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The Role of Renewable Energy Resources in Generation Expansion Planning and GHG Emission Reduction: A Case Study of West Papua

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ABSTRACT

The impact of the implementation of the renewable energy power plant to GHG emission has been analyzed in this study. Four types of the renewable power plant have been simulated in the model which are hydro, biomass, solar, and wind power plant. The bottom-up model has been developed to conduct the analysis. In the developed model, two scenarios have been generated. BAU scenario represents power system expansion planning without any renewable power plant. On the other hand, the RPP scenario represents the role of renewable power plant in the system. Contribution of renewable power plant has been analyzed in two aspects which are contribution to the production of electricity and to the reduction of GHG emission. The model has been implemented using LEAP software combined with the optimization solver. The comparison of two generated scenario is summarized as cost-benefit analysis. The result showed that the implementation of renewable energy power plant reduced GHG emission by 43.38% cumulatively with the contribution of generated electricity by 42.62%. Cost-benefit analysis shows that the implementation of the renewable energy power plant produces NPV of 47.10 Million USD less than the BAU scenario.

Keywords—renewable power plant, GHG emission, Long-range Energy Alternative Planning, cost-benefit

1. INTRODUCTION

Electricity need is continuing to increase in line with economic and population growth. Satisfying the demand for electricity with a reliable and secure system with the least cost combination of electric generation is the major challenge for the Generation Company (GENCO). Moreover, the highlight relates to environment requirement is an additional consideration for the planner of GENCO. On the other hand, cleaner generator technology will result in a more expensive cost. Therefore, a decision of Generation Expansion Planning (GEP) must consider the two opposite aspects.

Introducing emission reduction in GEP results in more capacity of cleaner generator technology must be built [1]. Renewable energy resources contribute to emission reduction. On the other hand, the implementation of the renewable-based power generator, such as with generator, also increases reliability of power system [2]. The impact of electricity generation on the environment can be used as a constraint in optimization modeling of GEP [3]. This model results in power system expansion to support green economy development. Many types of renewable energy resources have been considered in GEP model such as wind generator [2], [4], solar panel technology [2], [4]–[6], and hydropower [7]. Specifically, power system reliability can be influenced by wind turbine penetration [8]. Renewable energy implementation as a distributed generation has been published in [9].

A more comprehensive model of GEP was introduced in [10]. This model has multi-objective that consist of minimizing cost, maximizing reliability, and minimizing emission. Renewable technology is also included in this study. However, the intermittent nature of renewable energy resources must be considered in the planning process. Several studies include uncertainty variable in the model to produce a stochastic model [11]–[13].

Emission reduction relates to electricity generation can be achieved by reducing the usage of electricity. Reduction of electricity demand can be earned by energy efficiency, demand-side management (DSM), and demand response programs. Integrating energy efficiency program into power system planning has been introduced in [14]. The model of this study has been implemented in a competitive market. The energy efficiency of the side of energy resources can be used as a part of GEP model [15].The policy development of energy efficiency will have a significant impact on SO_2 and

NO_x emission reduction [16]. This study was implemented in China power system that mostly relies on coal-based power plant.

Emission reduction can be achieved by the implementation of DSM and load management for each demand sector [17]. The integration of DSM and renewable energy penetration can be analyzed simultaneously. Emission reduction can be achieved by delaying the capacity addition of renewable energy-based generator as the impact of DSM application [18]. Integrated demand side and supply side management can be introduced simultaneously into power system expansion planning [19]. Similar to DSM, demand response with the main goal to reduce the peak load of the electrical power system is an important part of power system planning. The comparison of power system expansion policy with or without demand response is explained in [20]. A stochastic model of GEP with demand response has been published in [21]. Economical and environment benefit can be increased by implementing demands response in GEP model [22]. In a microgrid, the optimal design of renewable energy resources has been investigated in [23]. For smaller system, the implementation of solar energy for residential sector has been published in [24].

The contribution of this study can be pointed out as:

1. The impact of renewable energy technology on the environment in GEP is analyzed.
2. Cost and environment benefit analysis relate to renewable energy implementation is conducted.

The case study of this research is West Papua Province of Indonesia. This province has much kind of renewable energy resource. Currently, these resources are not optimized yet to supply the need for electricity in this region.

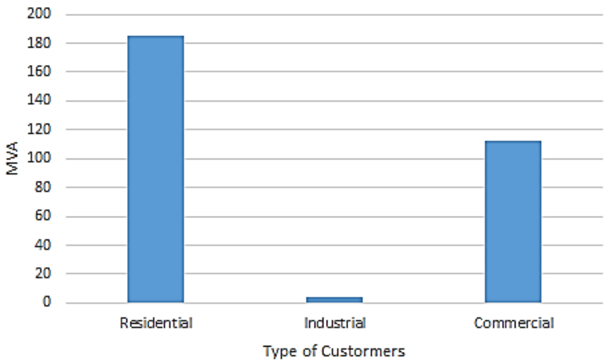

Figure 1. Connected demand capacity by type of customer.

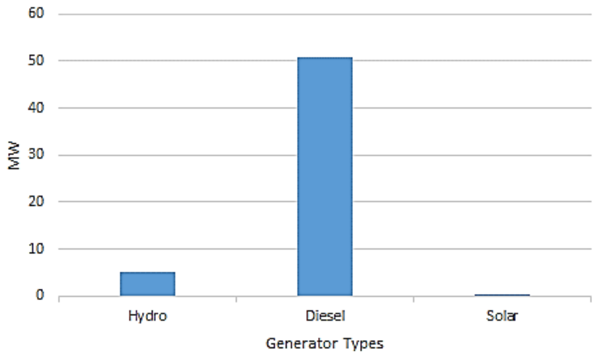

Figure 2. Generator installed capacity by type of technology.

