Department of Mechanical and Aerospace Engineering

Hybrid Renewable Energy System Analysis for Indonesia's New Capital City Electrification

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Abstract

Indonesia current capital city is one of the fastest-sinking cities in the world. It will submerge by 2050 if concrete action is not taken. To address this issue, In August 2019, the Indonesian government announced the new location of new capital would be in East Kalimantan. The government plans to develop a new capital city with a green and sustainable city concept. A crucial issue has emerged with a massive number of people moving to the new capital city, which is energy demand. The new capital city will need additional power plants if energy security wants to be achieved. The total estimated requirement is 1,555 MW. The government highly consider renewable energy option to provide electricity for the new capital city. For this reason, this study tries to investigate the feasible hybrid renewable energy system in terms of economic and environmental aspect through the modelling software.

HOMER is selected to be the modelling software. This study used one-year Jakarta city demand data from 2019 obtained from PLN as an electricity load profile input. The average daily demand in the new capital city forecasted to be 1,387,013 kW, and the peak demand is in October. Relevant assumptions and constraints obtained from the literature review are employed to the simulation. Some parameters in HOMER are also adjusted to match the possible realistic result. There are three scenarios that were simulated using HOMER to get the optimum hybrid renewable energy system and one scenario as the base model with only utilise conventional resources. The results are Solar PV generates higher capacity than any other renewable technology, hybrid renewable energy systems give more stable and well-balanced electricity output. Pumped hydro storage is the suitable storage technology in the new capital city. By using abandoned ex-coal mining pits, pumped hydro storage is capable of storing excess electricity from renewable energy generation.

The 23% hybrid scenario is the realistic choice for the government, as the remaining budget can be allocated to the development of the new capital city. The land selection for renewable energy technology that will not disrupt the surrounding environment in the new capital city is ex-coal mining field in Semboja East Kalimantan. It is an open area with small peat vegetation. Tabang hydropower can be built as long as the environmental impacts can be minimised and contained with adequate mitigation, while Kayan hydropower should be stopped as damming the Kayan river would eliminate endemic species habitats and the inundation impact will vanish homes and livelihood of Kalimantan's indigenous peoples, the Dayak Kayan.

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Chapter 1: Introduction

1.1 Background

Among the many effects of climate change, the increase in sea level is often seen as one of the most threatening. The effects of sea-level rise are straightforward, indicated by more coastal erosion and sea floods occurrence. The rise in the sea level could have major effects on river deltas and could wipe out entire islands and island countries. Indonesia, as an island nation, experiences the impact of these phenomena, especially Jakarta. According to Lin and Hidayat (2018), Jakarta is one of the fastest-sinking cities in the world. It will submerge by 2050 if concrete action is not taken. In August 2019, the Indonesian government announced the new location of new capital would be in East Kalimantan. The relocation decision was taken due to the strain on the Jakarta had become too much. The government plans to develop the new capital city with a green and sustainable city concept ("forest city").

This concept became the answer to the doubt environmentalists. Such doubts are very reasonable; exploitation in East Kalimantan is already at an alarming stage. Deforestation to make way for oil palm plantation has been a problem for a long time. The main issue of land clearing by burning the rainforests, which consist mostly of peatland, is the release of million metric tonnes of carbon dioxide into the atmosphere. According to Indonesian government projection, up to 1.5 million people-mostly civil servants and their families will be transferred to the new capital city. As a result, hundreds of thousands of acres of land will be needed. However, the minister of national planning has promised not to clear any protected forests (Bendix, 2019).

Another crucial issue has emerged with a massive number of people moving to the new capital city, which is energy demand. The Ministry of Energy and Mineral Resources (MEMR) estimates that the new capital city will need additional power plants if energy security wants to be achieved. According to PLN (State Electricity Company) as the only sole provider of electricity in Indonesia, the total estimated requirement is 1,555 MW. However, as per the PLN business plan in 2019, additional power plant capacity until 2024 is only 691 MW. It still needs 864 MW more to guarantee electricity supply plus 30% reserve. The government highly consider renewable energy option to provide electricity for the new capital city. This is in line with the green and sustainable city concept as is often proclaimed by the Indonesian president. Current renewable energy capacity in East Kalimantan is 21.2 MW while the provincial target should be 89.6 MW, but they are not easy to fulfil.

The main challenge is Indonesia power plant dominated by the coal-fired power plant. Moreover, East Kalimantan holds one of Indonesia's largest coal reserves. Current renewable energy plant in the new capital city area is biomass, which is the most common generation in Indonesia. East Kalimantan has another form of renewable resources generation such as wind energy, solar energy, and hydropower that can be utilised. When renewable energy is utilised as the power producer, intermittent supply solution must be well thought out. It is natural characteristics of renewable resources like the sun not always shining, and the wind blows following the seasonal pattern. Suitable backup storage is needed to overcome this problem.

Another issue that should be addressed is the costs. The capital, installation, and maintenance cost of renewable technology is higher than the conventional. The government likely will have a tight budget for developing the new capital city energy system. Hence the most balance between cost and technology scheme definitely chosen. Positive impacts of renewable energy generation mainly reduction of carbon emission generated from electricity production. It also improves public health and the environment as well as energy security. Therefore, this study will investigate the most feasible renewable energy technology to support electricity demand in the new capital city.

1.2 Research Questions

- Can renewable energy system fulfil the 1,555 MW electricity shortage in the new capital city?
- Is the fulfilment of electricity shortages with a hybrid renewable energy system still meet the limit of government budget?
- Can carbon emissions in the new capital city be lower with the entry of renewable energy?
- What type of energy storage that fittingly well for new capital city area?
- Where is the best land selection for renewable energy technology without having to disrupt the socio-ecological system on a large scale?

