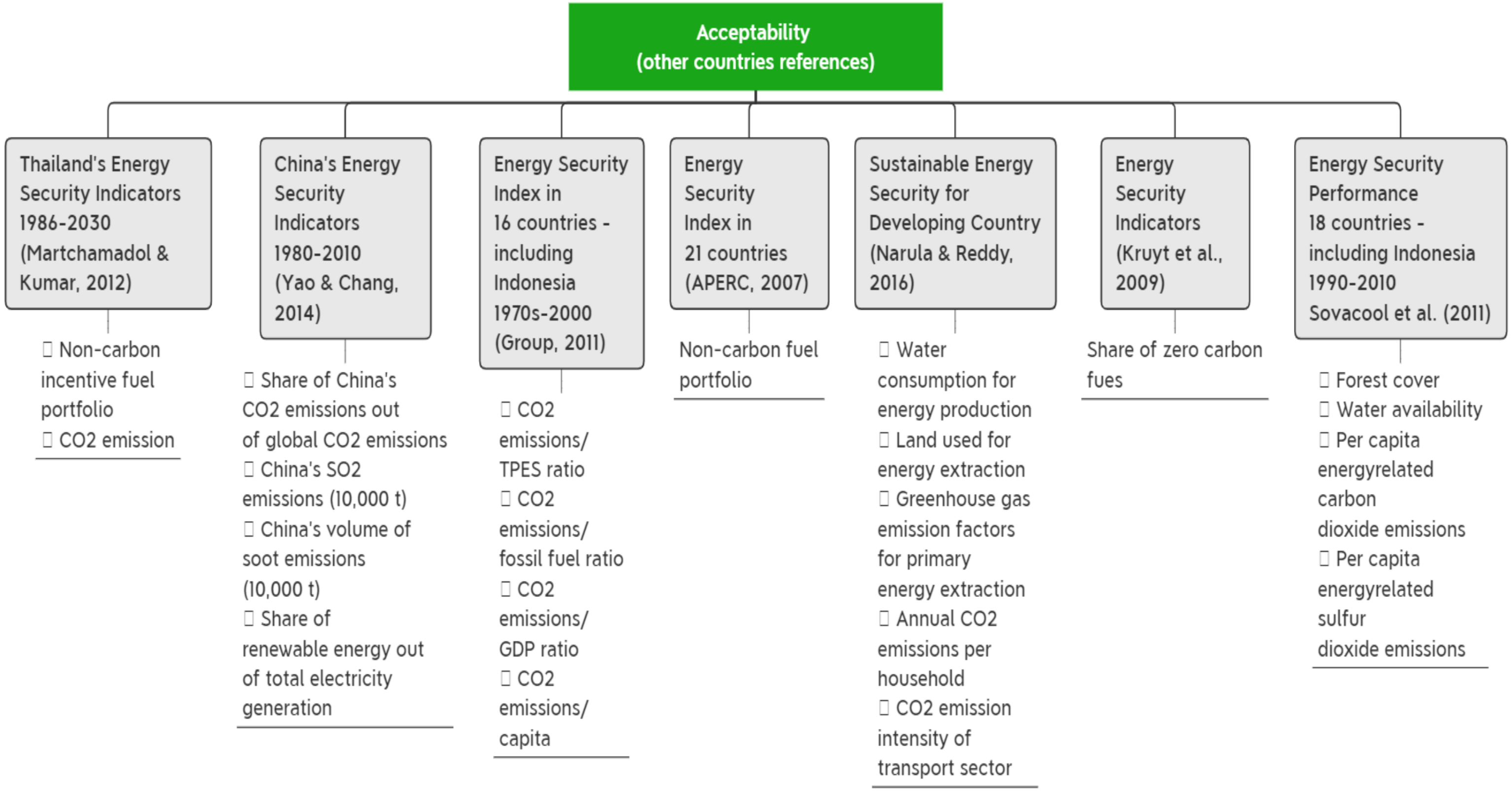


Figure 78. Acceptability dimension indicators from other countries case references

5.2.5 Intensity Dimension

The last dimension to be discussed is the intensity dimension which measures how much energy provision impacts generating economic value. The improvement of technology, system, and engineering practices can enhance the level of energy intensity. Lower energy intensity will increase energy security level due to the reduction of required energy activity. Energy efficiency and energy intensity are crucial for solving energy security problems(Kemmler & Spreng, 2007). Most of the references put energy intensity as their main indicators (Erahman et al., 2016; Kanchana & Unesaki, 2014; Martchamadol & Kumar, 2012; Prambudia & Nakano, 2012; Quantitative Assessment of Energy Security Working Group, 2011). The other indicators are electricity intensity and energy use per capita (Figure 79).

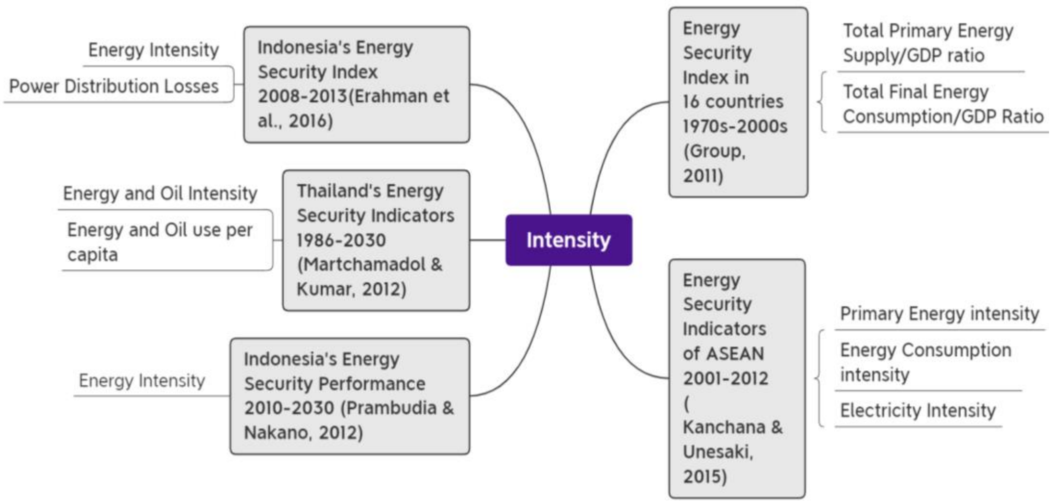


Figure 79. Intensity dimension indicators from existing Indonesia case references

5.3 Energy Security Indexing Process

After dimension and indicator formulation, there is a data collection process. Some supporting data can be assessed from Indonesia's existing national energy policy and national energy general plan modeling. The other required data is generated from other sources. There are three main steps in the energy security indexing process: the normalization of indicators, the weighting process, and aggregating all normalized indicators. Based on the previous energy security research, 28 studies have used the normalization method, 30 and 31 studies utilized the weighting and aggregation process, respectively (Ang et al., 2015).

5.3.1 Normalization

All of the indicators will have different units and scales, and then the normalization process is needed to make it dimensionless before it can be aggregated into a composite index (Narula & Reddy, 2016). Commonly, the indicator will be normalized into 0 as a relative minimum value and 1.0 as a relative maximum value. Several approaches can be used in the normalization process, such as the Min-Max approach, distance to reference, and standardization(DESMOND, 2014). Min-max utilized the minimum, and maximum values of the observed parameter in a scale form with one value will be a reference. This method brings a benefit to see the parameter result based on the highest and lowest value. Still, the disadvantage is the recalibration will be needed if the additional data has occurred. The distance to the reference method is calculating the difference between the indicator value to benchmark value. The disadvantage of the method is the result may highly sensitive to the benchmark value. The standardization method uses z-transformation to normalize the deviation of the indicator value to the mean of the data. This method is suitable for comparison among the countries' analysis. (Sovacool & Brown, 2010) use the z-transformation method to generate the measurement of the energy security dimension among industrialized countries in OECD. However, it needs a large number of data and the recalibration process is needed if the new data is added to the calculation process. The min-max method is the most popular one, and this study will use this method for the normalization process. (Cabalu, 2010) used this method to analyze the natural gas intensity indicator in Asia. 44% of 83 previous research about energy security was used the min-max method(Ang et al., 2015). The min and max method is explained in this equation as follows:

$$e_{j,k} = \frac{E_{j,k} - \min_{j=1,k=m}^{j=a,k=m}(E_{j,k})}{\max_{j=1,k=m}^{j=a,k=m}(E_{j,k}) - \min_{j=1,k=m}^{j=a,k=m}(E_{j,k})} \tag{50}$$

where:

$e_{j,k}$ = relative value of energy security index (0<x<1)

$E_{j,k}$ = energy security index in scenario j for indicator k

a = number of scenario

m = number of indicator

The value of the energy security index with this method close to zero value means that it has a low value of energy security index than other scenarios. On the other hand, the value of the energy security index close to one which means it has a high value of energy security index compared to other scenarios (Ridhanda, 2016).

5.3.2 Weighting

The weighting process can be executed from expert opinion or other methods. The input of the expert will be obtained from the survey, interviews, or Delphi method. The expert opinion is set in the boundary of the provided variable, and no subjective opinions can be proposed. Sometimes the provided variable is not based on the supporting theory and lacks connection to the actual condition. Weights could also be generated from the specific algorithm. The most commonly utilized weighting method is the equal weight, where there is no difference among the indicator(DESMOND, 2014). This method is quite simple and convenient to use where all of the indicators were treated equally. 38% of 83 previous research about energy security was used equal weight in their weighting process (Ang et al., 2015).

The other weighting process is using fuel or import share, Principal Component Analysis (PCA), Analytic Hierarchy Process (AHP), and Data Envelopment Analysis (DEA) methodology. The fuel or import share method will prioritize selected fuel in the energy mix over the other fuel. This method does not apply to the non-fuel product. PCA will not choose the priority among indicators, but it develops clear information on each indicator. AHP will be based on the expert opinion to decide the importance of the indicators. However, the weight of each expert is not clearly explained. DEA can be conducted to generate the weight in the country comparison, but it can't be used in a single country analysis.

5.3.3 Aggregation

Then, the aggregation process is a cumulative value of all weighted normalized indicators. The cumulative value will be a composite index known as the energy security index. The most used way of aggregation is the additive aggregation method, where the indicator will be multiplied by their weight and be collected into one finalized index. In this study, all indicators will be combined into sub-indexes in the energy security dimension. Then, the sub-indexes will be calculated and aggregated into one energy security index. The advantage of this method is its simplicity. Most of the previous energy security researches measured the energy security index in a simple index with a small datasets. Scenario analysis or uncertainty is not considered in the analysis. The energy security indexing process is shown in Figure 80.

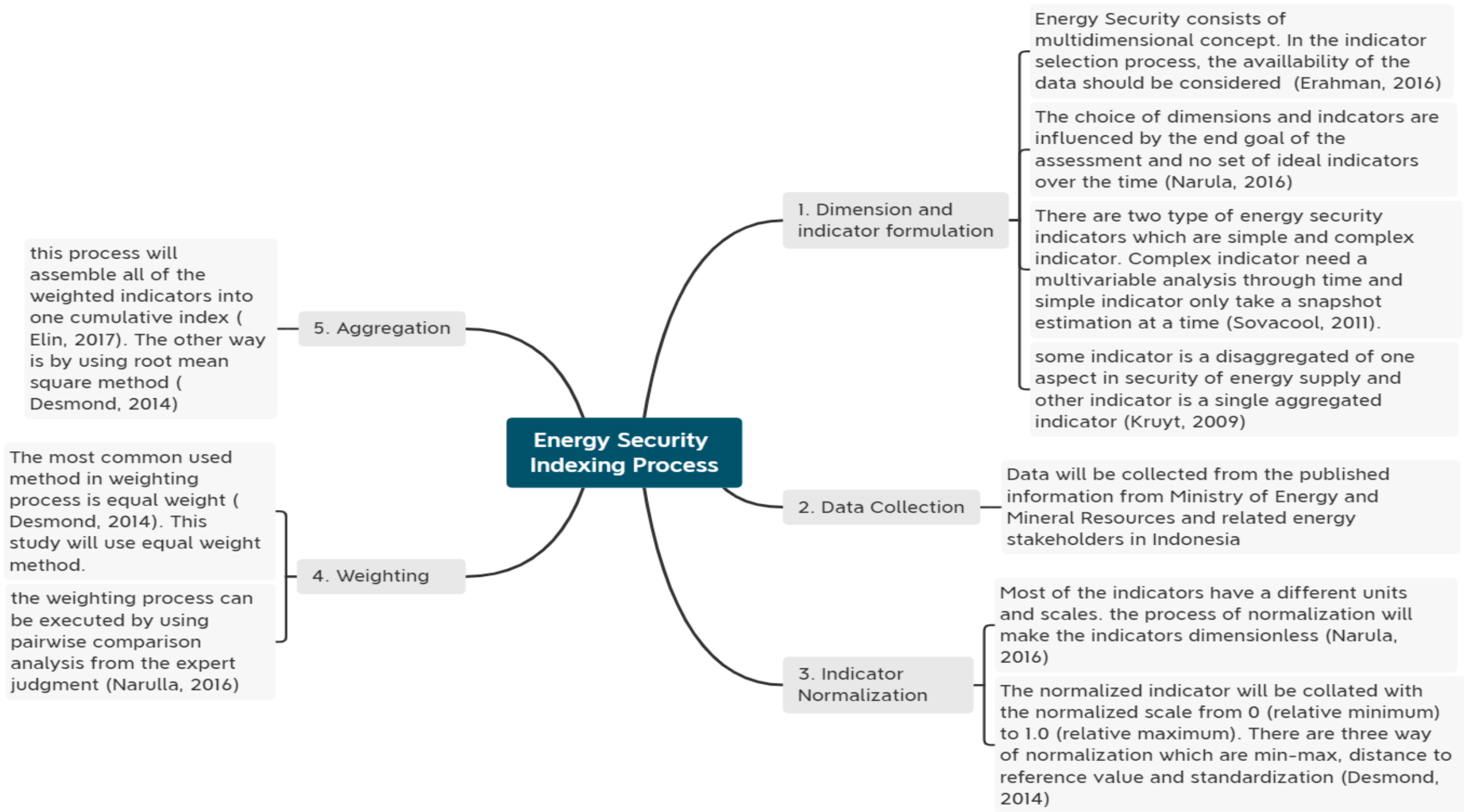


Figure 80. Energy Indexing Process

5.4 Energy Security Indicators in Oil Refinery Development Perspective

The selection of energy security indicators for oil refinery development was chosen after the literature review from the relevant reference above. This study decides to choose which indicator is significant and can be measured in the process. The result shows that the indicators for availability dimension in oil refinery development are crude oil production per capita(Erahman et al., 2016), fuel oil production per capita(Erahman et al., 2016), self-sufficiency of oil(Erahman et al., 2016; Prambudia & Nakano, 2012; Sovacool et al., 2011), oil reserve and resources(Kruyt et al., 2009b; Martchamadol & Kumar, 2012), import of crude oil (APERC, 2007; Martchamadol & Kumar, 2012; Prambudia & Nakano, 2012; Yao & Chang, 2014), and fuel oil(Hamdani & Sepriana, 2014; Prambudia & Nakano, 2012).