2. CURRENT SITUATION OF ELECTRICAL SYSTEM OF WEST PAPUA

2.1. Electrical System

Based on the document of [25], Electrical system of West Papua is currently considered as an isolated system to supply the demand of 10 regencies and 1 city. The system consists of 6 isolated systems of 20 kV with a maximum load of more than 1 MW. In addition, there are 48 systems with maximum load less than 1 MW. The smaller systems are considered as village electrical system that distributed in 48 locations.

In 2015, the electrification ratio of West Papua was 75.78%. The total peak load of overall system is 70.2 MW. Four types of generator technology are used to supply the system demand, which are diesel, mini-hydro, solar panel, and natural gas generator. The biggest system is Sorong system with total peak load is about 37 MW. Connected capacity by customers in 2015 is shown in Figure 1 and installed generator by types is shown in Figure 2 [26]. It is obvious that diesel power plant dominating the composition of generator technology in West Papua. About 5 MW of hydropower plant and very few of solar panel in the form distributed generation is used in the electrical system of West Papua.

2.2. Energy Resources

West Papua province has several energy resources of fossil-based and renewable-energy based resources. The office of energy and mineral resources of West Papua has reported several reserves of fossil energy which coal reserve of 151 Ton, natural gas reserve of 24 TSCF, and oil reserve of 121 MMSTB. Currently, natural gas has utilized to generate electricity of 15 MW in Fakfak regency. Additionally, natural gas reserve is also available in Salawati Island very close to Sorong regency. In Bintuni gulf, there is a natural gas reserve and has been utilized to generate electricity by only 5 MW.

Renewable energy potential in this province is mainly in the form of hydro potential. The hydro potential is distributed in many locations. Currently, only about 5 MW hydropower has been used to generate electricity.

The current state of the electrical system in West Papua cannot meet the demand properly by only using diesel generator. In addition, load of the system has high growth and for the next 3 years electrical system of West Papua has a negative power balance. Temporally solution for this problem has been conducted by operating 20 MW mobile power plant with dual fuel of diesel and natural gas.

On the other hand, there is abundant energy resource available in the province. Therefore, the expansion planning of power system should be conducted to overcome the negative balance. Moreover, power system planning should be based on local resource, especially renewable energy resource. Beside environmental benefit, utilization of locally available resource can be used to accelerate the development of the province.

3. RESEARCH METHODOLOGY

Top-down and bottom-up models can be used to analyze reduction potential of greenhouse gas (GHG) emissions of electricity generation. Process cycle of electricity generation includes primary energy processing to final energy demand. Top-down models use economic perspective while bottom-up models use a systematic perspective to analyze electricity generation systems. The optimization procedure can be used in combination with bottom-up models to meet electricity demand at minimum cost. In this study, Long-range Energy Alternative Planning (LEAP) software is used. By general, LEAP is an energy analysis tool including an electricity generation system. This software was developed by the Stockholm Environment Institute (SEI) [27].

3.1. LEAP Model

LEAP uses quantitative data for the current account and projected scenario. The main feature of LEAP is the capability to analyze the different scenario in the model. Scenarios are developed based on demand and supply data. This tool can be used to analyze complete energy model and its impact on GHG emission [28]. LEAP also can be used to analyze energy systems for specific sectors, such as cement industry [29], transportation sector [30], household sector [31], and industrial sector [32]. Several studies have used LEAP software to analyze power systems expansion planning, such as the impact of global climate change to electricity sector [33], renewable energy implementation in electrical power [34], and CO_2 mitigation in electricity sector [35].

LEAP uses population and economic data as a driver variable. These data are entered to LEAP as a key assumption. Main parameters of LEAP are sector and subsector activity level, production of energy in the transformation sector, and environmental impact of energy transformation. LEAP uses Tier 1 GHG emission factor of fifth report of the intergovernmental panel on climate change (IPCC) to calculate the environmental impact. This impact is implemented as global warming potential (GWP) as air pollution. For each fuel in energy transformation has a specific factor of each type of gas emission. LEAP consider CO_2, NO_x, and CH_4 as gasses that contribute to GWP.

The forecasting of electricity demand is conducted in LEAP demand module. This module can be designed for available data. LEAP offers no specific data structure in the demand module. Therefore, LEAP provides to the user to design demand by sector or subsector with high flexibility. Analysis of demand sectors is done in LEAP use four different methods which are final energy intensity, useful energy, stock analysis, and transport analysis.

Energy conversion from primary energy sources into electricity is done in the transformation module. In this module, conversion, transportation, export, and import of primary energy sources can be simulated. Related to demand module, a different scenario can be used to express different configuration of projected transformation. Therefore, scenarios are used to reflect alternative assumption of technology and policy.