1.3 Aim and Objectives

The aim of this project is to fulfil the additional need for power in the new capital of Indonesia with renewable energy. The feasible hybrid design combination will be investigated to maximise the utilisation of clean energy resources. Thus, the electrification of the new capital makes less impact on the environment. In order to achieve the aim of the project, the objectives to accomplish the outcome are as follows:

- To estimate the possible demand in new capital using electricity demand in the current capital city of Jakarta as the reference and to forecast the demand growth.
- To identify and analyse renewable energy potential in the research area as simulation data input.
- To investigate and select the most optimum hybrid renewable system using software modelling tools.
- To evaluate and suggest the best system option in regard to environmental and economic aspect.

1.4 Scope of the Project

What will be included in the project:

- Research location will be undeveloped regions in East Kalimantan province between Kutai Kertanegara and Penajam Paser Utara as the proposed area of new capital.
- Indonesia's General Planning for National Energy requires at least 23% renewable fraction generation.
- Possible renewable energy resources in the area included biomass, solar PV, wind energy and hydropower are considerate in the hybrid combination.
- Social and environmental impact is among focus attention when determining hybrid system location.

What will not be included in the project:

- An energy policy that might be changed due to political aspects.

1.5 Methodology

The methodology of this project specifically consists of some steps that need to be taken towards achieving the aims and objectives. These steps are as follows:

1. Analysing Jakarta daily demand profile: Current Indonesia's capital (Jakarta) daily electricity demand in 2019 will be studied to gain information about its variation pattern in different period throughout the year. Future demand will be estimated and will be used as an input for simulation.
2. Identifying available existing power generations: The characteristics and capacity of existing power plants will be classified to understand their abilities and able to manage the energy system with more efficiency. Types of fuel and resource will be carried out to be the base for improvement.
3. Investigate the renewable energy potential at the location: Windspeed, solar radiation and river flow will be examined to get knowledge about its variation and performance range throughout the year.
4. Costs of components: Installation cost, operation & maintenance, and replacement cost of each renewable technology will be determined in order to use for the input parameter of each component.
5. Simulation scenario: HOMER is chosen as the programme for this project, as it can support the optimisation of the hybrid combination design and the provision of emissions and financial data for scenarios.
6. Perform environmental impact assessment: The assessment is performed to get the most unharmful area if it is transformer into renewable technology platforms such as solar farm, wind farm or hydropower facility.
7. Results and Conclusion.

Chapter 2: Literature Review

Indonesia is one of the largest archipelago countries in the world. Located in South East-Asia, the total country area is 8.3 million km^2, comprising of 17,504 islands and 77% water surface (National Mapping Agency, 2018). Most of Indonesia's citizens live on five major islands, namely Sumatra, Kalimantan, Java, Sulawesi, and Papua. In term of electricity services, there is an unbalanced distribution between these islands. Java island where the capital city of Jakarta located, the quality of electrification access is very good. East Kalimantan will accommodate the future capital city of Indonesia, which will be developed on the territory of Kutai Kartanegara and North Penajam Paser. The construction is scheduled to begin in 2020, and complete in 2024. Developing a new city without making environmental sustainability a priority would risk causing the same problems that have plagued Jakarta. Jakarta's air is polluted not only by the badly managed transportation sector but also by many coal-fired powers stations around Jakarta. The new capital is proposed with a green city concept and will be supported by renewable energy. This chapter will elaborate the literature studies related to the study of the potential renewable energy resources along with its supporting technology in East Kalimantan.

Figure 2.1 New Capital City Map (BBC, 2019)

2.1 East Kalimantan Current Electric Power Situation

The electric power system in East Kalimantan is a 150 kV interconnected system between Central and South Kalimantan, which consists of Mahakam and Barito high voltage distribution system along with isolated 20 kV medium voltage distribution. Mahakam network mostly serves the major city in East Kalimantan. For this reason, the development of Mahakam distribution system grew rapidly over the year. In 2018, the Mahakam system was connected with the Barito system where its main function is handling South and Central Kalimantan. By connecting these two large systems, the power supply in the East Kalimantan system, which was originally excess can be channelled to the South and Central Kalimantan system. So, it has an impact on reducing the cost of production by diesel fuel-fired power plants due to the increasing number of operating non-diesel fuel-fired power plants on 150 kV transmission.

Despite the refinement, East Kalimantan still heavily relies on fossil fuels, especially coal as its mainly on-grid power producer and diesel generator sets for off-grid power. The installed capacity of power generation in East Kalimantan as of 2018 is around 1,073 MW. The capacity breakdown by fuel type is shown in Figure 2.2, where 467 MW generated from coal, 374 MW from gas, and 225 MW from diesel fuel. Renewable energy sources take 7.1 MW or only 1% of entire energy production. The State Electricity Company (PLN) dominates the power market, which 88% of installed capacity is yielded by their power plants, whereas the rest 12% is a combination of Independent Power Producer (IPP), Rent, and Excess Capacity (PLN, 2019). These four electrical stakeholders have a different type of power plants prime movers such as steam turbine, gas turbine, and combined-cycle, including gas turbine, boiler and steam turbine and using exhaust gas from the gas turbine to generate electricity. It leads to a disparity of cost and emissions since these two aspects are highly dependent on the fuel used with many still using coal and diesel fuel in this case. The current condition is not ideal for supporting government idea of the new green capital city, which is expected to use renewable resources as one of the primary energy inputs. At the same time, East Kalimantan has massive coal reserve to be utilised. Cooperation between existing power plants and the potential of the renewable energy power plant can be the answer to the dilemma.