For the energy security indicator in the affordability dimension, the result shows that it will be represented by the petroleum product price per GDP per capita(Erahman et al., 2016), cost of subsidy(Prambudia & Nakano, 2012), and price of fuel oil(Kruyt et al., 2009b; Sovacool et al., 2011). Emission per fuel consumption(Erahman et al., 2016), CO_2 emission(Hamdani & Sepriana, 2014; Martchamadol & Kumar, 2012; Quantitative Assessment of Energy Security Working Group, 2011), and emission intensity (Erahman et al., 2016; Prambudia & Nakano, 2012; Quantitative Assessment of Energy Security Working Group, 2011) will be utilized to explain the acceptability dimension.

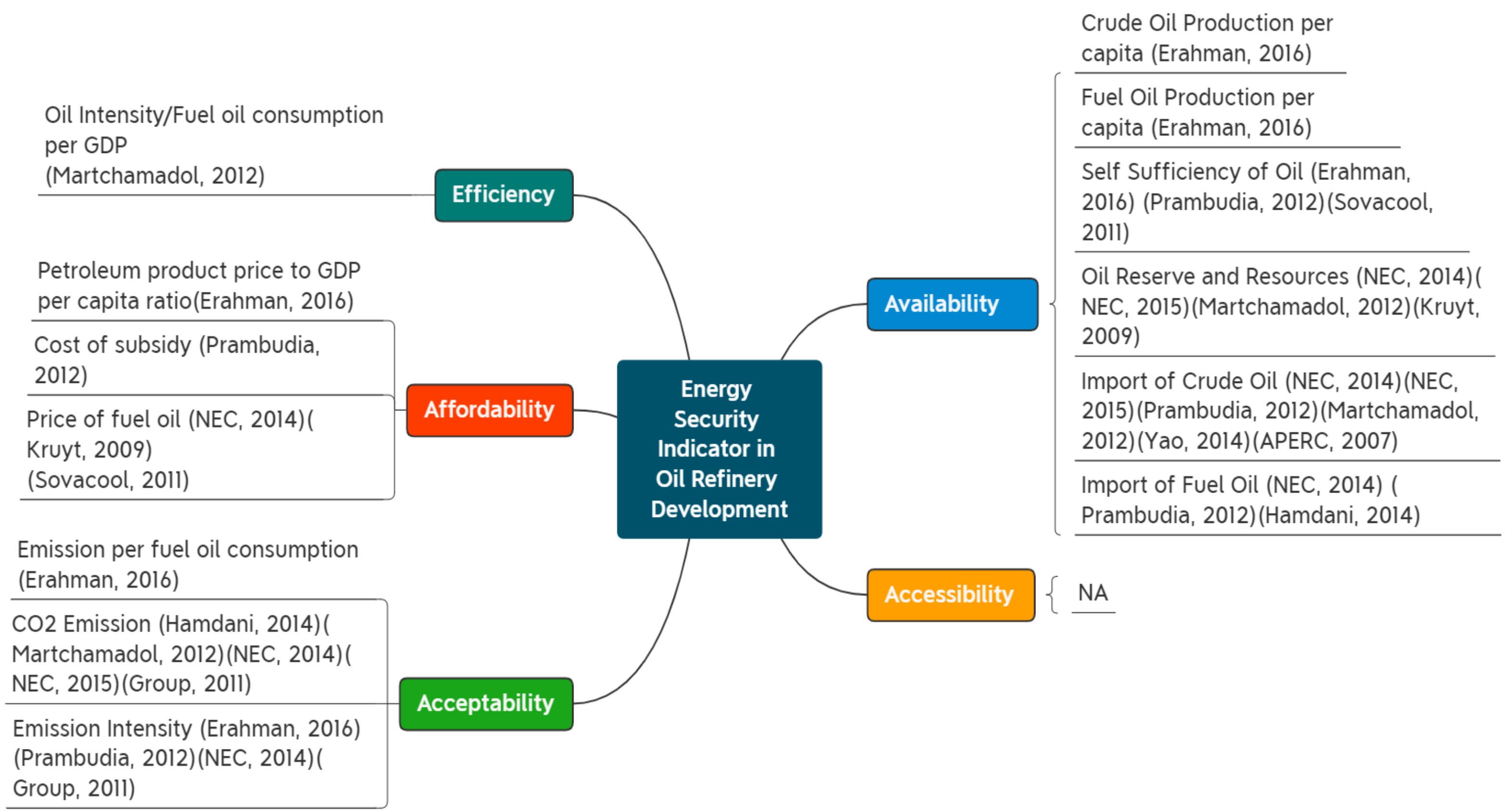


Figure 81. Energy Security indicators in oil refinery development analysis

The accessibility dimension will not be measured because no reference indicators indicate suitability in oil refinery development. Lastly, the efficiency dimension will be explained by the oil intensity or oil consumption capability to generate an economic benefit in GDP. Crude oil and fuel oil production per capita definition is the total crude oil and fuel oil production per population in barrels per capita. This indicator will have to bring a positive impact on energy security. The self-sufficiency of oil means that the share of domestic production over refined product consumption. Higher self-sufficiency shows that the domestic fuel oil production capability to handle the overall fuel oil consumption. The import of crude oil and fuel oil indicates the share of crude import and fuel oil import to total domestic consumption, respectively. Higher import of crude oil and fuel oil will negatively impact energy security in one country. Oil reserves and resources are the average crude oil reserve to crude oil production ratio. Higher reserves mean that the country can provide domestic oil production for a longer period.

The petroleum price per GDP per capita ratio shows the share of petroleum prices in a people's income. Higher prices mean that people will find it difficult to afford the petroleum product or fuel oil. The cost of the subsidy is the ratio of government expenditure in fuel subsidy to total government spending. The price of fuel oil itself is an indicator to express the affordability of the people to get fuel oil. Total emission is important in the measurement of the environmental impact of fuel oil provision. Emission per fuel oil consumption means the CO_2 emission level related to refinery development per fuel oil consumption. Oil intensity is the total fuel consumption per GDP.

Table 22. The explanation of energy security indicators in oil refinery development

Dimension	Code	Indicator	Definition	Formula	Unit	Impact
Availability	AVL01	Crude Oil production per capita	Total Crude Oil Production per population	$\frac{\text{Total Crude Oil Production}}{Population}$	Barrels/Capita	+
	AVL02	Fuel Oil production per capita	Total Fuel Oil Production per population	$\frac{\text{Total Fuel Oil Production}}{Population}$	Barrels/Capita	+
	AVL03	Self Sufficiency of Oil	Share of domestic production over refined product consumption	$\frac{\sum C_{fuel,i}}{\sum P_{fuel,i}}$	%	+
	AVL04	Import of Crude Oil	Share of crude import to total domestic crude consumption	$\frac{\sum M_{\text{crude, i}}}{\sum P_{crude,i}}$	%	-
	AVL05	Import of Fuel Oil (Refinery Products)	Share of refined product import to total domestic fuel oil consumption	$\frac{\sum M_{fuel,i}}{\sum C_{fuel,i}}$	%	-
	AVL06	Oil Reserve and Resources	Average crude oil reserve to crude oil production ratio	$\frac{\sum_{i=1}^{n} R_i / p_i}{n}$	%	+
Affordability	AFF01	Petroleum Price per GDP per capita ratio	Petroleum price per GDP per capita	$\frac{\sum t_{\text{fuel, i}}}{\sum GDPC_i}$	%	-
	AFF02	Cost of Subsidy	Expenditure in Subsidy per total government spending	$\frac{\sum SUB_t}{\sum GS_t}$	%	-
	AFF03	Price of Fuel Oil	The price of fuel oil in Indonesia	$t_{fuel,i}$	USD	-
Acceptability	ACP01	Emission per fuel oil consumption	CO2 emission related to refinery development per fuel oil consumption	$\frac{\sum EM_i}{\sum C_i}$	kgCO2/USD	-
	ACP02	CO2 Emission	Total CO2 emission	$\sum EM_i$	kgCO2	-
	ACP03	Emission Intensity	CO2 emission related to refinery development per GDP	$\frac{\sum EM_i}{GDP_i}$	kgCO2/USD	-
Efficiency	EFF01	Oil Intensity	Total fuel oil consumption per GDP	$\frac{\sum PC_i}{GDP_i}$	BOE/USD	-

5.5 Energy Security Indicators in Power Generation Development Perspective

Energy Security from the power generation perspective, especially for developing countries like Indonesia focuses on providing a sufficient amount of electricity without any shortages at affordable cost and improved electricity access. Electricity provision shall be improved as a production input to support economic development. Increasing GDP and population is the key factor that increases electricity consumption(Nepal & Paija, 2019).

The selection of energy security indicators for power generation development was chosen after the literature review from the relevant references. This study decides to choose which indicator is significant and can be measured in the process. The result shows that the indicators for availability dimension in power generation development are increased utilization of new and renewable energy resources and reserves (NEC, 2015), Self-sufficiency of electricity (Erahman et al., 2016; Prambudia & Nakano, 2012), the share of renewable energy in total primary energy supply(Kanchana & Unesaki, 2014; Sovacool et al., 2011), electricity consumption per capita (Narula & Reddy, 2016), and electricity production per capita (Erahman et al., 2016).

For the energy security indicator in the affordability dimension, the result shows that it will be represented by the electricity price per GDP per capita ratio(Erahman et al., 2016), cost of subsidy(Prambudia & Nakano, 2012), and price of fuel oil(Kruyt et al., 2009b; Sovacool et al., 2011) and overall power system cost(Hamdani & Sepriana, 2014).

The selection of acceptability indicator will include Emission per electricity consumption(Erahman et al., 2016), CO_2 emission(Hamdani & Sepriana, 2014; Martchamadol & Kumar, 2012), and emission intensity (Erahman et al., 2016; Prambudia & Nakano, 2012; Quantitative Assessment of Energy Security Working Group, 2011).

The accessibility dimension will be measured by the electrification ratio(Erahman et al., 2016; Hamdani & Sepriana, 2014; Kanchana & Unesaki, 2014; Narula & Reddy, 2016) and reserve margin of generation capacity(Quantitative Assessment of Energy Security Working Group, 2011). Lastly, the efficiency dimension will be explained by the electricity intensity(Kanchana & Unesaki, 2014) or the capability of electricity consumption to generate an economic benefit in GDP.

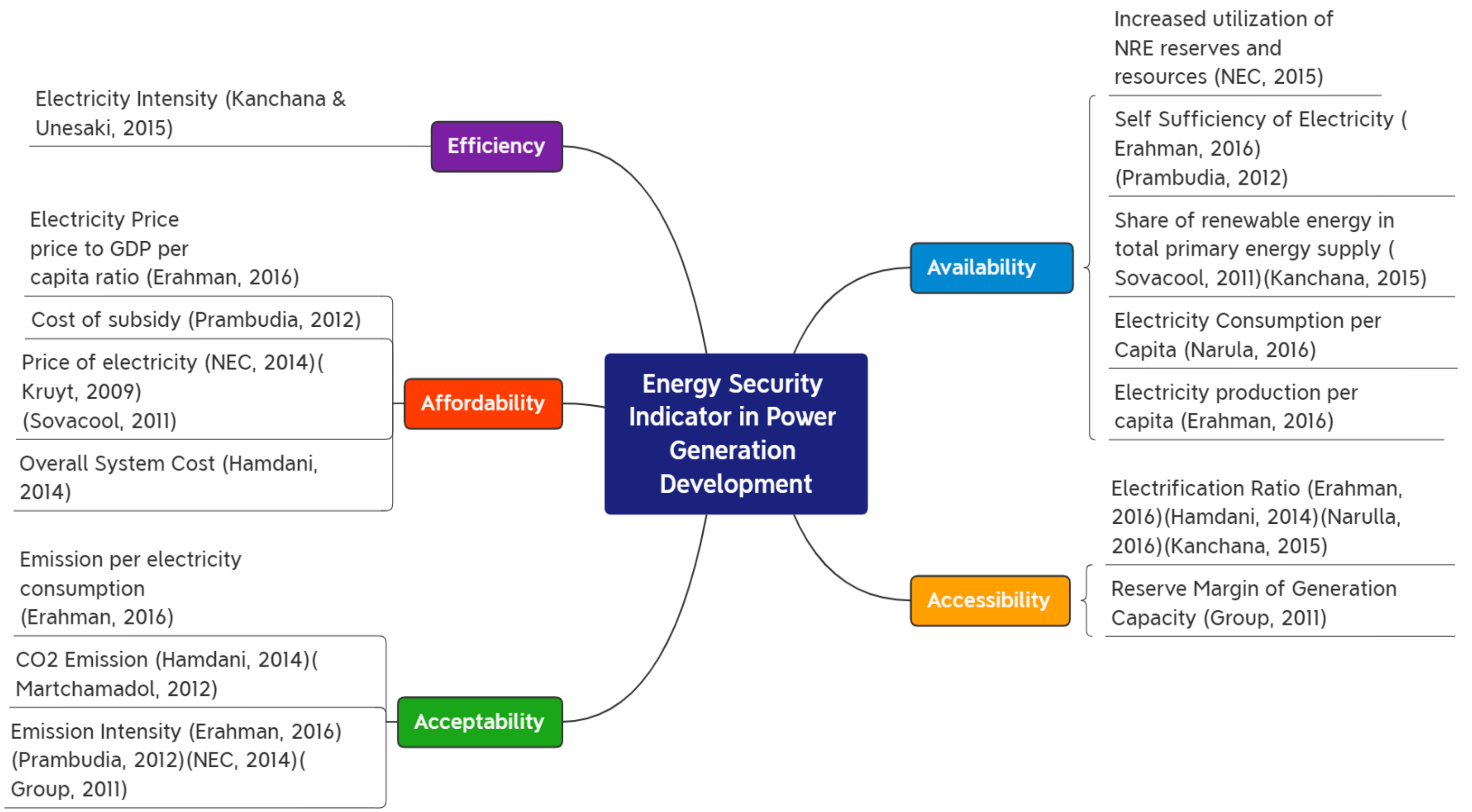


Figure 82. Energy Security indicators in power generation development analysis

Electricity production and consumption per capita definition is the total electricity production and consumption per population in kWh per capita. This indicator will have to bring a positive impact on energy security. The self-sufficiency of electricity means that the share of domestic production electricity over electricity consumption. Higher self-sufficiency shows that domestic electricity production capacity to handle the overall electricity consumption. Increased utilization of New and Renewable energy reserves and resources means the amount of electricity production from renewable energy sources. The share of renewable energy in total primary energy supply indicates the share of renewable energy electricity production to total electricity production.