3.2. Analytical procedure

Electricity demand in this study is aggregated in three sectors, which are a household, industrial, and commercial sector. For each sector, electricity demand was calculated by (1)

$$e_i = I_i * A_i \tag{1}$$

where i is an index for the sector, e_i is electricity consumption for sector i in MWh, I_i is the intensity of electricity for sector i, and A_i is the activity level of sector i. For household sector, the unit of electricity intensity and activity level is $\frac{MWh}{H}$ and H respectively. H is the number of households. For industrial and commercial sector, the unit of electricity intensity and activity level is $\frac{MWh}{GDP}$ and GDP respectively. GDP is sectoral gross domestic product. Based on (1), total energy consumption for each projected year can be expressed in (2)

$$TE_t = \sum_i e_{i,t} = \sum_i I_{i,t} * A_{i,t}\, , \forall t \tag{2}$$

where t is year index and TE_t is total electricity consumption in year t. Activity level for each sector, A_i, is projected by the linear regression method. The activity level of the household sector is projected based on population growth. Whereas, economic activity for industrial and commercial sector is projected based on the growth of the GDP. Therefore, TE_t is expressed projected electricity consumption of West Papua.

Generator capacity will be calculated endogenously by LEAP. This method will maintain the minimum planning reserve margin (PRM) that must be defined by the planner. PRM of the system is calculated by (3)

$$PRM_t = \frac{100(TC_t - PL_t)}{PL_t} \tag{3}$$

where PRM_t is expressed in percent, TC_t is the total capacity of transformation module (in MW), and PL_t is the peak load of the system (in MW). The total capacity of the transformation module is calculated by (4)

$$TC_t = \sum_j P_j \, CV_j, \forall t \quad (4)$$

where P_j are capacity and CV_j is capacity value for each generation process. j is an index for a generation process that represents generator technology. Data of each generation technology must include capacity value, process efficiency, dispatch rule, exogenous capacity, and cost parameter. In simulation process, candidate generators for thermal technology are pulverized coal (PC), gas turbine (GT), and natural gas combined cycle (NGCC). For renewable energy, candidate generators are solar panel, wind turbine, bimass, and hydropower. Data for each generation technology is based on [36]

3.3. The optimization process

LEAP can determine the expansion of electrical power system by the optimization process. The detail explanation of the optimization model has been published in [37]. LEAP acts as an interface of this model. The optimization model can be solved by implementing the model to the optimization solver. LEAP uses two kinds of optimization solver which are General Linear Programming Toolkit (GLPK) solver that can be obtained freely and CPLEX solver from IBM that also can be obtained freely via an academic initiative program.

3.4. Data and data sources

Data collection is an important part of modeling. Reliable data will produce reliable model that accurately represent the real-world problem. It is very challenging work to collect complete and reliable data for all parameter due to a lack of energy-related data in Indonesia. In this study, data for LEAP has been collected from several data sources. The main driver-variable has been collected from national statistics council of Indonesia. Current power plant capacity has been collected from electricity national company.

Driver variables of the model are illustrated as follow. GDP and the GDP growth of West Papua are illustrated in Figure 3. The GDP of West Papua in 2017 is 3.98 Billion USD. In the same year, the growth of GDP is 6.80%. The average annual GDP growth between 2011 to 2017 is 3.36%. GDP value is based on the 2010 constant price.

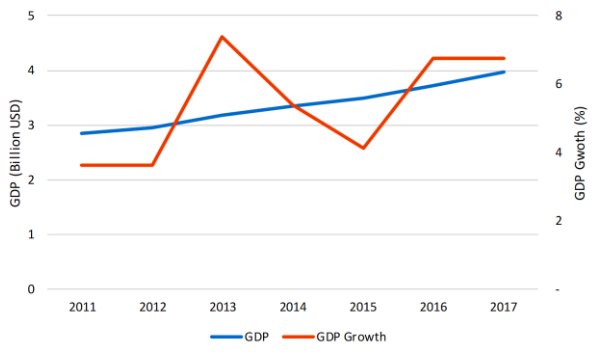

Figure 3. GDP and GDP growth in West Papua Province (source: National Statistics Council of Indonesia)

The population and population growth are shown in Figure 4. It is can be seen that the number of population is almost linearly increasing between 2011 to 2017. On the other hand, population growth is slightly decreasing in that time interval. The annual average population growth in this time interval is 2.59%. In 2017, the population of West Papua province was 915,630 people.

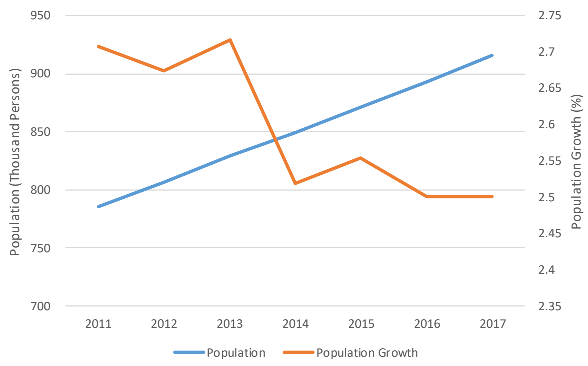

Figure 4. Population and population growth in West Papua (source: National Statistics Council of Indonesia).

Consumed electricity for each sector is shown in Figure 5. In 2015, total electricity sold by the electricity company in West Papua was 455.58 GWh. The household sector is dominating by 59.65% of total consumed electricity. This sector consumes electricity of 271.77 GWh. Industrial and commercial sector consume electricity of 6.79 GWh and 177.02 GWh respectively with the share of total consumed electricity of 1.49% and 38.86% respectively.