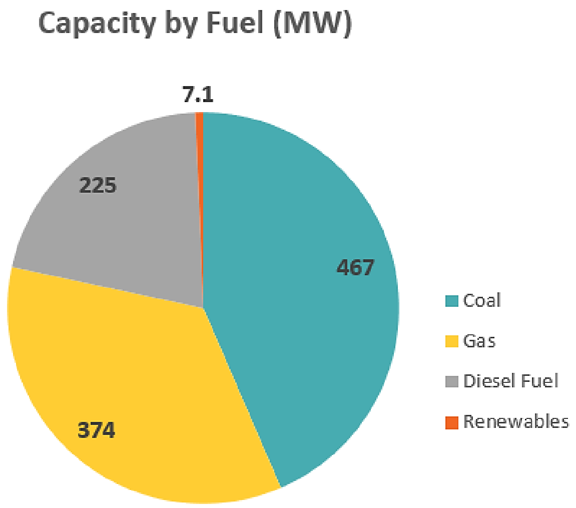


Figure 2.2 East Kalimantan Installed Capacity by Fuel Type

According to Muslimin, Tambunan and Wahyuda (2019), Based on their research to overcome combined economic emission dispatch (CEED) problem using mathematical model, the entry of renewable energy into electricity supplier collaboration has reduced total costs and emissions in East Kalimantan. Economic dispatch (ED) relates to the minimisation of fuel costs by considering the optimal power generation in each power plant unit of the power generation system, while emission dispatch deals with the minimisation of the emission of harmful gas emissions and particulates from the system (Mahdi et al., 2018). The collaboration of PLN, IPP and renewable energy resulted in 2.52% decreased cost during peak load, whereas when low load resulted in 26.23% decreased cost. For emissions, when peak load dropped 1.02%, while when low load down 6.2%. This collaboration produces the smallest total fuel cost to meet all demands and also generates more significant energy reserves than any other supplier combination. Alternatively, a combination of the PLN, Rent, and renewable energy resulted in a cost decrease of 4.9% during peak load, while when low load resulted in 29% decreased cost. For emissions, when peak load down 4.39% while when low load down 8.61%. Although this scenario gives better performance in cost and emission reduction, if there is damage in one of the PLN largest capacity, all available power plant will not able to anticipate the continuity of power supply, unlike the previous scenario. The research results are in line with data released by PLN on its 2019-2028 electricity procurement plan, shown in Table 2.1 that IPP has more capability to provide power supply than Rent owned power plant when combined with PLN owned power plant.

Introduction of renewable energy into the current electrical power system evidently will trigger environmental and economic improvement. It is aligned with the government target to arrange the fulfilment of electricity in the new capital with renewable energy which is expected to exceed the ability of existing power plants. This study will explore the opportunity to boost renewable resources usage in East Kalimantan, knowing the fact that its only 1% of total power production.

Table 2.1 East Kalimantan Power Plant Owner Data (PLN, 2019)

Owner	Power Plant Capacity (MW)					
	Diesel Fired Power Plant	Gas-Fired Power Plant	Combined Cycle Power Plant	Machine Gas-Fired Power Plant	Steam Fired Power Plant (Coal)	Total
PLN	159	180	60	62.8	220	662.3
IPP	-	92	-	-	150	242
Excess	-	-	-	4	53.5	57.5
Rent	47.5	40	-	9.2	-	96.7

2.2 East Kalimantan Current Electricity Demand

Electricity demand pattern is usually unique and has its own characteristics depending on the place, activity and climate. Such an environment of Indonesia generally, East Kalimantan is a tropical climate and has two seasons, dry and rainy seasons. The typical tendency of electricity demand in each season of Indonesia has been widely studied before, one of them is by Akil and Mitani (2017). They used Makassar city as a sample for their seasonal electricity demand forecasting research using fuzzy approach model. Makassar is the largest city in Eastern Indonesia, and its population is similar to the total population of three major cities in East Kalimantan combined. The climate is also relatively the same as throughout the region of East Kalimantan. They used historical hourly data of electricity demand from all user sector in five areas of Makassar and meteorological variables from January to March 2014 for the rainy season, and from June to August 2014 for the dry season.

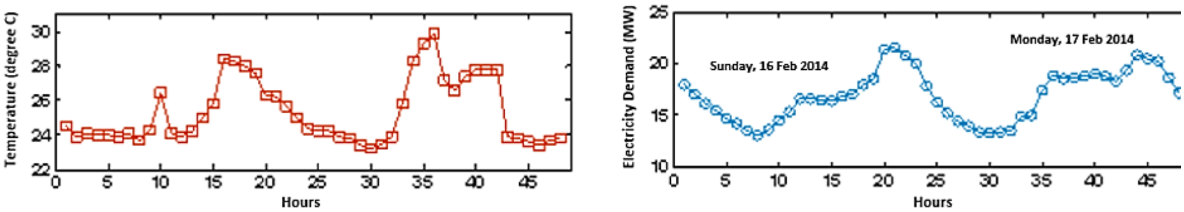


Figure 2.3 Temperature Values and Load Pattern (Akil and Mitani, 2017)

Figure 2.3 shows the usual pattern of tropical electricity load, observed for two days in February and air temperature values for the same days in February. The figure indicates the load demand curve appeared predominantly at daytime, following temperature variability. Amount of daily electricity demand is not constant, with minimum and maximum demand periods. Load demand patterns between holiday and non-holiday have some differences. Further, the load on Monday, particularly during the day, is higher than on Sunday with the highest demand for daytime at 3 pm and at 7 pm for the evening. It means time, temperature, and type of the day, i.e. holiday or non-holiday influence fluctuation of daily load demand.