The electricity price per GDP per capita ratio shows the share of electricity prices in a people's income. Higher prices mean that people will find it difficult to afford electricity. The cost of the subsidy is the ratio of government expenditure in electricity subsidy to total government spending. Overall system cost is an indicator to express the total electricity production cost in the power system. Total emission is important in the measurement of the environmental impact of power generation development. Emission per electricity consumption means the CO_2 emission level related to power generation development per electricity consumption. Electricity intensity is the total electricity consumption per GDP in BOE/USD. The higher value of affordability, acceptability, and intensity indicators will negatively impact the energy security index in power generation development, as shown in Table 23.

Table 23. The explanation of energy security indicators in power generation

Dimension	Code	Indicator	Definition	Formula	Unit	Impact
Availability	AVL01	Electricity production per capita	Electricity Production per population	$\frac{\text{Total Electricity Production}}{Population}$	Barrels/Capita	+
	AVL02	Electricity Consumption per capita	Electricity Consumption per population	$\frac{\text{Total Electricity Consumption}}{Population}$	Barrels/Capita	+
	AVL03	Self Sufficiency of Electricity	Share of domestic electricity production over total consumption	$\frac{\sum DP_{electricity,i}}{\sum P_{electricity,i}}$	%	+
	AVL04	Increased utilization of New and Renewable energy reserves and resources	Electricity production from renewable energy	$\sum REP_i$	TWh	+
	AVL05	Share of renewable energy in total primary energy supply	Share of electricity production from renewable energy over total electricity production	$\frac{\sum REP_i}{\sum P_i}$	%	+
Affordability	AFF01	Electricity Price per GDP per capita ratio	Electricity price per GDP per capita	$\frac{\sum t_{\text{electricity, i}}}{\sum GDPC_i}$	capita/kWh	-
	AFF02	Cost of Subsidy	Expenditure in electricity subsidy per total government spending	$\frac{\sum SUB_t}{\sum GS_t}$	%	-
	AFF03	Overall System Cost (LCOE)	Levellized cost of electricity in the system	$LCOE_t$	USD/kWh	-
Acceptability	ACP01	Emission per electricity consumption	Total Emission of the powerplant per electricity consumption	$\frac{\sum EM_i}{\sum C_i}$	kgCO2/USD	-
	ACP02	CO2 Emission	Total CO2 emission	$\sum EM_i$	kgCO2	-
	ACP03	Emission Intensity	CO2 emission related to power generation development per GDP	$\frac{\sum EM_i}{GDP_i}$	kgCO2/USD	-
Efficiency	EFF01	Electricity Intensity	Total electricity consumption per GDP	$\frac{\sum PC_i}{GDP_i}$	BOE/USD	-
Accessibility	ACC01	Electrification Ratio	The number of households with electricity access per total households	$\frac{\sum ElectrifiedHousehold_t}{\sum Household_t}$	%	+
	ACC02	Reserve Margin of generation capacity	Percentage of power generation reserve capacity to the electricity consumption	$\frac{\sum EP_t}{\sum EC_t}$	%	+

All of the indicators in the availability and accessibility dimension will have a positive impact on energy security. It means that a higher result of electricity availability and access will create higher energy security. However, all of the indicators in the affordability, acceptability, and efficiency dimensions will negatively impact the energy security index. It means that higher price, emission, and electricity intensity will create a lower energy security index.

5.6 Introduction of Electric Vehicle in Oil Refinery Development

Total Indonesia's final energy consumption (TFEC) in 2018 is divided into five categories, which are transportation, industry, household, commercial, and other sectors. The transportation sector indicated the highest energy consumption with 391 Million BOE or 42% of the TFEC. It has followed by the industrial and household sectors with 334 Million BOE (36%) and 151 Million BOE (16%), respectively. Furthermore, the fuel oil consumption in 2018 shows that the transportation sector has the highest share with 87% with the next high share is only the industrial sector at 8%. This study also found that Passenger vehicles (28%) and motorcycles (34%) are the two biggest fuel consumers in Indonesia. The introduction of an electric vehicle for motorcycles and passenger vehicles will be crucial to reduce fuel consumption in Indonesia. A system dynamic model has been developed for the introduction of electric vehicle policy. The fuel oil consumption will be derived into several sectors including the transportation sector. The transportation sector energy consumption will be divided into road transportation, water transportation, air transportation, and railway transportation consumption. Road transportation consumption will include passenger vehicles, buses, trucks, and motorcycles. Historically, the number of passengers in Indonesia in 2018 is 16.4 Million units and increased by 9.8% every year on average. Bus and truck number in 2018 shows 2.5 Million units and 7.7 Million units, respectively. Both vehicles are also increasing with 7.7% and 8.7% growth on average. Moreover, the highest growth is coming from the motorcycle with 146.8 Million units. The shares of motorcycle ownership in Indonesia has reached 54.8%, which means that every two-person in Indonesia has one motorcycle.

Different system dynamic model structures have shown in Figure 83

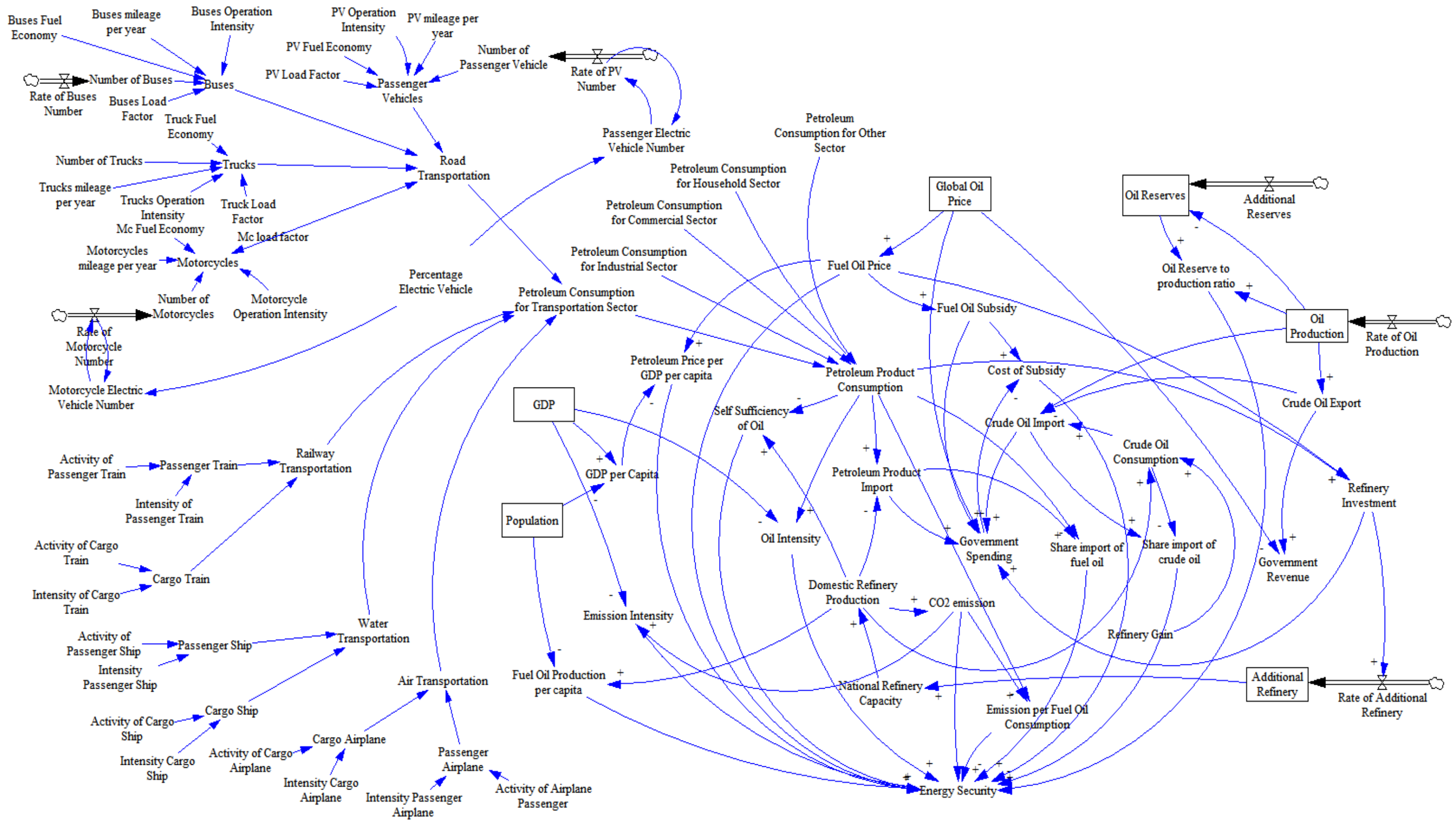


Figure 83. System dynamic model structure in electric vehicle introduction policy

This structure has been developed from the previous model with the change in the fuel oil consumption parameter. Previously the fuel consumption parameter was developed from the time series model with GDP, global oil price, and population as an independent variable. The fuel oil consumption has changed into different sector consumption and additional transportation sector breakdown in this model structure. The introduction of the electric vehicle policy will be put in the number of passenger vehicles and motorcycles. It means that the rate of growth of passenger vehicles and motorcycles will be penetrated by electric vehicles. The equations of petroleum product consumption change in the new structure are as follows:

Petroleum products or fuel oil consumption equations:

$$PC_t = PCT_t + PCI_t + PCH_t + PCC_t + PCO_t \quad (51)$$

PCT_t : PC_t in transportation sector at year t
PCI_t : PC_t in industrial sector at year t
PCH_t : PC_t in household sector at year t
PCC_t : PC_t in commercial sector at year t
PCO_t : PC_t in other sector at year t

$$PCT_t = RTC_t + RLC_t + WTC_t + ATC_t \quad (52)$$

$RTC_t : PC_t$ in road transportation at year t
$RLC_t : PC_t$ in railway transportation at year t
$WTC_t : PC_t$ in water transportation at year t
$ATC_t : PC_t$ in air transportation at year t

$$RLC_t = PTC_t + CTC_t \quad (53)$$

$PTC_t : PC_t$ for passenger train at year t
$CTC_t : PC_t$ for cargo train at year t

$$PTC_t = \sum_i \sum_j PTAL_{t,j,i} \times PTEI_{n,j,i} \quad (54)$$

$$CTC_t = \sum_i \sum_j CTAL_{t,j,i} \times CTEI_{n,j,i} \quad (55)$$

AL_t: Activity level at year t
EI_t: Energy Intensity at year t

$$WTC_t = PSC_t + CSC_t \quad (56)$$

$PSC_t : PC_t$ for passenger ship at year t
$CSC_t : PC_t$ for cargo ship at year t

$$PSC_t = \sum_i \sum_j PSAL_{t,j,i} \times PSEI_{n,j,i} \quad (57)$$

$$CSC_t = \sum_i \sum_j CSAL_{t,j,i} \times CSEI_{n,j,i} \quad (58)$$

$$ATC_t = PAC_t + CAC_t \quad (59)$$

$PAC_t : PC_t$ for passenger airplane at year t
$CAC_t : PC_t$ for cargo airplane at year t

$$PAC_t = \sum_i \sum_j PAAL_{t,j,i} \times PAEI_{n,j,i} \quad (60)$$

$$CAC_t = \sum_i \sum_j CAAL_{t,j,i} \times CAEI_{n,j,i} \quad (61)$$

Then, the road transportation sector fuel consumption will also be developed with the details as follows:

$$RTC_t = PVC_t + BC_t + TC_t + MC_t \quad (62)$$

$PVC_t : PC_t$ by Passenger Vehicle at year t
BC_t : PC_t by Buses at year t
TC_t : PC_t by Trucks at year t
MC_t : PC_t by Motorcycle at year t

$$PVC_t = \sum_{pv} s \times \frac{m_{pv,t}}{fe_{pv,t}} \qquad (63)$$

$$s_{pv,t} = s_{pv,t-1} \times s_{rate,pv} \qquad (64)$$

$$s_{rate,pv} = s_{rate,pv,t} - s_{rate,EV,t} \qquad (65)$$

$$s_{rate,EV,t} = f_{EV} \times s_{rate,pv,t} \times P_{EV,pv} \qquad (66)$$

$s_{c,t}$: Number of Vehicle type (c) at year t

$s_{rate,c,t}$: rate of New Vehicle type (c) at year t

$m_{c,t}$: mileage of vehicle type (c) at year t

$$BC_t = \sum_{buses} s \times \frac{m_{buses,t}}{fe_{buses,t}} \qquad (67)$$

$$s_{buses,t} = s_{buses,t-1} \times s_{rate,buses} \qquad (68)$$

$$TC_t = \sum_{truck} s \times \frac{m_{truck,t}}{fe_{truck,t}} \qquad (69)$$

$$s_{truck,t} = s_{truck,t-1} \times s_{rate,truck} \qquad (70)$$

$$MC_t = \sum_{motorcycle} s \times \frac{m_{motorcycle,t}}{fe_{motorcycle,t}} \qquad (71)$$

$$s_{motorcycle,t} = s_{motorcycle,t-1} \times s_{rate,motorcycle} \qquad (72)$$

$$s_{rate,motorcycle} = s_{rate,motorcycle,t} - s_{rate,EV,t} \qquad (73)$$

$$s_{rate,EV,t} = f_{EV} \times s_{rate,motorcycle,t} \times P_{EV,motorcycle} \qquad (74)$$

$fe_{c,t}$: fuel economy of vehicle type (c) at year t

$f_{EV,t}$: percentage of EV in the rate of new vehicle at year t

$P_{EV,c}$: Government Policy to introduce electric vehicle of vehicle type (c) in the additional new vehicle (1 or 0)

There will be some scenarios to analyze the impact of the electric vehicle introduction policy's impact on oil refinery development. The scenarios will be divided into nine scenarios: a base scenario where there is no change in the input parameter, the group scenario of 1, 2, and 3 are the scenario of EV policy is introduced only in a motorcycle with the percentage EV share in an additional motorcycle are 5%, 10%, and 15% respectively. On the other hand, scenario 4, 5, and 6 are introduced only in a passenger vehicle with the percentage EV share in the additional passenger vehicle are 5%, 10%, and 15% respectively. Scenario 7, 8, and 9 is the combination EV policy both for passenger vehicle and motorcycle with a similar percentage of EV share in the additional of both vehicles. The parameter change in the scenario analysis is explained in Table 24.

Table 24. Scenario analysis in the introduction of electric vehicle in system dynamic

Scenario	EV policy for Passenger Vehicle	EV Policy for Motorcycle	Passenger EV share in additional PV	Motorcycle EV share in additional Motorcycle
Base	No	No	0%	0%
Scenario 1 Motorcycle EV 5%	No	Yes	0%	5%
Scenario 2 Motorcycle EV 10%	No	Yes	0%	10%
Scenario 3 Motorcycle EV 15%	No	Yes	0%	15%
Scenario 4 Passenger EV 5%	Yes	No	5%	0%
Scenario 5 Passenger EV 10%	Yes	No	10%	0%
Scenario 6 Passenger EV 15%	Yes	No	15%	0%
Scenario 7 Passenger EV 5% + Motorcycle 5%	Yes	Yes	5%	5%
Scenario 8 Passenger EV 10% + Motorcycle 10%	Yes	Yes	10%	10%
Scenario 9 Passenger EV 15% + Motorcycle 15%	Yes	Yes	15%	15%

The system dynamic analysis result shows that the petroleum consumption for the road transport sector will be varied depending on the scenario. The base scenario shows the highest petroleum product consumption, and scenario 9 shows the opposite. A higher number of electric vehicles will reduce the number of petroleum products or fuel consumption as shown in Figure 84.