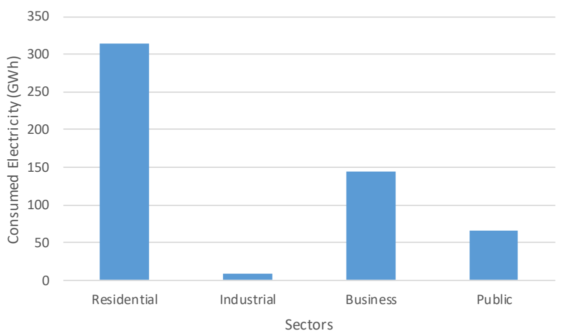

Figure 5. Consumed electricity by sectors.

Electricity intensity is calculated as a ratio of consumed electricity to the activity level for each sector. For the household sector, the final intensity of electricity is divided into two subsectors that represent urban and rural area. Moreover, each urban and rural subsector is divided into activity-based of electricity usage which is cooking, lighting, air conditioning, refrigerating, and other devices. Detail intensity of household sector is shown in **Table 1**. In rural area, electricity intensity is only applied for electrified rural household.

The industrial subsector is divided into 9 subsectors. Electricity intensity is measured based on a ratio of consumed electricity by the industrial sector and its GDP. Nine subsectors of industrial sector are food, textile, wood processing, pulp and paper, chemical, cement and non-metal, metal, machinery, and other manufacture industry. Detail electricity intensity of industrial sector and subsector is shown in **Table 2**.

Table 1. Electricity Intensity of the Household Sector.

Household	Intensity (MWh/Household)	
Urban	Cooking	0.13
	Lighting	0.38
	Air Conditioning	0.55
	Refrigerating	0.39
	Another Device	0.53
Rural	Cooking	0.13
	Lighting	0.38
	Air Conditioning	-
	Refrigerating	0.39
	Another Device	0.53

Table 2. Electricity Intensity of Industrial Sector.

Industrial	Intensity (MWh/Billion USD)
Food	0.022
Textile	0.002
Wood	0.004
Pulp and Paper	0.001
Chemical	0.000
Cement and non-metal	0.001
Metal	-
Machinery	0.000
Other manufacture	0.020

The commercial sector is divided into government and private subsector. The different measure is applied for each subsector. Electricity intensity for government subsector is a ratio of consumed electricity to space area of governmental office. On the other hand, electricity intensity of private subsector is a ratio of consumed electricity to its GDP. Detail electricity intensity of commercial sector is shown in **Table 3**.

3.5. Scenario generation

As described earlier in (1) and (2), projected electricity is defined by projected activity level and electricity intensity. In this study, electricity intensity is assumed to constant along the projection period. It is showed that no change in the pattern of consumed electricity by all sector. On the other hand, the activity level is defined by (5)

$$A_{i,t} = A_{i,t-1}\left(1 + \alpha_{i,t} * \Delta_{i,t}\right) \quad (5)$$

where $A_{i,t}$is the activity level of sector i in year t, $A_{i,t-1}$ is the activity level of sector i in the previous year, α_i is elasticity of sector i in year t, and Δ_i is activity growth of sector i in year t.

This study develops a model with two scenarios which are baseline or business as usual (BAU) and renewable power plant (RPP) scenario. BAU scenario results in a combination of power plant with fossil fuel technology to meet the increasing demand. On the other hand, RPP scenario implements renewable-energy based power plant to meet a portion of electricity demand. RPP scenario builds power plant with renewable energy sources of solar panel and biomass as abundant resources in West Papua.

Table 3. Electricity Intensity of Commercial Sector.

Commercial		Intensity	Unit
Government	Lighting	0.021	MWh/m^2
	Air Conditioning	0.043	
	Transport	0.003	
	Other	0.011	
Private	Lighting	2.63	MWh/Billion USD
	Air Conditioning	5.143	
	Transport	2.331	
	Other	0.588	

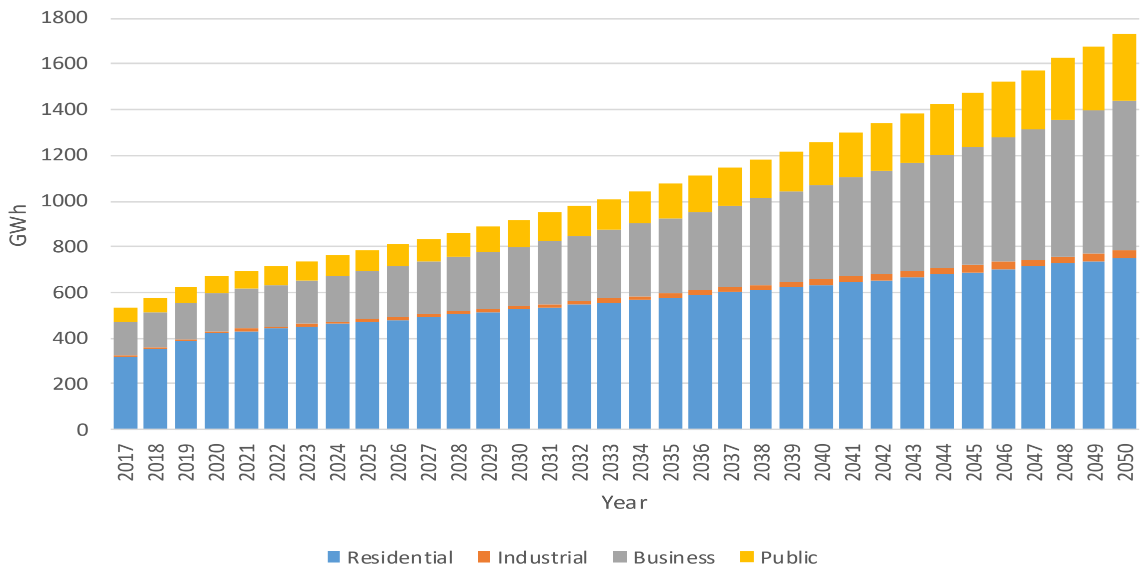

Figure 6. Electricity demand projection by sectors.