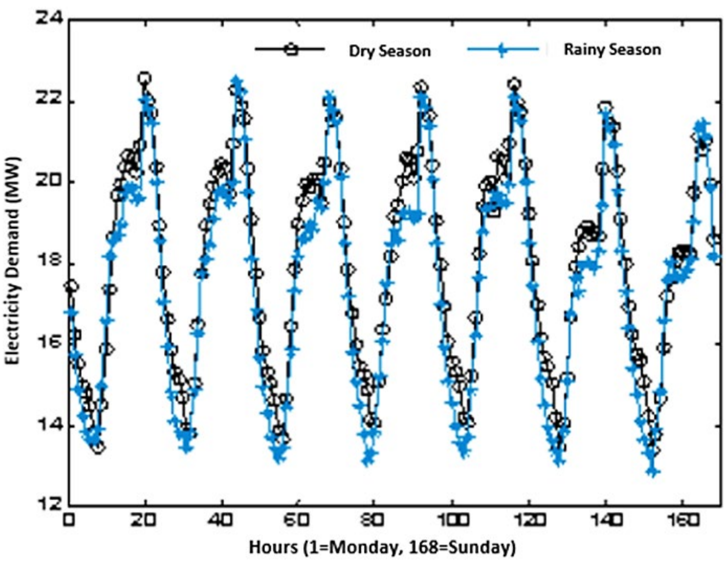


Figure 2.4 Comparison of average daily demand between dry and rainy season (Akil and Mitani, 2017)

Figure 2.4 compares the average daily demand for electricity during the rainy season with the dry season. From Figure 2.4, the load profile is slightly different in both seasons. Daytime electricity demand is comparatively higher during the dry season than in rainy season. The effect of cooler temperature at rainy season reduced the usage of air conditioner at many locations leads to the lower electricity demand.

The Ministry of Energy and Mineral Resources (2019) reported that electricity consumption in East Kalimantan in 2018 reached around 4,935 GWh with the composition of consumption per user sector dominated by the residential sector around 2,585 GWh (52%), business around 1,016 GWh (21%), industrial around 934 GWh (19%), and the public around 401 GWh (8%). The electrification ratio in East Kalimantan reached 100% in 2019.

2.3.1 Discussing the Future Electricity Demand with the Capital movement

The need for electricity in East Kalimantan Province is projected to grow by an average of 7.1% per year in the next ten years or around 7.4% per year for the next 20 years. Based on these projections, the estimated electrical energy needs of around 3,897 GWh in 2019 will increase to 7,243 GWh in 2028 and 15,069 GWh in 2038. In an effort to meet the electrical energy needs and in the context of achieving the national power plant energy mix target, then in the next ten years, an additional power plant will be needed on average around 171 MW per year, and for the next 20 years, the average is around 144 MW per year. With the addition of the power plant, the electricity supply in East Kalimantan will increase from around 1,073 MW in 2019 to around 2,640 MW in 2028 and 3,671 MW in 2038. The power plant will not only supply electricity to East Kalimantan Province but also to other provinces in the same system through the distribution system (MEMR, 2019). The estimation was made without considering the relocation of the capital city to East Kalimantan due to the calculation was performed before the Government ruled the decision.

According to The Indonesian Renewable Energy Society assessment, up to 4,500 GWh of electricity will be needed each year for the new capital to power the daily activities of its 1.5 million residents or equal to slightly more than one-seventh of the electricity consumed by the current capital Jakarta and the Tangerang satellite district (Harsono, 2019). The new evaluation from The Ministry of Energy and Mineral Resources estimates additional power plants with a total capacity of 1.555 MW would be required for the new capital until 2024. The need for electricity is to ensure the efficiency of the supply with a power reserve of 30 per cent (Richter, 2019).

2.3.2 Carbon Emission

At the current moment, the fossil-fuel-based power plant is still the primary producer of electricity in East Kalimantan as it yields a high energy rate with excellent efficiency. Thermal power plant technology is developed based on fossil fuel as this resource dominates the energy market supply. Coal is a cheaper option than oil or gas. The application of coal power plant takes 44 per cent of the East Kalimantan total electricity generation. Expansive mining in the region and government support contributes this number greatly. Combining this with rising energy demand due to rapid population growth from people moving to the new capital, more extensive coal exploitation may be inevitable. Carbon emissions resulted from the combustion process as the main method to generates electricity is harmful to the environment. Carbon dioxide (CO_2) is the primary cause of global warming from its ability to trapped heat from the sun in the Earth's atmosphere. In addition, Indonesia as a country emitted greenhouse gas (GHG) emission for 2.4bn tonnes of CO_2 equivalent ($GtCO_2e$) in 2015, according to data compiled by the Potsdam Institute for Climate Impact Research (Gütschow et al., 2016). The emission for that year represented 4.8 per cent of the overall global emissions in the world (Dunne, 2019). As can be seen in Figure 2.5, for the energy sector specifically, from 2014 to 2016 Indonesia recorded GHG emissions of 538,025 $GgCO_2e$ for the three major greenhouse gases, namely CO_2, CH_4, and N_2O (Boer et al., 2018).