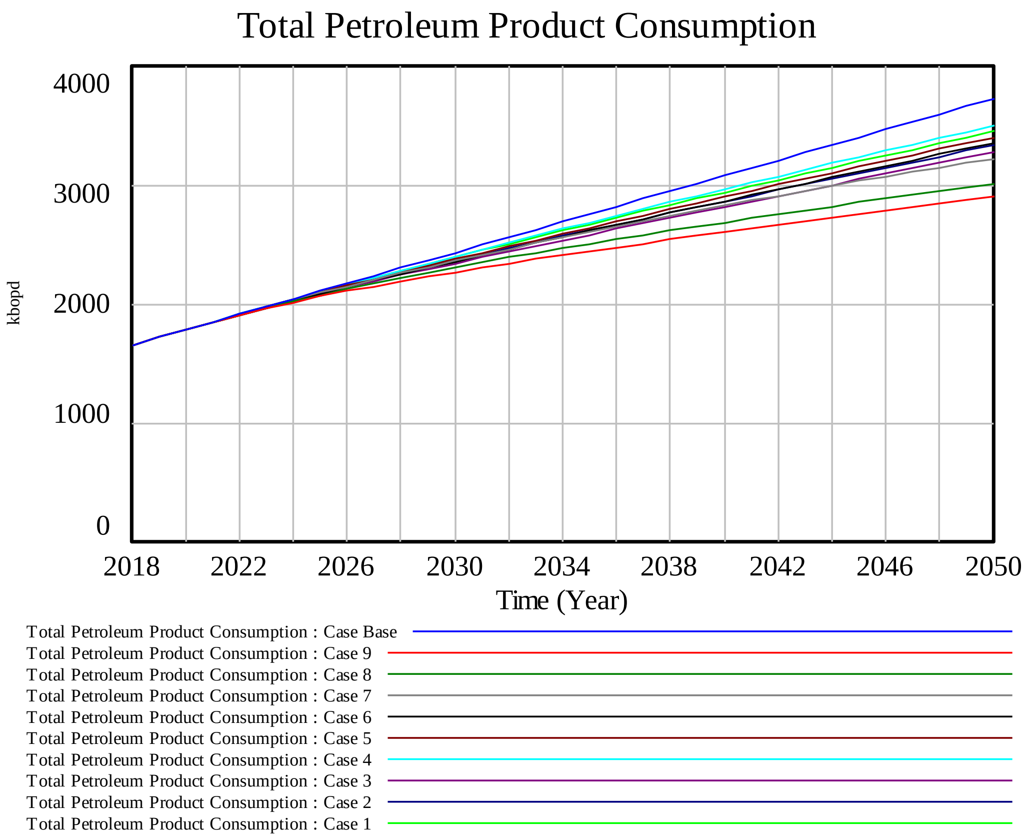
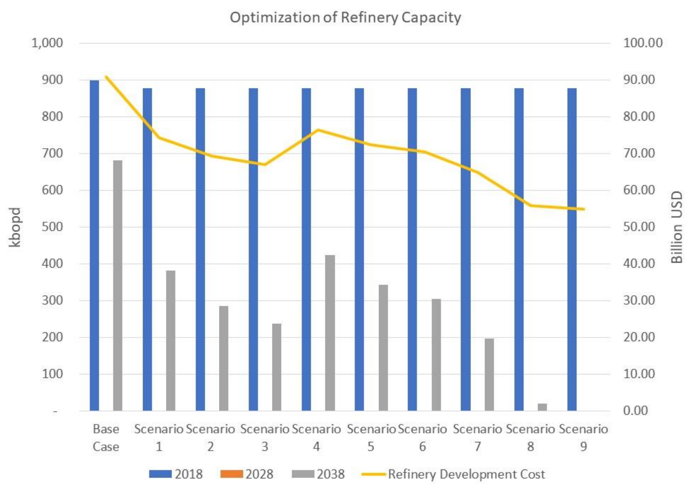


Figure 84. Total petroleum product consumption in EV introduction

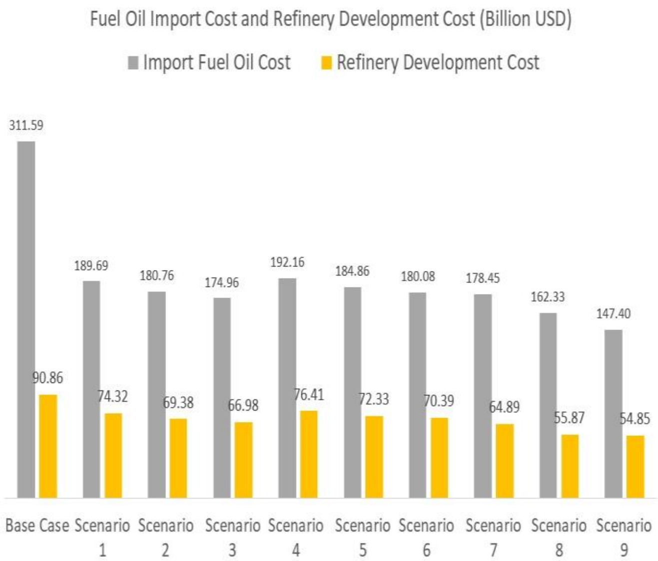
Optimization of oil refinery development was also conducted on these scenarios to see what is the impact of electric vehicle impact on refinery development cost. The result shows that scenario 9 has the lowest refinery development cost with only 54.85 Billion USD or a decreased 39.6% than the Base case where no electric vehicle was added to the system. A comparison between the introduction of electric vehicles in a passenger vehicle and motorcycle indicates that the higher share of the electric motorcycle will reduce the refinery development cost higher than the passenger vehicle did. The electric motorcycle introduction will require 66.9-69.3 Billion USD, and the electric passenger vehicles will require 70.3-76.4 Billion USD with a similar pattern of EV share.



Scenario	Refinery Development Cost (Billion USD)
Base	90.86
Scenario 1 Motorcycle EV 5%	74.32
Scenario 2 Motorcycle EV 10%	69.38
Scenario 3 Motorcycle EV 15%	66.98
Scenario 4 Passenger EV 5%	76.41
Scenario 5 Passenger EV 10%	72.33
Scenario 6 Passenger EV 15%	70.39
Scenario 7 Passenger EV 5% + Motorcycle 5%	64.89
Scenario 8 Passenger EV 10% + Motorcycle 10%	55.87
Scenario 9 Passenger EV 15% + Motorcycle 15%	54.85

Figure 85. Refinery development cost comparison in EV introduction scenario analysis

From the import of fuel oil cost perspective, the result shows that scenario 9 has the lowest import of fuel oil costs with only 147..40 Billion USD or a decreased of 52.6% than the Base case where there is no electric vehicle was added to the system. A comparison between the introduction of electric vehicles in a passenger vehicle and motorcycle indicates that the higher share of the electric motorcycle will reduce the import of fuel oil costs higher than the passenger vehicle did. The electric motorcycle introduction will require 174.9-189.6 Billion USD, and the electric passenger vehicles will require 180.1-192.16 Billion USD with a similar pattern of EV share. Scenario 9 result also shows that 15% additional passenger EV and electric motorcycle will decrease the capacity of additional refinery in the future with no additional refinery capacity is needed in the period of 2038-2050.



Scenario	Fuel Oil Import Cost (Billion USD)
Base	311.59
Scenario 1 Motorcycle EV 5%	189.69
Scenario 2 Motorcycle EV 10%	180.76
Scenario 3 Motorcycle EV 15%	174.96
Scenario 4 Passenger EV 5%	192.16
Scenario 5 Passenger EV 10%	184.86
Scenario 6 Passenger EV 15%	180.08
Scenario 7 Passenger EV 5% + Motorcycle 5%	178.45
Scenario 8 Passenger EV 10% + Motorcycle 10%	162.33
Scenario 9 Passenger EV 15% + Motorcycle 15%	147.40

Figure 86. Fuel oil import cost comparison in EV introduction scenario analysis

From the potential of financing source perspective, The result shows that scenario 9 has the lowest percentage of crude oil revenue and increasing fuel oil price with only 95.3% and 1.66%, respectively. It means that increasing fuel oil price as a financing source will decrease 0.94%, and the percentage of crude oil export revenue will decrease to 62.6% than the Base case where no electric vehicle was added to the system.

A comparison between the introduction of electric vehicles in passenger vehicles and motorcycles indicates that the higher share of the electric motorcycle will reduce the required percentage of the increasing price of fuel oil or crude oil export revenue.

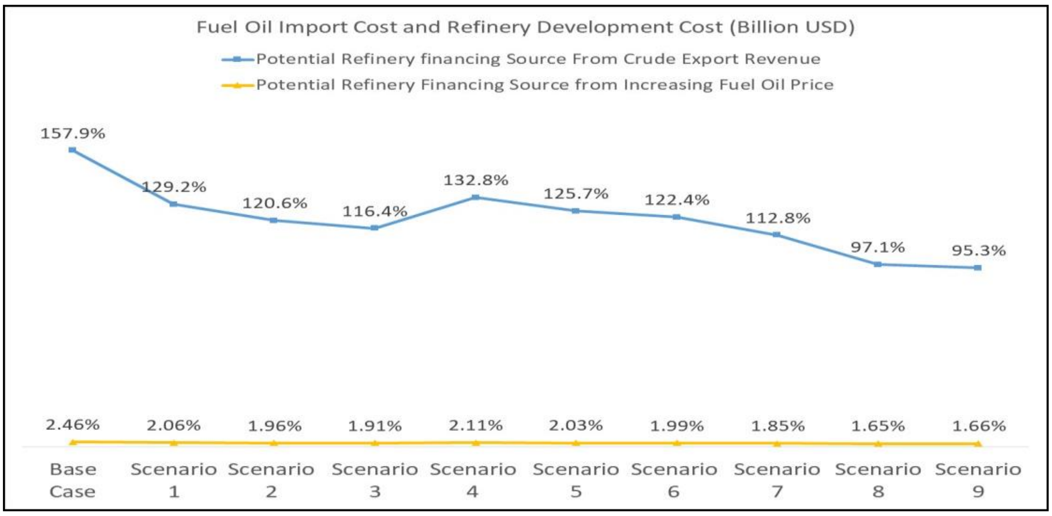
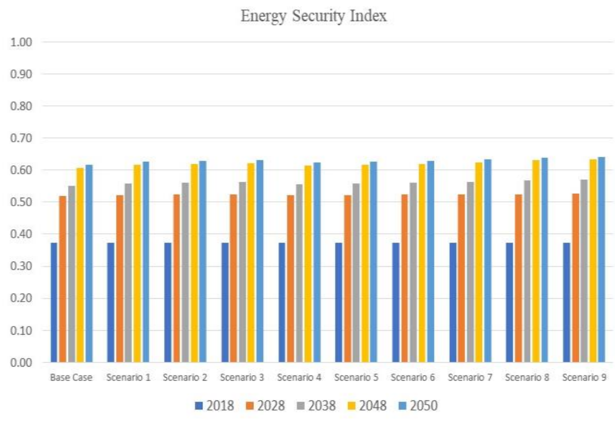


Figure 87. Potential financing Source for Refinery Development in EV introduction

From the perspective of energy security, the result indicates that a higher percentage of new electric passenger vehicles and motorcycles will create better energy security. The result shows that a highest share (15%) of the additional electric vehicle, both motorcycle EV and passenger EV will produce the best energy security index among 2028, 2038, 2048, and 2050, as shown in Figure 88.



Energy Security Indicator	2018	2028	2038	2048	2050
Base Case	0.37	0.52	0.55	0.61	0.62
Scenario 1	0.37	0.52	0.56	0.62	0.63
Scenario 2	0.37	0.52	0.56	0.62	0.63
Scenario 3	0.37	0.52	0.56	0.62	0.63
Scenario 4	0.37	0.52	0.56	0.61	0.62
Scenario 5	0.37	0.52	0.56	0.62	0.63
Scenario 6	0.37	0.52	0.56	0.62	0.63
Scenario 7	0.37	0.52	0.56	0.62	0.63
Scenario 8	0.37	0.52	0.57	0.63	0.64
Scenario 9	0.37	0.53	0.57	0.63	0.64

Figure 88. Energy Security Index in EV introduction

A higher percentage of New Electric Passenger Vehicle and Motorcycle will reduce petroleum product consumption and create a better energy security index. The electric motorcycle introduction will bring lower refinery development cost and petroleum product import cost than the electric passenger vehicle. 15% share of additional electric vehicle scenario both motorcycle EV and passenger EV will produce the lowest percentage of potential financing for refinery development, which is 95.3% from the crude export revenue or 1.66% of increasing fuel oil price.

5.7 Introduction of Electric Vehicle in Power Generation Development

Indonesia's electricity consumption in 2018 is divided into four categories: industrial, household, commercial, and public sectors. However, the transportation sector didn’t indicate any existence in electricity consumption due to no electric vehicle was used in Indonesia. The previous chapter found the introduction of an electric vehicle will reduce fuel oil consumption. Moreover, it also brings an impact on the existence of electricity consumption from the transportation sector. Due to the number of passenger cars (28%) and motorcycle (34%) are the two biggest fuel consumers in Indonesia, the introduction of an electric vehicle for motorcycle and passenger cars will be crucial to shift the orientation of the energy system in Indonesia which previously dependent on the fuel supply to an electricity-based system. Another system dynamic model has been developed for the introduction of electric vehicle policy in the electricity sector. The transportation sector will be added as a new sector of electricity consumption.