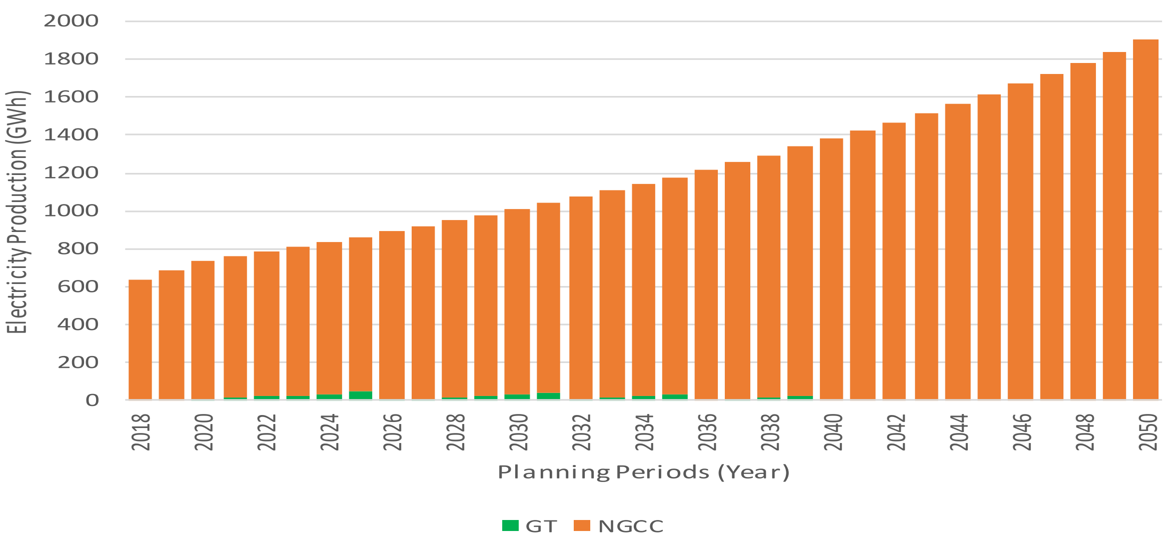

Figure 7. Generated electricity by power plant process based on BAU scenario.

RPM is set to 30% for both BAU and RPP scenario. For all generated scenario, the optimization process will be applied by using CPLEX solver of IBM.

4. RESULT AND DISCUSSION

4.1. Electricity Demand Projection

Based on an explained parameter from the previous section, the projection of electricity demand of West Papua is shown in Figure 6. Annual average growth of total electricity demand is 3.64% per year. The household sector has the lowest annual average growth in electricity demand, which is 2.66% per year. Industrial, commercial, and public sector almost have the same rate of annual average growth of electricity demand which is 4.67%. Total electricity demand in the end of projection period is 1,734.76 GWh.

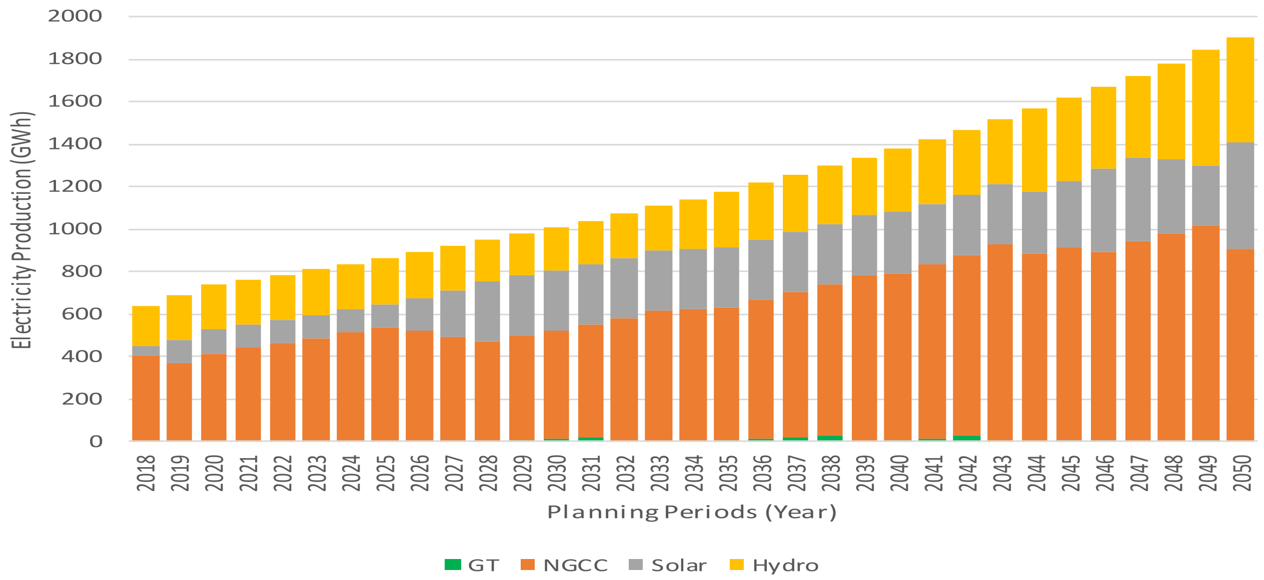

Figure 8. Generated electricity by power plant process based on RPP scenario.