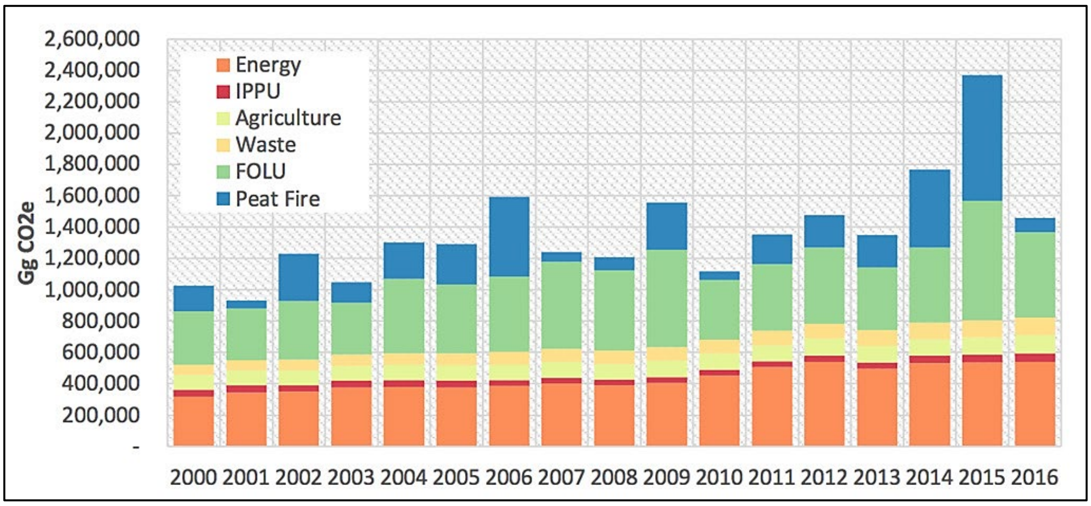


Figure 2.5 Indonesia GHG Emissions Trend in 2000 – 2016 (Boer et al., 2018)

Moreover, based on the projection of electricity generation sector in East Kalimantan using LEAP (Long-range Energy Alternative Planning) software by Kresnawan, Safitri and Darmawan (2018) and Jayadi, Sudiarto and Setiabudy (2019). It can be concluded that if business as usual scenario where diesel, gas machine, steam gas, and gas turbine still dominate the power generation, the CO_2 emission in East Kalimantan will be significantly increased in the future. On the other hand, when renewable energy introduces into the power generation system, the greenhouse gases can be reduced dramatically for the average of 50% from business as usual emissions. The detail information is presented in Table 2.2. To sum up, renewable energy will play an important role in reducing the carbon emission in the forthcoming capital city in East Kalimantan. It is parallel with the Government plan to build an environmentally friendly capital city to sustain commitment at COP-21 in Paris to reduce GHG emissions by 29% by 2030 by self-effort.

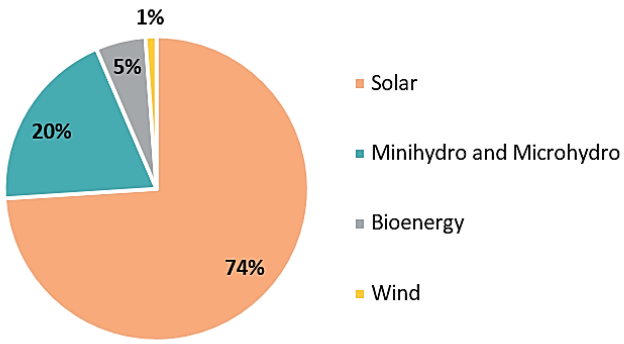
Table 2.2 CO_2 Emission Projection

Author	Emission (million tonnes CO_2 equivalent)		% Reduction	Final Year Projection
	Business as Usual Scenario	Renewable Energy Mix Scenario		
Kresnawan, Safitri and Darmawan (2018)	2.4	1.1	53%	2035
Jayadi, Sudiarto and Setiabudy (2019)	11	5.6	49%	2038

2.4 East Kalimantan Renewable Energy Potential

Renewable energy as replacement of fossil fuel is a promising alternative as renewable energy sources discharge low carbon emissions. Another consideration of renewable energy option is to response the uncertainty and depletion of current energy supplies from fossil fuels. Renewable energy technologies consume energy from non-depletion sources. Examples of renewable technologies are solar energy, wind energy, hydropower, geothermal, and biomass. Most of the renewable energy sources are available within the borders of the country; hence the disruption from international political events can be minimalised. This reason alone is the main attractions factor for the policymaker to start adopting renewable energy technologies. Another reason is the increase in technology affordability due to growing demand for it. Renewable energy supplies should be sustainable since it obtained naturally from surrounding energy flows.

In 2015, Indonesia set the country's target of achieving 23% of primary energy supply from modern renewable energy by 2025, as part of a joint aim set by ASEAN member states. This target also reflected in Government Regulation No. 79 of 2014 on National Energy Policy. According to Directorate General of New Renewable Energy and Energy Conservation, East Kalimantan has a total potential of 18,217 MW from renewable resources. The total breakdown is shown in Figure 2.6. In order to examine their abilities in hybrid combinations, the following section will clarify the potential of bioenergy, hydropower, wind and solar power in East Kalimantan.



Resources Potential (MW)	
Solar	13,479
Minihydro and Microhydro	3,562
Bioenergy	964
Wind	212
Total	18,217
23% Target	4190

Figure 2.6 Renewable Resources Potential Breakdown in East Kalimantan

2.4.1 Bioenergy

A concrete example of bioenergy utilisation in East Kalimantan is the biogas power plant project in Muai Village that has been operational since 2012 and captures biogas from wastewater collection in a palm oil factory. To power the palm oil plant, the biogas is fed to two biogas engines with generator sets with a total capacity of 2.1 MW. The project is CDM-registered and has already issued 27,782 CERs (Global Green Growth Institute, 2015). Prior to the project, electricity was created with a biomass boiler running on palm kernel shell and palm oil fibro, as well as a number of diesel generator sets. The fact that East Kalimantan has 456,145 hectares planted area of oil palm with 7,600,298 ton of production in 2013 (Anderson et al., 2015) is promising to tap energy from the potential number of biomass and biogas.

Table 2.3 Biomass Potential in Kalimantan Region (Directorate of Bioenergy, 2016)

Biomass Type	Feedstock (tonnes)	Power Potential (MWe)
Palm Oil		
Fibre	2,937,137	948
Shell	1,404,718	584
Empty Fruit Bunch	549,169	637
Palm Oil Mill Effluent	12,770,161	331
Frond	23,503,430	5,495
Re-planting	1,128,530	817
Total	**42,293,145**	**8,812**

It is reported by Directorate of Bioenergy (2016) that Kalimantan region has a total potential of 8,812 MW of electricity from palm oil biomass as shown in Table 2.3. Palm oil frond is the largest number produced with the amount of 23.5 million tonnes followed by palm oil mill effluent with the amount of 12.8 million tonnes. These two-biomass type alone can generate 5,495 MWe and 331 MWe, respectively. Fibre palm oil particularly, potentially generates 948 MWe due to established biomass power plant is widely available to use a thermal boiler with good efficiency.