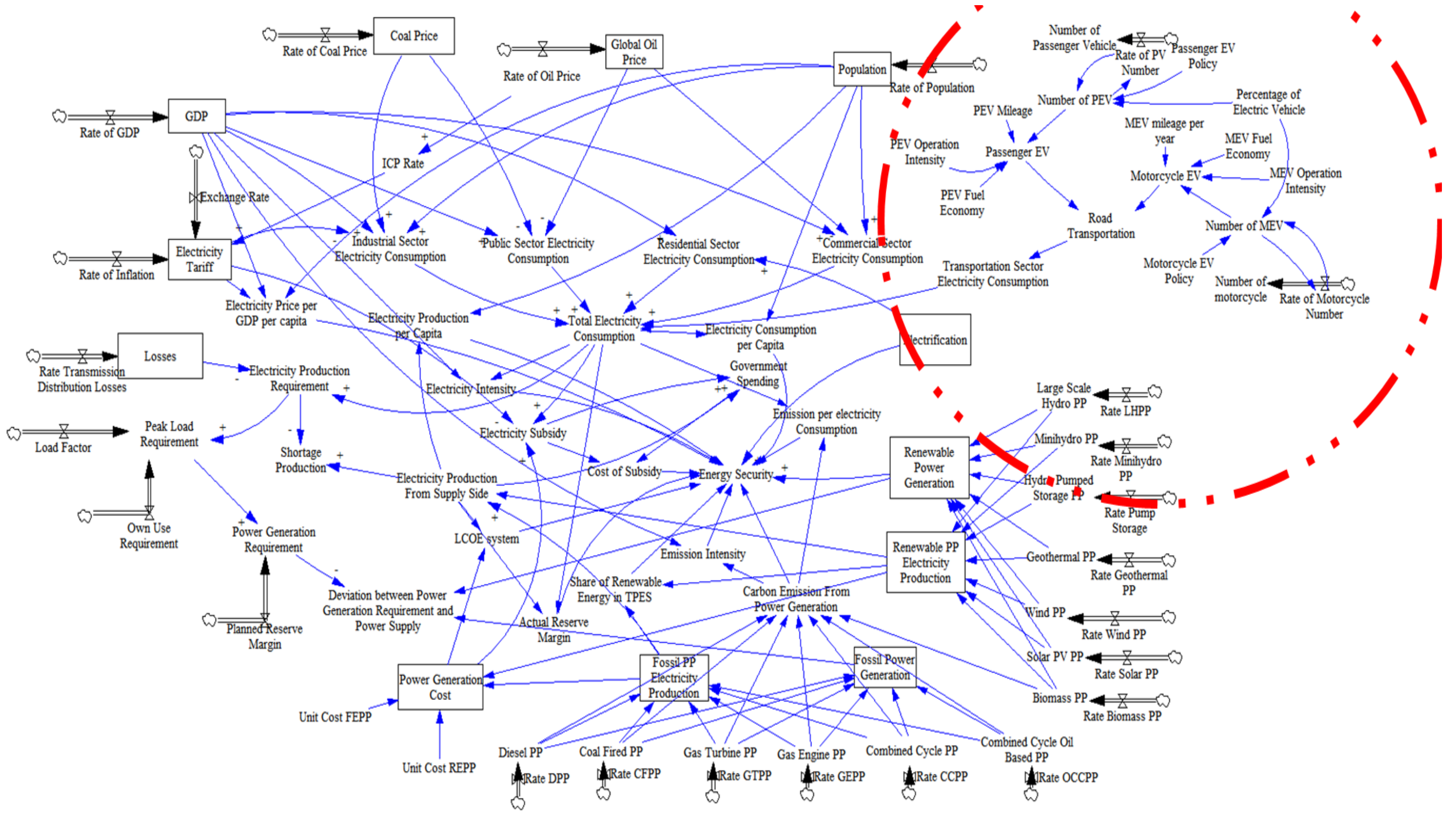


Figure 89. System dynamic model structure in electric vehicle introduction policy

In the transportation sector, electricity consumption will only put electric passenger vehicles and motorcycles. The existence of an electric bus and truck is not available in this study. Different system dynamic model structures have shown in Figure 89. This structure has been developed from the previous model with a change in the electricity consumption parameter. Previously the electricity consumption parameter was developed from the household, industrial, commercial, and public sectors. The new model adds the transportation sector as the new sector that consumes electricity. Simultaneously, the other sector's consumption is based on the time series model with GDP, coal, oil price, and population as an independent variable. In this model, the transportation sector electricity consumption has been added with a new structure. New electric passenger vehicles and electric motorcycles will be penetrated from the percentage rate of new passenger vehicles and motorcycles in a year.

The equations on the transportation sector electricity consumption will be added to the system dynamic model as follows:

$$TRC_t = EPV_t + EMC_t \tag{75}$$

TRC_t : Electricity consumption on transportation sector at year t
EPV_t : EC_t by Passenger Vehicle at year t
EMC_t : EC_t by Motorcycle at year t

$$EPV_t = \sum_{epv} s \times \frac{m_{epv,t}}{fe}_{epv,t} \tag{76}$$

$$s_{epv,t} = s_{epv,t-1} \times s_{rate,epv} \tag{77}$$

$$s_{rate,epv} = s_{rate,epv,t} - s_{rate,EV,t} \tag{78}$$

$$s_{rate,EV,t} = f_{EV} \times s_{rate,pv,t} \times P_{EV,pv} \tag{79}$$

$s_{c,t}$: Number of Vehicle type (c) at year t
$s_{rate,c,t}$: Rate of New Vehicle type (c) at year t
$m_{c,t}$: Mileage of vehicle type (c) at year t

$$EMC_t = \sum_{emc} s \times \frac{m_{emc,t}}{fe_{emc,t}} \tag{80}$$

$$s_{emc,t} = s_{emc,t-1} \times s_{rate,emc} \tag{81}$$

$$s_{rate,emc} = s_{rate,emc,t} - s_{rate,EV,t} \tag{82}$$

$$s_{rate,EV,t} = f_{EV} \times s_{rate,motorcycle,t} \times P_{EV,motorcycle} \tag{83}$$

$fe_{c,t}$: Fuel economy of vehicle type (c) at year t
$f_{EV,t}$: Percentage of EV in the rate of new vehicle at year t
$P_{EV,c}$: Government Policy to introduce electric vehicle
of vehicle type (c) in the additional new vehicle (1 or 0)

Similar to the previous chapter, the scenarios will be divided into nine scenarios: a base scenario where there is no change in the input parameter, the group scenario of 1, 2, and 3 are the scenario of EV policy is introduced only in a motorcycle with the percentage EV share in an additional motorcycle are 5%, 10%, and 15% respectively. On the other hand, scenario 4, 5, and 6 are introduced only in a passenger vehicle with the percentage EV share in the additional passenger vehicle are 5%, 10%, and 15% respectively. Scenario 7, 8, and 9 is the combination EV policy both for passenger vehicle and motorcycle with a similar percentage of EV share in the additional of both vehicles

The parameter change in the scenario analysis is similar to the previous EV scenario. This study assume that passenger EV and electric motorcycle fuel economy are 26 kWh per 100 miles and 6.37 kWh per 100 miles, respectively(Williams et al., 2017).

The system dynamic analysis result shows that the electricity consumption for the transportation sector will be varied depending on the scenario. Scenario 9 shows the highest electricity consumption, and the base scenario shows no electricity consumption. A higher number of electric vehicles will increase electricity consumption. From the perspective of energy security in power generation development, the result indicates that a higher percentage of new electric passenger vehicles and motorcycles will create better energy security. Optimization of power generation development is also conducted on these scenarios to see the impact of electric vehicle impact on the power generation sector.

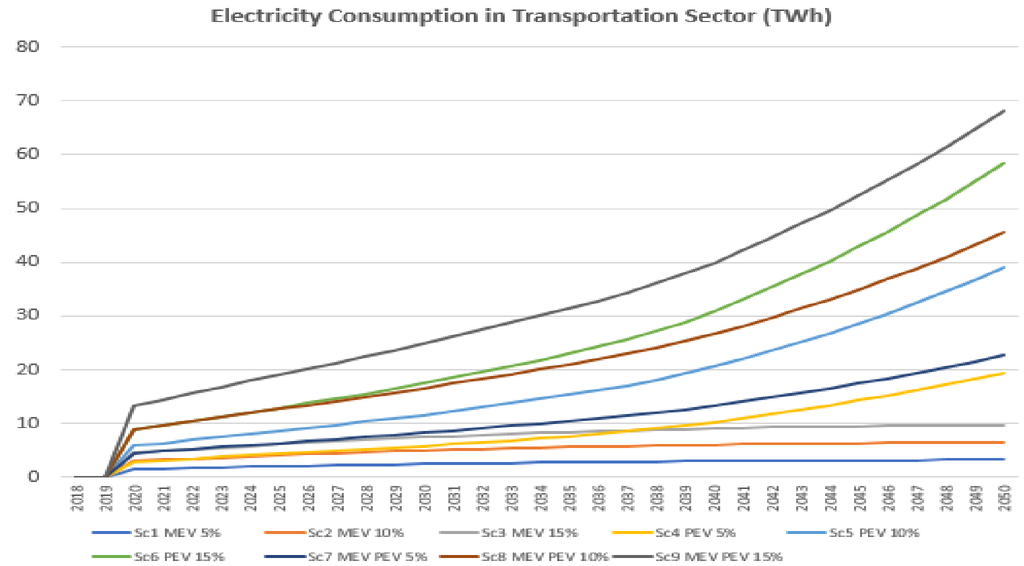


Figure 90. Total electricity consumption in the transportation sector in EV introduction

The result shows the change in the transportation sector electricity consumption with the details as follows:

a. Scenario 9 with 15% of PEV and MEV in the additional rate of the vehicle per year will show the highest electricity consumption.

b. Scenario 1, Scenario 2, and Scenario 3 with the additional only for electric motorcycles will increase the electricity consumption in the transportation sector with the range of 1.51-4.54 TWh in 2021 and 3.25-9.77 TWh in 2050.

c. Scenario 4, Scenario 5, and Scenario 6 with the additional only for electric passenger electric vehicle will increase the electricity consumption in the transportation sector with the range 2.93-8.81 TWh in 2021 and 19.4-58.4 TWh in 2050

d. Scenario 7, Scenario 8, and Scenario 9 with the additional electric vehicle both for electric passenger electric vehicle and electric motorcycle will increase the electricity consumption in the transportation sector with the range 4.45-13.3 TWh in 2021 and 22.7-68.1 TWh in 2050

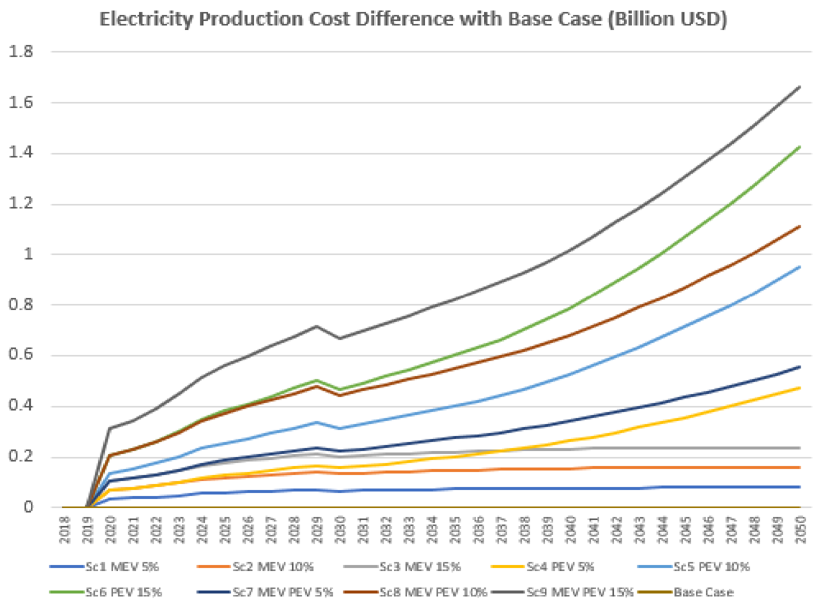


Figure 91. Electricity production cost in EV introduction

The result also shows the comparison of each scenario in terms of electricity production cost with the details as follows:

a. Scenario 9 with 15% of PEV and MEV in the additional rate of the vehicle per year will show the highest additional electricity production cost
b. Scenario 1, Scenario 2, and Scenario 3 with the additional only for electric motorcycle will increase the additional electricity production cost with the range 0.03-0.10 Billion USD in 2021 and 0.07-0.23 Billion USD in 2050
c. Scenario 4, Scenario 5, and Scenario 6 with the additional only for electric passenger electric vehicle will increase the additional electricity production cost with the range 0.06-0.20 Billion USD in 2021 and 0.47-1.42 Billion USD in 2050
d. Scenario 7, Scenario 8, and Scenario 9 with the additional electric vehicle both for electric passenger electric vehicle and electric motorcycle will increase the additional electricity production cost with the range 0.10-0.20 Billion USD in 2021 and 0.55-1.10 Billion USD in 2050

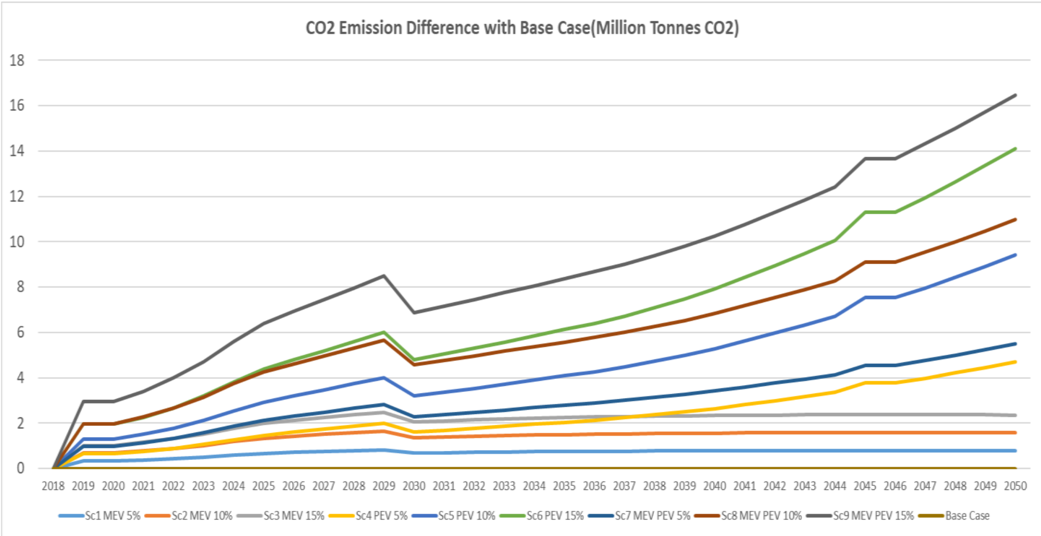


Figure 92. CO_2 emission in EV introduction

Each scenario will generate different CO_2 emission compared with the base case scenario with the details as follows:

- Scenario 9 with 15% of PEV and MEV in the additional rate of the vehicle per year will show the CO_2 Emission
- Scenario 1, Scenario 2, and Scenario 3 with the additional only for electric motorcycle will increase the additional electricity production cost with the range 0.33-1.00 Mt CO_2 in 2021 and 0.78-2.35 Mt CO_2 in 2050
- Scenario 4, Scenario 5, and Scenario 6 with the additional only for electric passenger electric vehicle will increase the additional electricity production cost with the range 1.30-1.95 Mt CO_2 in 2021 and 4.70-14.10 Mt CO_2 in 2050

- Scenario 7, Scenario 8, and Scenario 9 with the additional electric vehicle both for electric passenger electric vehicle and electric motorcycle will increase the additional electricity production cost with the range 0.98-1.97 Mt CO_2 in 2021 and 5.4-10 Mt CO_2 in 2050