The growth of household electricity demand is driven by the growth of population. In addition, the projected electricity demand of household sector is also driven by the national target of electrification ratio that will reach 100% in 2020. On the other hand, demand for electricity for the industrial and commercial sector is mainly driven by the growth of the GDP for each sector.

4.2. Power system expansion planning

To meet projected electricity demand, the electrical power system must generate sufficient electricity without any unmet or import electricity. Generated electricity based on BAU and RPP scenario is shown in Figure 7 and Figure 8 respectively. From these two figures, generated electricity by BAU and RPP scenario has the same amount. Compare to the projected electricity demand, generated electricity by all power plant is 13.06% higher. This percentage represents transmission and distribution losses in the system.

In Figure 7, BAU scenario result in a natural gas combined cycle (NGCC) technology as the most economical power plant. NGCC has annual average share of 95.98% compared to the total generated electricity by the system. Gas turbine (GT) technology contribute to the system with an annual average share of 1.07%. The diesel power plant, as an existing power plant, is operated only in the base year of the projection period. Meanwhile, the diesel power plant is not economical along the projection period based on the optimization process. In 2050, the total generated electricity is 1,903.42 GWh.

The RPP scenario results in the same amount of generated electricity compare to the BAU scenario. From the view of process technology, RPP scenario results in a different pattern of power plant technology. It is shown in Figure 8 that renewable-energy based power plant has significant contribution to generating electricity. In average, annual share of total renewable power plant has a contribution of 42.62% compared to total generated electricity. For the renewable energy-based power plant, hydropower has the most significant contribution by 22.74% of total generated electricity. Meanwhile, solar technology has a share of contribution of 19.88% compared to the total generated electricity.

By the increasing of the renewable power plant, the fossil-based power plant has less contribution to generated electricity. By RPP scenario, the overall fossil-based power plant has a contribution of 57.38% of the total generated electricity. NGCC, GT, and diesel power plant have a share of 54.06%, 0.38%, and 2.94% respectively compared to total generated electricity. As explained in the previous section, the diesel power plant only generates the electricity in the base year, and it is not economical during the projection periods.

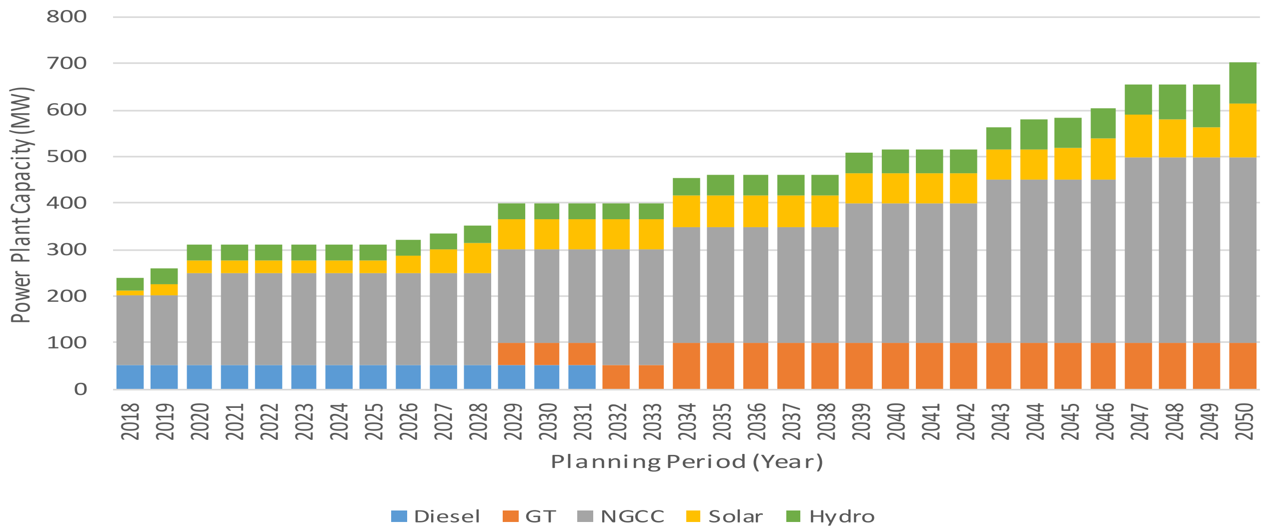

Figure 9. Power plant capacity based on RPP scenario.

Figure 8 and Figure 9 show capacity of the power plant to the system by BAU and RPP scenario, respectively. Based on the BAU scenario, there are two types of power plant technologies that must be built which are GT and NGCC. It is shown in Figure 9 that diesel power plant has been retired in 2031. The total additional capacity of power plant along the projection periods is 600 MW. Capacity addition of power plant consists of GT and NGCC with the capacity for each technology is 50 MW and 550 MW respectively.