2.4.2 Hydropower

When it comes to hydropower, East Kalimantan is crossed by the Mahakam river, one of the biggest rivers in Indonesia. Its catchment area is approximately 77,100 km^2 makes it a promising resource to build hydropower plant, especially micro-hydro. The study conducted by Susilowati, Irasari and Susatyo (2019) explained that Mahakam watershed is mostly plateau where generally, they have high but variable peak discharges during the rainy season, and a low flow period when rainfall is reduced. Such feature of the Mahakam River with low head and large flow would suit the Low Head Micro-Hydro Technology. From the same study, seven micro hydros combined in the Mahakam river could supply 11,932 kW with runoff river type hydropower plant with the low head turbine.

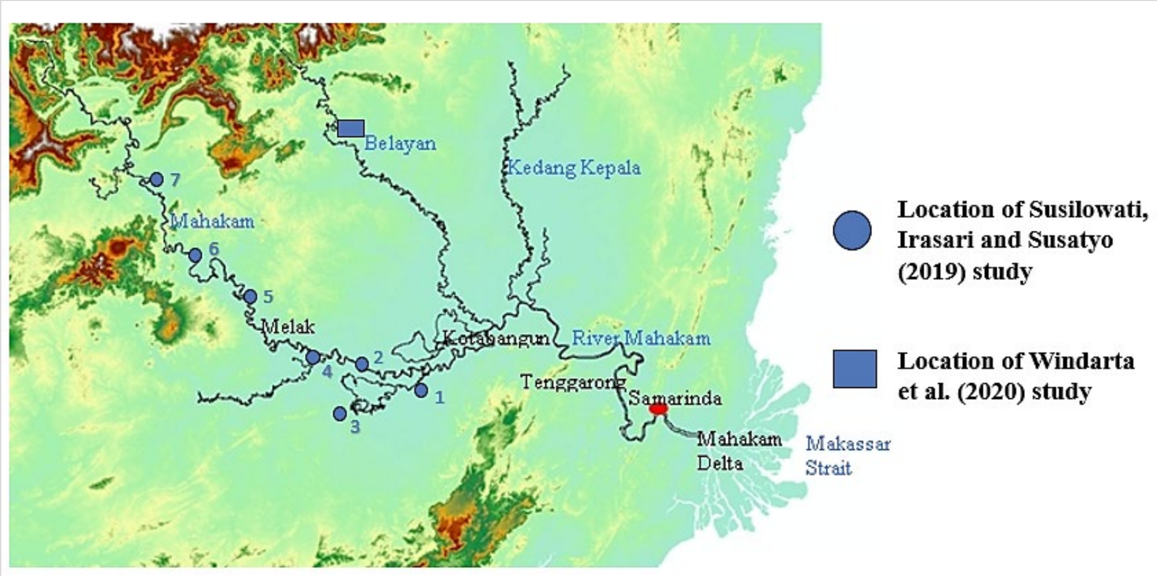


Figure 2.7 Elevation Map of Mahakam catchment area and location of literature studies

Another study conducted by Windarta et al. (2020) in one of Mahakam river tributary, Belayan river, explained that it is possible to build a dam type hydropower in the Tabang area near the new capital city site. They claimed by using dam elevation data of 76.55 m and the water discharge per unit is 106.09 m^3/s, the efficiency of generators produced from water turbines is 97%, the generator can produce an output power of 70 MW, it is estimated four turbines are capable of being installed in the construction thus the total output become 280 MW.

The Indonesian Government is now building Kayan hydropower in North Kalimantan and expected to be finished in 4 years and will generate 900 MW for the first phase. It is planned to channel the electricity produced by the plant to East Kalimantan (Harsono, 2019). However, to build such a big dam will impact the environment greatly, such as the safety of fish and other biotas on the water (Erinofiardi et al., 2017). Many social and environmental impacts had been caused by the construction of a medium to the large-scale hydropower plant is also admitted in Aroonrat and Wongwises (2015) study.

2.4.3 Solar PV Energy

Indonesia has a relatively high solar resource density throughout the region, but another good aspect of Indonesia's solar resource is that it is fairly stable throughout the year. This is different from higher-latitude areas, where seasonal variability is significant. Several climatic factors, mainly solar irradiance and ambient temperature, influence energy production from a PV system (Kunaifi, Reinders and Veldhuis, 2020). Irradiance is the electromagnetic radiation power on a surface, which is expressed in watts per square metre (W/m^2). The higher the irradiance on the module surface, the more energy is emitted. From measurements made during 1981–2018, East Kalimantan ambient temperature was recorded at 36.6 °C. The air temperature affects the performance of PV systems where, at lower temperatures, silicon PV modules transform solar irradiance to higher efficiency in electricity (The World Bank, 2017). As a result, the effects of climate and system parameters on solar electricity have been shown to be significant, particularly on the performance of PV plants.