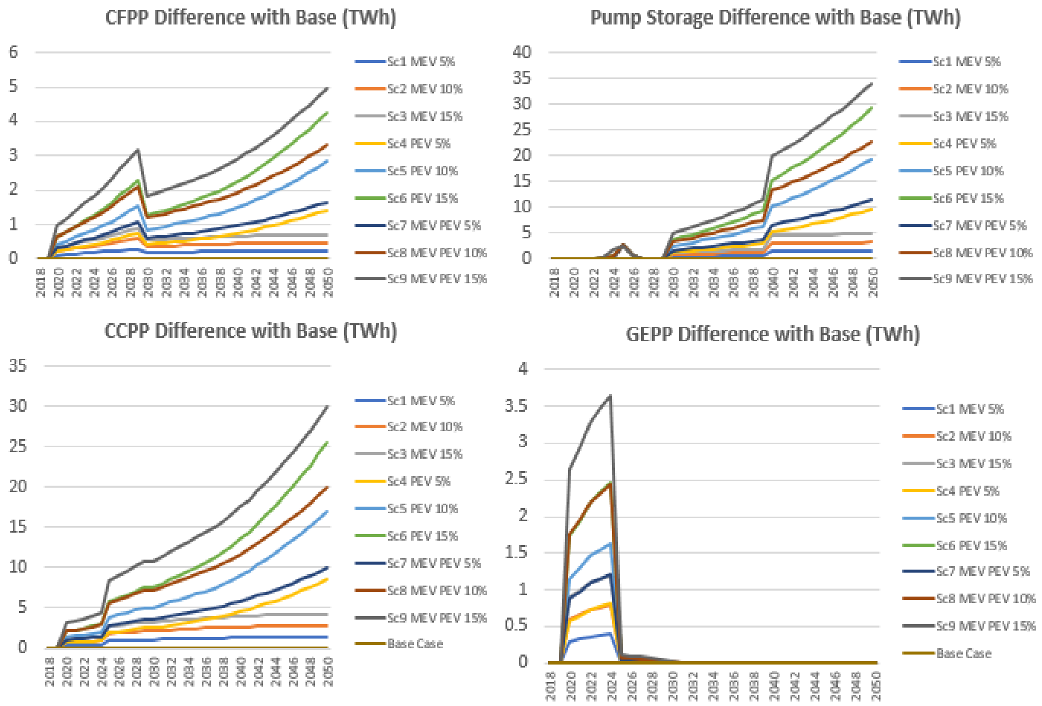


Figure 93. Additional capacity in EV introduction

Each scenario will bring the additional required capacity of the power plant. Every powerplant type that is needed will be added into the system at a specific time and capacity. The introduction of the electric vehicle may increase electricity production with the details are as follows::

a. Coal-Fired Powerplant (CFPP) with 1 TWh in 2020 to 5 TWh in 2050

b. Pump Storage Powerplant (PSPP) with 0.5 TWh in 2024 to 35 TWh in 2050

c. Combined Cycle Powerplant (CCPP) with 0.6 TWh in 2020 to 30 TWh in 2050

d. Gas Engine Powerplant (CFPP) with 3.5 TWh during 2020-2024

With a higher share of additional electric vehicle scenario, both motorcycle EV and passenger EV will produce higher electricity consumption, energy security index, lowest CO_2 emission, and highest electricity production cost.

After both essays were conducted, a comparison of the impact of electric vehicle introduction to the oil refinery and power generation development was also analyzed. The comparison result shows a potential saving of development cost between the oil refinery and power generation by the introduction policy of electric vehicle. A higher share of electric vehicles in the transportation sector will reduce the development cost of oil refinery while also increase power generation development cost. The electric vehicle introduction will increase the power generation cost but it still produces lower cost than oil refinery development.

An electric motorcycle introduction will create a higher saving of oil refinery and power generation cost than electric passenger vehicle introduction. The electric motorcycle introduction will reduce higher oil refinery development costs with lower additional power generation costs than an electric passenger vehicle. This study also emphasizes the introduction of the electric vehicle, especially electric motorcycle, into the transportation sector to reduce the required oil refinery development and improve the power generation sector. The highest share of electric vehicles in the transportation sector will decrease the refinery development cost from 90.86 Billion USD in the Base scenario to 54.85 Billion USD in the scenario with 15% additional electric passenger vehicle and motorcycle in 2050. However, it will also increase the electricity production cost from 1030.3 Billion USD in the Base scenario to 1053.8 Billion USD in the scenario with 15% additional electric passenger vehicle and motorcycle.

Table 25. EV Scenario Difference in Oil Refinery and Power Generation Development Cost, 2050

Scenario	Refinery Development Cost (Billion USD)	Electricity Production Cost	Difference with Base Case in Refinery Development	Difference with Base Case in Power Generation Development	Added Value (Negative Value means saving)
Base	90.86	1030.30	0.0	-	-
Scenario 1 Motorcycle EV 5%	74.32	1031.40	-16.5	1.1	(15.44)
Scenario 2 Motorcycle EV 10%	69.38	1032.50	-21.5	2.2	(19.28)
Scenario 3 Motorcycle EV 15%	**66.98**	**1033.60**	**-23.9**	**3.3**	**(20.58)**
Scenario 4 Passenger EV 5%	76.41	1037.00	-14.4	6.7	(7.75)
Scenario 5 Passenger EV 10%	72.33	1043.70	-18.5	13.4	(5.12)
Scenario 6 Passenger EV 15%	70.39	1050.40	-20.5	20.1	(0.36)
Scenario 7 Passenger EV 5% + Motorcycle 5%	64.89	1038.10	-26.0	7.8	(18.16)
Scenario 8 Passenger EV 10% + Motorcycle 10%	55.87	1046.10	-35.0	15.8	(19.18)
Scenario 9 Passenger EV 15% + Motorcycle 15%	54.85	1053.80	-36.0	23.5	(12.50)

The difference in oil refinery development is about 36 Billion USD in oil refinery development cost and 23.5 Billion USD in power generation development. It concludes that Indonesia’s government might not need to develop more oil refineries if the electric vehicle is successfully implemented. An electric vehicle introduction will take lower development costs of power generation than spending higher on oil refinery development. The highest difference between refinery development cost and power generation cost in 2050 is coming from the scenario 3 with 15% additional electric motorcycle with 20.58 Billion USD. It means the increasing penetration of electric motorcycle can save more budget for the government compared to other scenarios.

Chapter 6. General Summary

This dissertation consists of two essays. The first one is a discussion on the development of oil refineries to increase energy security in Indonesia. It was conducted using two methodologies: optimization using mixed-integer linear programming, and system dynamic analysis. This essay provides an evaluation of the importance of increasing oil refinery capacity and how it will have an impact on improving the energy security index.

The proposed refinery development in Indonesia will be divided into three periods of development, which are the 1st 10-year period (2018-2027), 2nd 10-year period (2028-2037), 3rd 12-year period (2038-2050). The optimization result shows that Indonesia needs an additional refinery with 898 kbopd (1st period) and 682 kbopd (3rd period). There is no need to build additional refinery development in the 2nd period (2028-2037) due to 900 kbopd additional new refinery will be added as stated in the government plan in 2021-2024. Cumulative additional refinery development from 2018-2050 by 1,580 kbopd or equal to 135.4% of the existing capacity in 2017 with 1,166 kbopd. This result shows that Indonesia has to double its refinery development for 2018-2050 to reduce fuel oil import dependence.

To reduce the fuel oil import dependence in Indonesia, the required refinery development cost from 2018-2050 is 90.86 Billion USD. This paper encourages the Indonesian government to seek an alternative source of financing for refinery development through crude export revenue or increasing petroleum product price as a part of the effort to secure its energy security. The analysis results show that the percentage of crude export revenue that needs to be collected every year as a source of refinery development financing is about 157.91% of total crude oil export revenue, which means that the government could not consider this option. On the other hand, the percentage of petroleum prices that need to be added every year as a refinery-financing source is about 2.46%. The additional refinery development will decrease the fuel oil import from 711.48 Billion USD to 311.59 Billion USD. It will save 399.89 Billion USD or 56.20% cost saving.

Refinery development optimization will increase the availability dimension due to improving fuel oil production and decreasing fuel import dependence while also decrease the acceptability dimension due to increasing emissions from the oil refinery. The affordability dimension will increase due to the decreasing share of subsidy per government spending (higher refinery investment). There will be no difference between the two cases for the intensity dimension. Overall, it will increase the energy security index from 2018 to 2050 due to the improvement of availability and affordability dimension but a decrease in acceptability dimension.

System dynamic analysis has been conducted in the first essay. The result shows that Case 1 Additional Refinery is the only case which increases the energy security index by 15.81% on average compared to Base Case because of the reduction of fuel oil import and increasing domestic fuel oil production. Case 4 Higher Oil Production will have the highest impact by decreasing the energy security index at 27.40% on average. It is because the higher oil production will deplete the oil reserve faster than the other Case. Case 2 Higher GDP, Case 3 Higher Oil Price, and Case 5 Higher Population will also decrease the energy security index but not significant, with only 0.01%-1.20% on average. The increasing energy security from the higher additional rate of refinery may bring negative impact to the increasing government spending, fuel price, fuel price per GDP per capita ratio and fuel subsidy. Moreover, the analysis also found several policy implications that need to be considered to improve energy security in the oil sector by optimizing refinery capacity, increasing the additional oil reserves and lowering fuel oil consumption. Due to limited government budget, the development of additional oil refinery can be encouraged by the introduction of Foreign Direct Investment (FDI) through Public Private Partnership (PPP) scheme.

The second essay is related to the development of power generation to increase energy security in Indonesia. The power generation sector perspective is looking at the energy security concern is focusing on how this sector should diversify the energy supply from the highly dependent on fossil energy to renewable energy. A comparison between the business as usual scenario (BAU) and optimization (OPT) scenario has been conducted to see the difference in each energy security dimension.

The optimization with constraints of a 30% renewable energy share and 30% reserve margin will increase the energy security in the power generation development perspective. It suggests increasing the average share of Geothermal PP by 11.2% and

Large Hydro PP by 2.4%. From fossil power generation, the share of coal will be decreased by 25.7% while Combined Cycle PP increased by 18.2%. The optimization result shows a higher value of availability, acceptability, and accessibility dimension. However, it got a lower result in terms of the affordability dimension due to higher LCOE from 16.78 cUSD/kWh on average in BAU scenario to 32 cUSD/kWh on average in OPT scenario because of the increasing share of renewable energy. The average energy security index also increased from 0.45 on average in the BAU scenario to 0.60 on average in the OPT scenario.

The system dynamic analysis analyzed that the Case 5 higher additional renewable power generation will create the highest increasing impact on the energy security index in the power generation sector by increasing 75% compared to Base Case. Case 1 higher GDP also brings the increasing trend of energy security index by 29.1%. Case 4 higher additional fossil power generation will create the highest decreasing rate by 41.4%. Case 2 higher oil price is the most insignificant case due to only generate 0.01% decreasing rate.

Furthermore, system dynamic analysis also found several policy implications that need to be considered to improve energy security in the electricity sector by increasing renewable power generation and electricity consumption. However, the increasing rate of renewable power generation shall consider the consequences of high electricity production cost potential, especially for the high requirement of the natural gas power plant to stabilize the system. Although the increasing of fossil power generation increase the electricity production, it will decrease energy security level due to environmental issue such as increasing CO_2 emission, emission intensity and total emission per electricity consumption.

After both essays were conducted, one comparison of the impact of electric vehicle introduction to the oil refinery and power generation development was also analyzed. The comparison result shows that energy security can be improved by lower fuel oil consumption and higher electricity consumption. This study also suggest the introduction electric vehicle policy as a proposed policy suggestion to improve energy security both in the perspective from oil refinery and power generation sector. With a higher share of additional electric vehicle scenarios, both motorcycle EV and passenger EV will produce higher electricity consumption, energy security index, lowest CO_2 emission, and higher electricity production cost.

The result also shows that the electric motorcycle introduction policy will reduce higher oil refinery development costs with lower additional power generation costs than an electric passenger vehicle. The electric vehicle introduction will increase the power generation cost, but it still produces a lower cost than oil refinery development. This study also emphasizes the introduction of the electric vehicle especially electric motorcycle, into Indonesia's transportation sector to reduce the required oil refinery development and improve the power generation sector.

Bibliography

Adams, F. G., & Griffin, J. M. (1972). An economic-linear programming model of the US petroleum refining industry. *Journal of the American Statistical Association*, *67*(339), 542–551.

Al Hasibi, R. A., Hadi, S. P., & Widiastuti, A. N. (2013). Optimizing geothermal energy and hydro power in capacity expansion at the electrical system of Java-Madura-Bali. *Int. J. Eng. Comput. Sci. IJECS-IJENS*, *13*(1), 1–8.

Alfaro, L., Chanda, A., Kalemli-Ozcan, S., & Sayek, S. (2004). FDI and economic growth: The role of local financial markets. *Journal of International Economics*, *64*(1), 89–112.

Andrews, C. J. (2005). Energy security as a rationale for governmental action. *IEEE Technology and Society Magazine*, *24*(2), 16–25.

Ang, B. W., Choong, W. L., & Ng, T. S. (2015). Energy security: Definitions, dimensions and indexes. *Renewable and Sustainable Energy Reviews*, *42*, 1077–1093.

Ansari, N., & Seifi, A. (2012). A system dynamics analysis of energy consumption and corrective policies in Iranian iron and steel industry. *Energy*, *43*(1), 334–343.

Antara, K. B. (2018). *Www.antaranews.com*.

APERC, A. (2007). Quest for Energy Security in the 21st Century: Resources and Constraints. *Asia Pacific Energy Research Centre, Tokyo, Japan*.

APERC, A. (2016). *Powerplant Investment Planning Presentation*.

Asfani, D. A., Negara, I. M. Y., Nugraha, Y. U., Yuniarto, M. N., Wikarta, A., Sidharta, I.,

& Mukhlisin, A. (2020). Electric Vehicle Research in Indonesia: A Road map, Road tests, and Research Challenges. *IEEE Electrification Magazine*, *8*(2), 44–51.

Asiedu, N., Adu, P., Anto, E. K., & Duodu, A. (2019). Energy economics and optimal generation mix of selected power plants technologies in Ghana. *Scientific African*, *2*, e00015. https://doi.org/10.1016/j.sciaf.2018.e00015

Bank, G. W. (2018). *World development indicators 2018*. World Bank Publications.

Bappenas. (2018). *Indonesia PPP Book 2018*.

Bechtel. (1993). *PIMS (Process Industry Modeling System) User's Manual, Version 6.0*.

Biegler, T., & Zhang, D.-K. (2009). *The hidden costs of electricity: Externalities of power generation in Australia*. Australian Academy of Technological Science and Engineering.

Bodger, P. S., & May, D. G. (1992). A system dynamics energy model of New Zealand. *Technological Forecasting and Social Change*, *41*(1), 97–106.