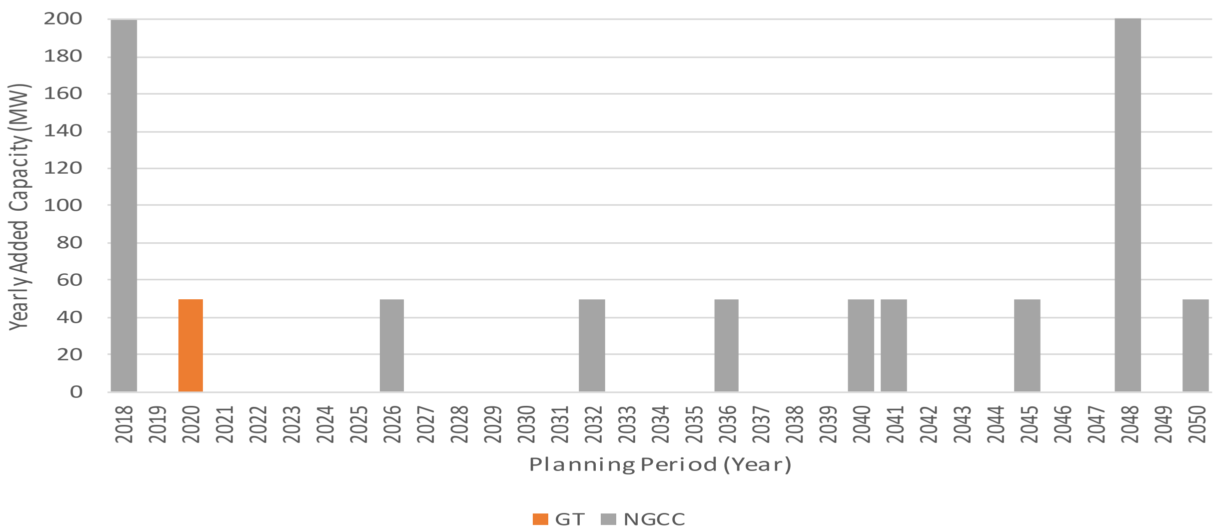

Figure 10. Yearly added capacity by power plant process based on BAU scenario.

The capacity of the power plant along projection periods based on RPP scenario is shown in Figure 9. RPP scenario produces higher value of the total added capacity compared to BAU scenario. Total capacity in the end of projection period by RPP scenario is 705 MW. The higher value compared to BAU scenario is resulted by the parameter of capacity factor for each renewable energy power plant. RPP result 205 MW capacity of renewable energy power plant that consists of hydropower and solar power plant. In the end of projection period, each renewable energy power plant has total capacity of 90 MW and 115 MW for hydropower and solar power plant respectively. For the thermal power plant, GT and NGCC have been chosen by the optimization process. The total capacity of the thermal power plant in the end of the projection period is 500 MW that consists of 100 MW GT and 400 NGCC power plant.

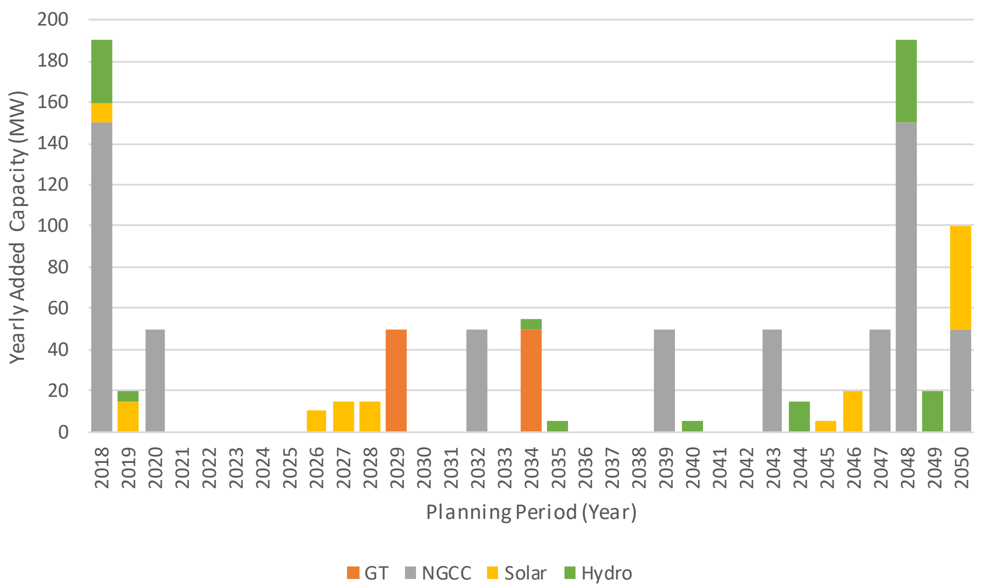

Figure 11. Yearly added capacity by power plant process based on RPP scenario.

The yearly added capacity of each power plant technology is shown in Figure 10 and Figure 11 for BAU and RPP scenario, respectively. The total retired capacity of BAU and RPP scenario is 300 MW and 450 MW, respectively. Based on the BAU scenario, there are 200 MW, 50 MW, and 50 MW capacity of NGCC, GT, and diesel respectively must be retired out of the system in the end of the projection period. Based on the RPP scenario, 250 MW of fossil power plant and 250 MW of renewable energy power plant must be retired in the end of the projection period. The retired capacity of fossil power plant consists of NGCC, GT, and diesel power plant with the capacity of 100 MW, 50 MW, and 50 MW respectively. For renewable power plant, there are 200 MW and 50 MW of hydropower and solar power plant respectively must be retired of the system in the of the projection period. The retirement of power plant capacity is caused by the defined parameter of the lifetime of each power plant technology. All type of power plant technology has equal lifetime which is 30 years.