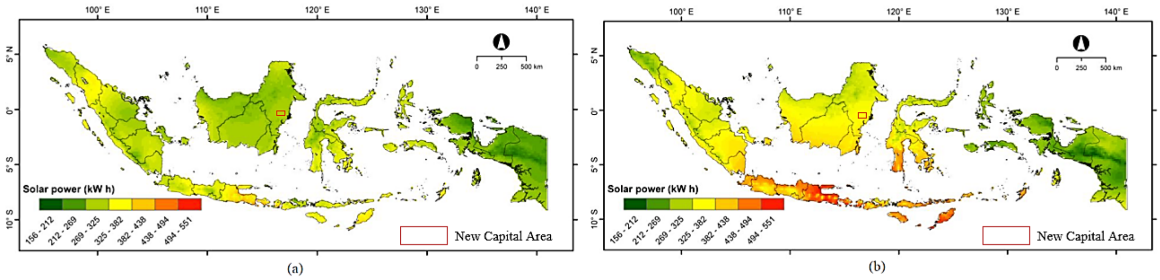


Figure 2.8 Profile of estimated solar energy potential in Indonesia during (a) rainy and (b) dry season (Wahyuono and Julian, 2018)

Based on Wahyuono and Julian (2018) research, Figure 2.8 indicates the profile of solar energy available in terms of practical solar energy potential. The solar irradiation potential has already been converted to the solar energy potential generated by a full PV-battery system with a PV module of 350 watts peak in a 100 m^2 area, and DC/AC inverter efficiency is set at 0.85. During the rainy season, East Kalimantan potentially generates 280 kWh meanwhile during the dry season the power is enhanced to 337 kWh since the clear sky is predominantly available throughout the day. Nonetheless, the power produced is relatively stable in both seasons, and no darker or brighter part of the year was observed.

2.4.4 Wind Power

The implementation of wind energy technology is still low in Indonesia. The total wind power generation installed in Indonesia is approximately 1.6 MW in non-commercial scales. Typically, the implementation of wind energy is for development or research project. In 2018, Indonesia launched its first wind farm in Sidrap, South Sulawesi. The wind farm consists of thirty turbines with total nominal power produced of 75 MW. In addition, Sidrap has suitable topographic conditions for wind energy, with 53% of the total area of 2,506 km^2 comprising hills and mountains giving a speed-up effect and having medium wind speed of 9.39 m/s at 80 m hub-height complement the match to build a large-scale wind farm (Maulidia et al., 2019).

Resources potential	Wind Speed at 50 m , (m/s)	Wind Power dencity, at 50 m , (W/m^{2})	Number of sites	Provinces
Marginal	3,0 – 4,0	< 75	84	Maluku, Papua, Sumba, Mentawai, Bengkulu, Jambi, East and West Nusa Tenggara, South and North Sulawesi North Sumatera, Central Java, Maluku, DIY, Lampung, Kalimantan
Fair	4,0 – 5,0	75 - 150	34	Central and East Java, DIY, Bali, Bengkulu, East and West Nusa Tenggara, South and North Sulawesi
good	> 5,0	> 150	35	Banten, DKI, Central and West Java, DIY, East and West Nusa Tenggara, South and North Sulawesi, Maluku

Source: LAPAN Wind Data .

Figure 2.9 Indonesia Wind Data Summary (Martosaputro and Murti, 2014)

Based on the study by Martosaputro and Murti (2014) shown in figure 2.9 Kalimantan as a whole has marginal wind resources potential. Wind speed available is only 3-4 m/s at 50 m height and wind power density below 75 W/m^2. However, if modern low-speed technology wind turbines are applied, this power could be exploited to achieve potentially 212 MW from wind power in East Kalimantan.

According to Global Wind Atlas, as illustrated in Figure 2.10, the new capital area, especially at hills and plateaus are in the north-west side, the maximum wind speed can reach more than 5 m/s at 100 m elevation. It can be an advantage to make large scale wind farm like Sidrap in South Sulawesi. The average hourly wind speed in Penajam experiences mild seasonal variation over the course of the year. According to weatherspark (2020), The windier part of the year lasts for four months, from June to October, with the calmer time of year lasts for eight months, from October to June. The wind is most often blowing from the south for seven months from April to December and from the north for the rest of the year.