Cabalu, H. (2010). Indicators of security of natural gas supply in Asia. *Energy Policy*, *38*(1), 218–225.

Carson, R. T., & Hanemann, W. M. (2005). Contingent valuation. *Handbook of Environmental Economics*, *2*, 821–936.

Chan, C. C. (1993). An Overview of Electric Vehicle Technology. *Proceedings of the IEEE*, *81*(9), 1202–1213. https://doi.org/10.1109/5.237530

Cherp, A., & Jewell, J. (2014). The concept of energy security: Beyond the four As. *Energy Policy*, *75*, 415–421.

Chi, K. C., Nuttall, W. J., & Reiner, D. M. (2009). Dynamics of the UK natural gas industry: System dynamics modelling and long-term energy policy analysis. *Technological Forecasting and Social Change*, *76*(3), 339–357.

Chowdhury, S., & Sahu, K. (1992). A system dynamics model for the Indian oil and gas exploration/exploitation industry. *Technological Forecasting and Social Change*, *42*(1), 63–83.

Clarke, K., & Graczyk, D. (2010). *India's Downstream Petroleum Sector: Refined Product Pricing and Refinery Investment*.

Cohen, G., Joutz, F., & Loungani, P. (2011). Measuring energy security: Trends in the diversification of oil and natural gas supplies. *Energy Policy*, *39*(9), 4860–4869.

Damayanti, S., Hidayatno, A., & Setiawan, A. D. (2020). *User Acceptance of Electric Vehicles in Indonesia: A Conceptual Model*. 110–115.

Danthurebandara, M., & Rajapaksha, L. (2019). Environmental consequences of different electricity generation mixes in Sri Lanka by 2050. *Journal of Cleaner Production*, *210*, 432–444. https://doi.org/10.1016/j.jclepro.2018.10.343

Davidsen, P. I., Sterman, J. D., & Richardson, G. P. (1990). A petroleum life cycle model for the United States with endogenous technology, exploration, recovery, and demand. *System Dynamics Review*, *6*(1), 66–93.

DESMOND, C. W. L. (2014). *Energy Security Indexes: A survey with application to Singapore*.

DeWitt, C. W., Lasdon, L. S., Waren, A. D., Brenner, D. A., & Melhem, S. A. (1989).

OMEGA: An improved gasoline blending system for Texaco. *Interfaces*, *19*(1), 85–101.

Ding, Z., Gong, W., Li, S., & Wu, Z. (2018). System dynamics versus agent-based modeling: A review of complexity simulation in construction waste management. *Sustainability*, *10*(7), 2484.

Downs, E. (2017). The Rise of China's Independent Refineries. *Center on Global Energy Policy*.

Ediger, V. Ş., & Çamdalı, Ü. (2007). Energy and exergy efficiencies in Turkish transportation sector, 1988–2004. *Energy Policy*, *35*(2), 1238–1244.

Emodi, N. V., Chaiechi, T., & Beg, A. R. A. (2019). Are emission reduction policies effective under climate change conditions? A backcasting and exploratory scenario approach using the LEAP-OSeMOSYS Model. *Applied Energy*, *236*, 1183–1217.

Erahman, Q. F., Purwanto, W. W., Sudibandriyo, M., & Hidayatno, A. (2016). An assessment of Indonesia's energy security index and comparison with seventy countries. *Energy*, *111*, 364–376. https://doi.org/10.1016/j.energy.2016.05.100

Farnoosh, A., Lantz, F., & Percebois, J. (2014). Electricity generation analyses in an oil-exporting country: Transition to non-fossil fuel based power units in Saudi Arabia. *Energy*, *69*, 299–308. https://doi.org/10.1016/j.energy.2014.03.017

Felsinger, K. (2008). *Public-private partnership handbook*. Asian Development Bank (ADB).

Fitriandi, P., Kakinaka, M., & Kotani, K. (2014). Foreign direct investment and infrastructure development in Indonesia: Evidence from province level data. *Asian Journal of Empirical Research*, *4*(1), 79–94.

Gardumi, F., Welsch, M., Howells, M., & Colombo, E. (2019). Representation of Balancing Options for Variable Renewables in Long-Term Energy System Models: An Application to OSeMOSYS. *Energies*, *12*(12), 2366.

Gary, J. H., Handwerk, G. E., & Kaiser, M. (1984). Refinery products. *Petroleum Refining: Technology and Economics, 2nd Ed. Marcel Dekker, Inc., New York*, 5–15.

Girardi, P., Gargiulo, A., & Brambilla, P. C. (2015). A comparative LCA of an electric vehicle and an internal combustion engine vehicle using the appropriate power mix: The Italian case study. *The International Journal of Life Cycle Assessment*, *20*(8), 1127–1142.

Göthe-Lundgren, M., T. Lundgren, J., & A. Persson, J. (2002). An optimization model for refinery production scheduling. *International Journal of Production Economics*, *78*(3), 255–270. https://doi.org/10.1016/S0925-5273(00)00162-6

Guerra, O. J., & Le Roux, G. A. (2011). Improvements in petroleum refinery planning: 1. Formulation of process models. *Industrial & Engineering Chemistry Research*, *50*(23), 13403–13418.

Guo, X., & Guo, X. (2015). China's photovoltaic power development under policy incentives: A system dynamics analysis. *Energy*, *93*, 589–598.

Hamdani, R. S., & Sepriana, S. (2014). *Integrated Energy Security and Clean Energy Model (IESCEM)*. 51.

Handayani, K., Krozer, Y., & Filatova, T. (2017). Trade-offs between electrification and climate change mitigation: An analysis of the Java-Bali power system in Indonesia. *Applied Energy*, *208*, 1020–1037.

Heaps, C. (2016). *Long-range Energy Alternatives Planning (LEAP) system.[Software version: 2017.0. 11] Stockholm Environment Institute. Somerville, MA, USA*.

Hosseini, S. H., & Shakouri, H. (2016). A study on the future of unconventional oil development under different oil price scenarios: A system dynamics approach. *Energy Policy*, *91*, 64–74.

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazillian, M., & Roehrl, A. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. *Energy Policy*, *39*(10), 5850–5870. https://doi.org/10.1016/j.enpol.2011.06.033

Huda, M., Aziz, M., & Tokimatsu, K. (2019). The future of electric vehicles to grid integration in Indonesia. *Energy Procedia*, *158*, 4592–4597.

Hughes, L. (2007). *Energy Security in Nova Scotia*. Canadian Centre for Policy Alternatives.

Hughes, L., & Shupe, D. (2010). Creating energy security indexes with decision matrices and quantitative criteria. *Montreal./Http://Www. Worl Denergy. Org/Documents/Congresspapers/415. PdfS*.

Hutagalung, A. M. (2014). *The economic value of Indonesia's natural gas: A quantitative* *assessment of three gas policies*.

Indonesia, B. P. S. (2017). Statistik Indonesia 2017. *Jakarta: Badan Pusat Statistik Indonesia*.

Indonesia, B. P. S. (2018). Statistik Indonesia Tahun 2018. *Jakarta Pusat*.

Indra, I. B. P. (2011). PPP Policy and Regulation in Indonesia. *Republic of Indonesia National Development Planning Agency*.

Izaguirre, A. K. (2003). *Private participation in infrastructure: Trends in developing countries in 1990-2001: Energy, telecommunications, transport, water*. World Bank Publications.

Jeon, C., Lee, J., & Shin, J. (2015). Optimal subsidy estimation method using system dynamics and the real option model: Photovoltaic technology case. *Applied Energy*, *142*, 33–43.

Jiao, J.-L., Han, K.-Y., Wu, G., Li, L.-L., & Wei, Y.-M. (2014). The effect of an SPR on the oil price in China: A system dynamics approach. *Applied Energy*, *133*, 363–373.

Kaiser, M. J. (2017). A review of refinery complexity applications. *Petroleum Science*, *14*(1), 167–194. https://doi.org/10.1007/s12182-016-0137-y

Kanchana, K., & Unesaki, H. (2014). ASEAN energy security: An indicator-based assessment. *Energy Procedia*, *56*(C), 163–171. https://doi.org/10.1016/j.egypro.2014.07.145

Karlsson, K., & Meibom, P. (2008). Optimal investment paths for future renewable based energy systems—Using the optimisation model Balmorel. *International Journal of*

Hydrogen Energy, *33*(7), 1777–1787. https://doi.org/10.1016/j.ijhydene.2008.01.031

Kementerian, L. H. (2019). Peraturan Menteri Negara Lingkungan Hidup Nomor 15 tahun 2019 tentang Baku Mutu Emisi Pembangkit LIstrik Tenaga Termal. *Jakarta: Menteri Negara Lingkungan Hidup*.

Kemmler, A., & Spreng, D. (2007). Energy indicators for tracking sustainability in developing countries. *Energy Policy*, *35*(4), 2466–2480.

Ketenagalistrikan, D. J. (2018). Statistik Ketenagalistrikan 2017. *Jakarta: Direktorat Jenderal Ketenagalistrikan*.

Keuangan, K. (2017). Anggaran Pendapatan dan Belanja (APBN) 2007-2017. *Kementerian Keuangan Republik Indonesia*.

Khoshniyat, F., & Törnquist Krasemann, J. (2017). *Analysis of Strengths and Weaknesses of a MILP Model for Revising Railway Traffic Timetables*. 17th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (ATMOS 2017).

Kiani, B., & Pourfakhraei, M. A. (2010). A system dynamic model for production and consumption policy in Iran oil and gas sector. *Energy Policy*, *38*(12), 7764–7774.

Kim, K., Jung, M.-W., Park, M., Koh, Y.-E., & Kim, J.-O. (2018). Public–Private Partnership Systems in the Republic of Korea, the Philippines, and Indonesia. *Asian Development Bank Economics Working Paper Series*, *561*.

Kirkpatrick, C., Parker, D., & Zhang, Y.-F. (2004). *Foreign direct investment in* *infrastructure in developing countries: Does regulation make a difference?*

Kosugi, T. (2016). Endogenizing the probability of nuclear exit in an optimal power-generation mix model. *Energy*, *100*, 102–114. https://doi.org/10.1016/j.energy.2016.01.083

KPMG. (2009). *Availability Payment Mechanisms For Transit Projects*.

Krewitt, W. (2002). External costs of energy—Do the answers match the questions?: Looking back at 10 years of ExternE. *Energy Policy*, *30*(10), 839–848.

Kruyt, B., van Vuuren, D. P., de Vries, H. J. M., & Groenenberg, H. (2009a). Indicators for energy security. *Energy Policy*, *37*(6), 2166–2181.

Kruyt, B., van Vuuren, D. P., de Vries, H. J. M., & Groenenberg, H. (2009b). Indicators for energy security. *Energy Policy*, *37*(6), 2166–2181.

Lap, T., Benders, R., van der Hilst, F., & Faaij, A. (2020). How does the interplay between resource availability, intersectoral competition and reliability affect a low-carbon power generation mix in Brazil for 2050? *Energy*, *195*, 116948. https://doi.org/10.1016/j.energy.2020.116948

Lavigne, D. (2017). OSeMOSYS Energy Modeling Using an Extended UTOPIA Model. *Universal Journal of Educational Research*, *5*(1), 162–169.

Lee, H., Pinto, J. M., Grossmann, I. E., & Park, S. (1996). Mixed-integer linear programming model for refinery short-term scheduling of crude oil unloading with inventory management. *Industrial & Engineering Chemistry Research*, *35*(5), 1630–1641.

Leiras, A., Hamacher, S., & Elkamel, A. (2010). Petroleum refinery operational planning using robust optimization. *Engineering Optimization*, *42*(12), 1119–1131.

Liu, M.-L., & Sahinidis, N. V. (1996). Long range planning in the process industries: A projection approach. *Computers & Operations Research*, *23*(3), 237–253.

Liu, X., Chen, D., Zhang, W., Qin, W., Zhou, W., Qiu, T., & Zhu, B. (2013). An assessment of the energy-saving potential in China's petroleum refining industry from a technical perspective. *Energy*, *59*, 38–49.

Löffler, K., Hainsch, K., Burandt, T., Oei, P.-Y., Kemfert, C., & von Hirschhausen, C. (2017). *Designing a Global Energy System Based on 100% Rwables for 2050: GENeSYS-MOD: An Application of the Open-Source Energy Modelling System (OSeMOSYS).*

Löffler, K., Hainsch, K., Burandt, T., Oei, P.-Y., Kemfert, C., & Von Hirschhausen, C. (2017). Designing a model for the global energy system—GENeSYS-MOD: An application of the open-source energy modeling system (OSeMOSYS). *Energies*, *10*(10), 1468.

Mahar Diputra, E. (2018). *Analysis of the Assessment Factors for Energy Planning in Indonesia using Analytic Hierarchy Process* (Master Thesis). Seoul National University, Seoul, South Korea.

Martchamadol, J., & Kumar, S. (2012). Thailand's energy security indicators. *Renewable and Sustainable Energy Reviews*, *16*(8), 6103–6122. https://doi.org/10.1016/j.rser.2012.06.021

Más, R., & Pinto, J. M. (2003). A mixed-integer optimization strategy for oil supply in distribution complexes. *Optimization and Engineering*, *4*(1–2), 23–64.

Matsuo, Y., Endo, S., Nagatomi, Y., Shibata, Y., Komiyama, R., & Fujii, Y. (2018). A quantitative analysis of Japan's optimal power generation mix in 2050 and the role of CO2-free hydrogen. *Energy*, *165*, 1200–1219.

Meilandari, E. D. (2020). *Optimization Analysis for Long-term Electricity Planning in Java Bali Power System in Indonesia* (Master Thesis). Seoul National University, Seoul, South Korea.

Menezes, B. C., Kelly, J. D., Grossmann, I. E., & Vazacopoulos, A. (2015). Generalized capital investment planning of oil-refineries using MILP and sequence-dependent setups. *Computers & Chemical Engineering*, *80*, 140–154. https://doi.org/10.1016/j.compchemeng.2015.05.013

Min, D., & Chung, J. (2013). Evaluation of the long-term power generation mix: The case study of South Korea's energy policy. *Energy Policy*, *62*, 1544–1552. https://doi.org/10.1016/j.enpol.2013.07.104

MirHassani, S. A. (2008). An operational planning model for petroleum products logistics under uncertainty. *Applied Mathematics and Computation*, *196*(2), 744–751. https://doi.org/10.1016/j.amc.2007.07.006

Moccero, D. (2008). *Improving the business and investment climate in Indonesia*.

Moore, B. (1979). *RPMS (Refinery and Petrochemical Modeling System): A system descriptive*.

Moran, T. H. (2012). Foreign direct investment and development. *The Wiley-Blackwell Encyclopedia of Globalization*.

Morcillo, J. D., Franco, C. J., & Angulo, F. (2018). Simulation of demand growth scenarios in the Colombian electricity market: An integration of system dynamics and dynamic systems. *Applied Energy*, *216*, 504–520.