4.3. Emission

There are three gasses of GHG emission, which are CO_2, NO_x, and SO_2. These three gasses are measured based on their Global Warming Potential (GWP) value. The yearly GHG emission for BAU and RPP scenario is shown in Figure 12. Based on the average value along the projection periods, BAU scenario results in 79.75% higher GHG emission compared to the RPP scenario. In other words, RPP scenario produces 44.13% lower compared to the BAU scenario in average along the projection periods. The average growth rate of GHG emission produces by BAU and RPP scenario to the end of the projection period is 3.51% per year and 2.68% per year respectively.

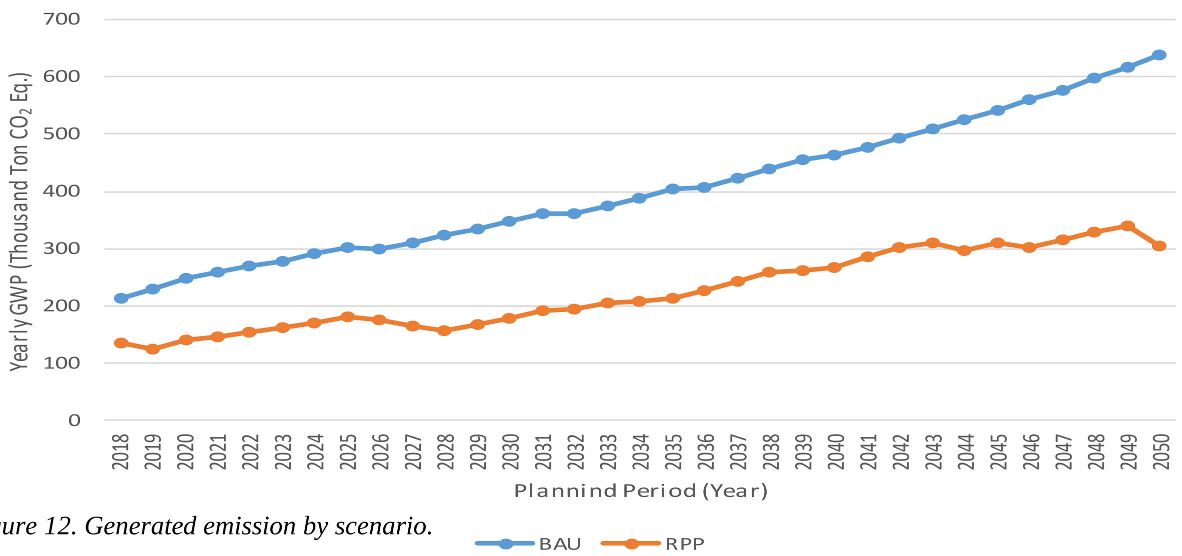

Figure 12. Generated emission by scenario.

Based on BAU and RPP scenario, cumulative GHG emission from 2017 to 2050 is 13,589.91 Million Ton CO_2 Equivalent and 7,694.96 Million Ton CO_2 Equivalent. From the view of cumulative value, RPP can eliminate GHG emission of 43.38% or 5,894.95 Million Ton CO_2 Equivalent compare to the BAU scenario. Cumulative value of GHG emission must be considered to conduct a cost-benefit analysis of the implementation of renewable energy resource as the primary energy of the power plant.

4.4. Cost-benefit analysis

Cos benefit of the implementation of the renewable power plant of the electrical system of West Papua is summarized in **Table 4**. This table is generated by comparing RPP scenario and BAU scenario. Therefore, each value of **Table 4** is the difference between RPP and BAU scenario. The cost of environmental externality by RPP scenario is 63.30 Billion USD less then BAU scenario. GHG saving that can be produced by RPP scenario is 5.90 Million Ton CO_2 Equivalent (cumulative value of GHG emission). Moreover, RPP produces lower Net Present Value of the planning cost of 47.10 Million USD. RPP scenario requires 8 Million USD less compared to BAU scenarios for the elimination of each Ton CO_2 Equivalent of GHG emission. Based on **Table 4**, the implementation of the RPP scenario has advantages compared to BAU scenario from the view of overall planning cost and environmental aspects.

Table 4. Comparison of RPP to BAU scenario.

Aspect	RPP
Environmental Externalities (Billion USD)	-63.3
Net Present Value (Billion USD)	-47.1
GHG Savings (Million Tonnes CO2e)	5.9
Cost of Avoiding GHGs (USD/Tonne CO_2Eq.)	-8

5. CONCLUSION

The role of a renewable-energy based power plant has been analyzed through this study. Electricity demand has been aggregated into four sectors. There are, four types of renewable energy power plant have been implemented in the model and the result of the optimization process shows that hydropower and solar power plan the most appropriate technology to be implemented in the system. Cost-benefit analysis has been conducted to compare RPP scenario and BAU scenario. The result showed that renewable energy potential of West Papua could contribute to generating electricity in meeting the demand. The share of 42.62% of total generated electricity is produced by renewable power plant. Cumulatively, RPP scenario that implements renewable power plant can eliminate 43.38% of GHG emission compared to BAU scenario.

To enhance the developed model, the optimization method can be combined with the uncertainty method to analyze renewable energy power plant in power system expansion planning. Moreover, energy supply chains can be developed based on the optimization method to result in more complex model based on economical, technological, and social perspectives.

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