Moro, L. (2000). Mixed integer optimization techniques for planning and scheduling production in oil refineries. *Chemical Engineering Department–Escola Politécnica Da Universidade de São Paulo, Ph. D. Thesis*.

Moro, L., Zanin, A., & Pinto, J. (1998). A planning model for refinery diesel production. *Computers & Chemical Engineering*, *22*, S1039–S1042.

Nababan, R. (2013). *Indonesia's Natural Gas Regulation, Pricing Mechanism, and its economic impact* (Master Thesis). Seoul National University, Seoul, South Korea.

Naill, R. F. (1972). *Managing the discovery life cycle of a finite resource: A case study of US natural gas.*

Narula, K., & Reddy, B. S. (2016). A SES (sustainable energy security) index for developing countries. *Energy*, *94*, 326–343.

Neiro, S. M., & Pinto, J. M. (2005). Multiperiod optimization for production planning of petroleum refineries. *Chem. Eng. Comm.*, *192*(1), 62–88.

Neiro, S. M., & Pinto, J. M. (2003). *Supply chain optimization of petroleum refinery complexes*. 59–72.

Nepal, R., & Paija, N. (2019). Energy security, electricity, population and economic growth: The case of a developing South Asian resource-rich economy. *Energy Policy*, *132*, 771–781. https://doi.org/10.1016/j.enpol.2019.05.054

Ochoa, P., & Van Ackere, A. (2009). Policy changes and the dynamics of capacity expansion in the Swiss electricity market. *Energy Policy*, *37*(5), 1983–1998.

Pan, L., Liu, P., & Li, Z. (2017). A system dynamic analysis of China's oil supply chain: Over-capacity and energy security issues. *Applied Energy*, *188*, 508–520.

Pereirinha, P. G., Quadrado, J. C., & Esteves, J. (2005). Sustainable Mobility: Part I–Main Problems. *CEE'05-International Conference on Electrical Engineering, in CD-ROM*.

Petroleum, B. (2018). BP energy outlook 2018. *London: British Petroleum*.

Pinto, J., Joly, M., & Moro, L. (2000). Planning and scheduling models for refinery operations. *Computers & Chemical Engineering*, *24*(9–10), 2259–2276.

Ponnambalam, K., Vannelli, A., & Woo, S. (1992). An interior point method implementation for solving large planning problems in the oil refinery industry. *The Canadian Journal of Chemical Engineering*, *70*(2), 368–374.

Prambudia, Y., & Nakano, M. (2012). Integrated simulation model for energy security evaluation. *Energies*, *5*(12), 5086–5110.

Prasetio, E. A., Belgiawan, P. F., Anggarini, L. T., Novizayanti, D., & Nurfatiasari, S. (2019). *Acceptance of Electric Vehicle in Indonesia: Case Study in Bandung*. 63–71.

Pusdatin, E. (2018). Handbook of Energy & Economic Statistics of Indonesia. *Jakarta: Ministry of Energy and Mineral Resources Republic of Indonesia*.

Quantitative Assessment of Energy Security Working Group. (2011). Developing an Energy Security Index. *Study on the Development of an Energy Security Index and an Assessment of Energy Security for East Asian Countries, ERIA Research Project Report*, *13*, 7–47.

Qudrat-Ullah, H. (2013). Understanding the dynamics of electricity generation capacity in Canada: A system dynamics approach. *Energy*, *59*, 285–294.

Railsback, S. F., & Grimm, V. (2019). *Agent-based and individual-based modeling: A practical introduction*. Princeton university press.

Rana, M. S., Ancheyta, J., Riazi, M., & Marafi, M. (2013). Future directions in petroleum and natural gas refining. *ASTM Manual Ser MNL*, *58*, 769–800.

Rezaee, S., Farjah, E., & Khorramdel, B. (2013). Probabilistic analysis of plug-in electric vehicles impact on electrical grid through homes and parking lots. *IEEE Transactions on Sustainable Energy*, *4*(4), 1024–1033.

Ridhanda, P. (2016). *Two Essays on Energy Security Evaluation of the Republic of Indonesia*. (Ph.D Dissertation). Seoul National University, Seoul, South Korea.

Rogan, F., Cahill, C. J., Daly, H. E., Dineen, D., Deane, J., Heaps, C., Welsch, M., Howells, M., Bazilian, M., & Gallachóir, B. P. Ó. (2014). LEAPs and bounds—An energy demand and constraint optimised model of the Irish energy system. *Energy Efficiency*, *7*(3), 441–466.

Sabri, M. F. M., Danapalasingam, K. A., & Rahmat, M. F. (2016). A review on hybrid electric vehicles architecture and energy management strategies. *Renewable and*

Sustainable Energy Reviews, *53*, 1433–1442.

Sai, R., Furubayashi, T., & Nakata, T. (2017). Preliminary study of energy security and energy resilience evaluation in Japan. *Transactions of the JSME (in Japanese)*, *83*(846), 16-00161-16–00161. https://doi.org/10.1299/transjsme.16-00161

Shahmohammadi, M. S., Yusuff, R. M., Keyhanian, S., & Shakouri, H. (2015). A decision support system for evaluating effects of Feed-in Tariff mechanism: Dynamic modeling of Malaysia's electricity generation mix. *Applied Energy*, *146*, 217–229.

Shih, Y.-H., & Tseng, C.-H. (2014). Cost-benefit analysis of sustainable energy development using life-cycle co-benefits assessment and the system dynamics approach. *Applied Energy*, *119*, 57–66.

Siagian, U. W., Yuwono, B. B., Fujimori, S., & Masui, T. (2017). Low-carbon energy development in Indonesia in alignment with Intended Nationally Determined Contribution (INDC) by 2030. *Energies*, *10*(1), 52.

Simoes, A., & Hidalgo, C. A. (2017). *The observatory of economic complexity*. The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development. Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence.

Sovacool, B. K. (2011). Evaluating energy security in the Asia pacific: Towards a more comprehensive approach. *Energy Policy*, *39*(11), 7472–7479. https://doi.org/10.1016/j.enpol.2010.10.008

Sovacool, B. K. (2013). Expanding renewable energy access with pro-poor public private partnerships in the developing world. *Energy Strategy Reviews*, *1*(3), 181–192.

Sovacool, B. K., & Brown, M. A. (2010). Competing dimensions of energy security: An international perspective. *Annual Review of Environment and Resources*, *35*, 77–108.

Sovacool, B. K., & Mukherjee, I. (2011). Conceptualizing and measuring energy security: A synthesized approach. *Energy*, *36*(8), 5343–5355.

Sovacool, B. K., Mukherjee, I., Drupady, I. M., & D'Agostino, A. L. (2011). Evaluating energy security performance from 1990 to 2010 for eighteen countries. *Energy*, *36*(10), 5846–5853.

Subekti, R. A. (2002). *Peluang dan Tantangan Pengembangan Mobil Listrik Nasional*. LIPI Press.

Suhadi, S. (2018). *Harmonization of Regulation on Land Acquisition For Infrastructure Development with Public-Private Partnership Scheme In Indonesia*. 1st International Conference on Indonesian Legal Studies (ICILS 2018).

Swanson, J. (2002). Business dynamics—Systems thinking and modeling for a complex world. *Journal of the Operational Research Society*, *53*(4), 472–473.

Utami, M. W. D., Haryanto, A. T., & Sutopo, W. (2020). *Consumer perception analysis of electric car vehicle in Indonesia*. *2217*(1), 030058.

Utami, M. W. D., Yuniaristanto, Y., & Sutopo, W. (2020). Adoption Intention Model of Electric Vehicle in Indonesia. *Jurnal Optimasi Sistem Industri*, *19*(1), 70–81.

Vivoda, V. (2010). Evaluating energy security in the Asia-Pacific region: A novel methodological approach. *Energy Policy*, *38*(9), 5258–5263.

Walls, W. (2010). Petroleum refining industry in China. *Energy Policy*, *38*(5), 2110–2115.

Wang, Z., & Deisboeck, T. S. (2008). Computational modeling of brain tumors: Discrete, continuum or hybrid? In *Scientific modeling and simulations* (pp. 381–393). Springer.

Welsch, M., Howells, M., Bazilian, M., DeCarolis, J., Hermann, S., & Rogner, H. (2012). Modelling elements of smart grids–enhancing the OSeMOSYS (open source energy modelling system) code. *Energy*, *46*(1), 337–350.

Widiyanto, A. (2016). *Estimating the Effects of Energy Subsidy Removal on Indonesa's Economic Sectors Using Input-Output Analysis* (Master Thesis). Seoul National University, Seoul, South Korea.

Widyaningsih, G. A. (2017). Peraturan Presiden Nomor 22 Tahun 2017 tentang Rencana Umum Energi Nasional. *Jurnal Hukum Lingkungan Indonesia*, *4*(1), 139–152.

Widyaparaga, A., Sopha, B. M., Budiman, A., Muthohar, I., Setiawan, I. C., Lindasista, A., Soemardjito, J., & Oka, K. (2017). Scenarios analysis of energy mix for road transportation sector in Indonesia. *Renewable and Sustainable Energy Reviews*, *70*, 13–23.

Wiebe, K. S., & Lutz, C. (2016). Endogenous technological change and the policy mix in renewable power generation. *Renewable and Sustainable Energy Reviews*, *60*, 739–751. https://doi.org/10.1016/j.rser.2015.12.176

Wiese, F., Bramstoft, R., Koduvere, H., Alonso, A. P., Balyk, O., Kirkerud, J. G., Tveten, Å. G., Bolkesjø, T. F., Münster, M., & Ravn, H. (2018). Balmorel open source energy system model. *Energy Strategy Reviews*, *20*, 26–34.

Wijaya, M. E., & Limmeechokchai, B. (2010). The hidden costs of fossil power generation in Indonesia: A reduction approach through low carbon society. *Songklanakarin Journal of Science & Technology*, *32*(1).

Williams, S. E., Davis, S. C., & Boundy, R. G. (2017). *Transportation Energy Data Book: Edition 36*. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States).

Yao, L., & Chang, Y. (2014). Energy security in China: A quantitative analysis and policy implications. *Energy Policy*, *67*, 595–604.

Yulianto, I. (2014). *Pertamina Energy Outlook 2015*. *1*, 1–15.

Yunita, W. (2018). *Scenario Analysis on Fossil Fuel Alternatives for Power Generation in Indonesia: Case of Maluku Region* (Master Thesis). Seoul National University, Seoul, South Korea.

Zhang, M., Li, H., Zhou, M., & Mu, H. (2011). Decomposition analysis of energy consumption in Chinese transportation sector. *Applied Energy*, *88*(6), 2279–2285.

Zussida, A. (2019). *Analysis of Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP* (Master Thesis). Seoul National University, Seoul, South Korea.

국문초록

최적화 모형 및 시스템다이내믹스 모형을 적용한 인도네시아의 정유 및 발전 시설 개발규모 최적화 연구

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본 연구에서는 인도네시아의 에너지안보 증진을 위한 대표적인 2대 에너지 전환 부문 시설인 정유시설과 발전시설을 대상으로, 인도네시아 정부의 개발정책에 연동한 이들 시설의 최적 개발 규모를 분석, 산정하고 이들 시설의 개발로 인한 인도네시아 에너지안보지수의 개선 정도를 추정하고자 하였다. 에너지안보지수(Energy Security Index)는 자원 가용성, 수용성, 경제성, 접근성 및 집약도 요소들로 구성되어있다. 정유시설과 발전시설의 발전은 하나의 에너지보안요소를 개선 혹은 감소시킬 수 있다.

에너지안보(Energy Security)의 개념은 일반적으로 국가의 주요 가치와 목표에 부합하는 방법으로 합리적인 가격으로 적절하고 신뢰할 수 있는 에너지 공급을 보장하는 것으로 정의된다. 에너지 안보에 대한 국가차원의 초점은 주로 경제성장과 국가 안정에 필수적인 에너지수요 충족을 위한 에너지의 안정적 공급방안 마련에 맞춰져 있는데, 국내 에너지 변환 시설의 개발은 이를 위한 매우 효과적이고 중요한 방법이다. 그러나 인도네시아의 에너지 밸런스에서 가장 중요한 두 가지의 변환 부문은 정유와 발전이지만 정유시설의 설비가 부족하고 발전시설의 다변화가 이루어지지 않은 실정이다. 인도네시아 정부는 이를 위하여 이미 정유 및 발전 부문의 개발계획을 수립하고 있다. 이에, 본 연구에서는 인도네시아가 필요한 정유시설과 발전시설의 최적개발규모를 최적화 모형과 시스템다이내믹스 모형을 활용하여 도출하고 이들 정유 및 발전시설의 개발이 인도네시아 에너지안보지수의 증진 효과를 산출하여 최적화 효과를 분석하였다.

본 연구에서는 먼저 인도네시아 정유소의 최적 개발 규모를 추정하기 위하여 혼합정수선형최적화(MILP) 모형과 시스템다이내믹스 모형을 적용하여 석유 수요 및 공급 측면에서 최적 정유시설규모를 에너지안보지수와 각 입력

요소의 상관관계를 통하여 분석하였다. 분석결과, Case 1이 유일하게 에너지안보지수를 기준시나리오대비 15.81% 증가시키는 대안임을 확인하였다.

다음으로 LEAP 및 OSEMOSYS 최적화 모형을 활용하여 최적 발전시설 규모 및 에너지 안보에 미치는 영향을 분석하였다. 재생에너지비중 30% 및 가채매장량마진 30%를 상정한 시나리오의 경우, 석탄발전은 25.7% 감소하는 반면 지열, 대수력, 천연가스복합발전은 각각 11.2%, 2.4%, 18.2% 증가하는 것으로 분석되었다. 이어서, 산출된 정유 및 발전 부문 최적개발규모의 분석결과가 인도네시아의 에너지안보지수의 개선에 비치는 영향을 산출하였는데, 에너지안보지수 중 availability, acceptability, 및 accessibility 를 모두 증가시키는 것으로 분석되었다.

본 논문에서는 또한 인도네시아의 전기자동차 육성 정책을 실시할 경우를 상정하여 앞서 분석한 정유 및 발전시설의 최적 규모에 미치는 영향을 살펴보았다. 본 논문의 주요 기여도를 정리하면 다음과 같다.

a. 인도네시아 최초로 최적화 모형 및 시스템다이내믹스 모형을 활용하여 2019~2050년 기간 동안 인도네시아의 정유시설 및 발전시설 최적개발규모 산정에 대한 평가를 실시하였으며, 그 결과는 추후 관련시설 개발에

필요한 기초자료를 제공하였다

b. 대표적인 에너지전환시설인 정유시설 및 발전시설의 개발이라는 관점에서의 인도네시아의 에너지안보지수를 평가하였다.

c. 전기차 도입 정책과 인도네시아의 정유시설 및 발전시설 개발정책간의 보완 정도를 평가하였다

주요어: 에너지안보, 정유시설, 발전시설, 인도네시아, 시스템동적모델

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