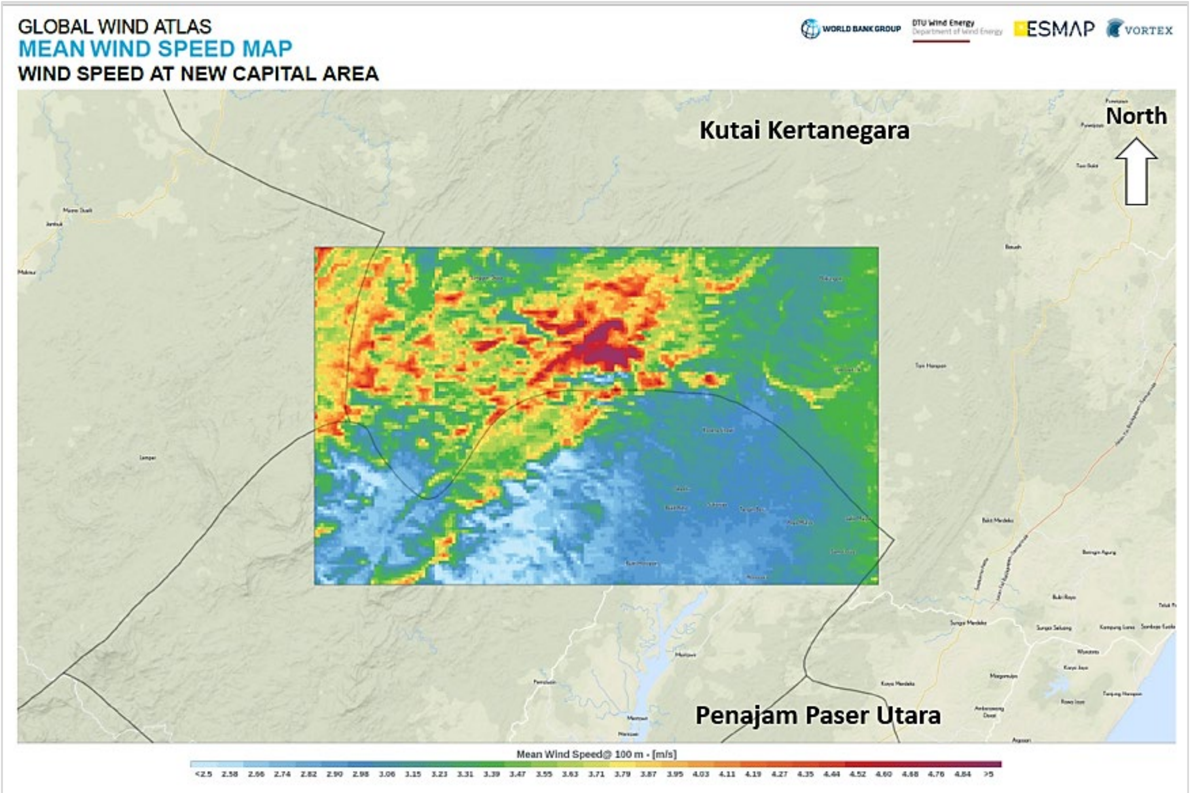


Figure 2.10 New Capital Area Wind Speed at 100 m

2.5 Energy Storage Technology

Renewable resources availability is intermittent and heavily rely on the weather or climate is a fact that is becoming a concern when developing renewable energy technologies. For instance, the availability of sunlight is more abundant during the dry season than in rainy season or the unavailability of the sun during the night. In contrast, river flow is greater during the rainy season than in dry season. Wind speed also tends to slightly higher during the rainy season in Indonesia. Although these phenomenon variations are not drastically different as in the higher-latitude region, the inconsistently available resources can affect the ability of renewable technologies to capture the energy. For this reason, power backup storage is an integral part of the system to achieve self-reliance, where energy is stored when demand exceeds supply and allows the system to supply electricity during peak demand making energy balance achievable. There are currently various storage system technologies available, with pumped hydro, flywheels and lithium-ion batteries are the most common use in the system.

2.5.1 Pumped Hydroelectric Storage

Pumped hydro is a type of storage of hydroelectric energy, consisting of two water reservoirs at different elevations. This configuration can generate power (discharge) as the water moves down through a turbine, and it draws power as it pumps water (charge) from the lower reservoir to the upper reservoir (EERE, 2020). When the electricity demand is above the base-load or in peak situation, the system will engage in discharge mode. Meanwhile, when electricity demand is below the base-load, available energy surplus from another type of power generation such as solar PV and wind turbine will be consumed. As the system change to charge mode to pump the water from the lower reservoir to the upper reservoir. The working mechanism of the pumped storage system is illustrated in Figure 2.11.

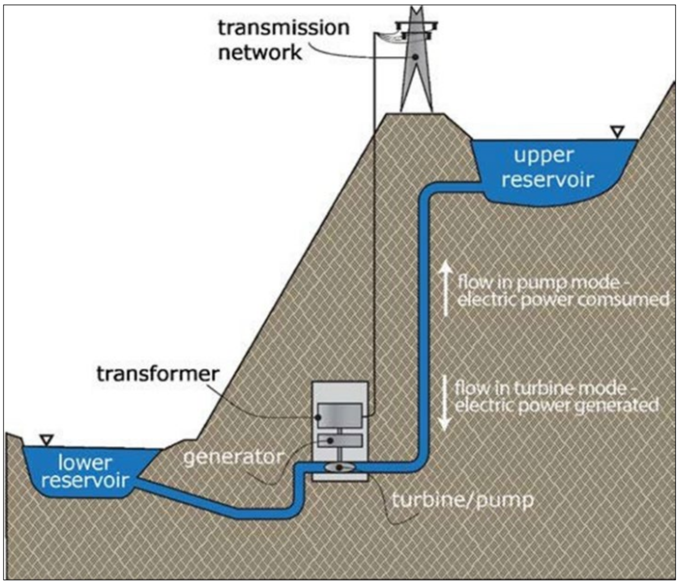


Figure 2.11 Pumped Storage Diagram Scheme (Viadero, Singh and Rehbein, 2017)

The advantage of a pumped hydro system is it does not require high capital cost compared to other forms of storage technologies. However, there are specific criteria to allow this system to function properly. The requirements that have to be fulfilled are water availability and different height geographically. Based on research by Devi et al. (2018), there is an ex-coal mining land in Kutai Kartanagera region near the new capital that potentially can be transformed into pumped storage hydro powerplant. The system starts operating time is projected in 2028 when two ex-coal mining craters is entirely filled by rainwater. From the three designed system made by their team, the highest pumped storage system efficiency that can be obtained is 75.46%. Turbine power produced by the system in their study is not constant at the time. Mainly because the flow rate of the water depends on the hydrostatic pressure, which declines by the time, however, the system can produce 119 MWh during discharge mode and the energy needed when charge mode is assumed to equal to the maximum power produced by the turbine which is 158.7805 MWh.

2.5.2 Flywheel Technology

Flywheel storage systems store input of electric power in the form of kinetic energy. As shown in Figure 2.12, most configurations consist of a rotating shaft, where very small frictional losses store the kinetic energy. A built-in motor-generator increases the flywheel speed to collect energy. The energy is then discharged by drawing down the kinetic energy using the same motor-generator.

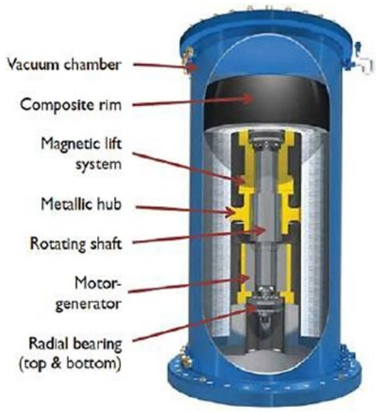


Figure 2.12 Flywheel Diagram (Lin, 2017)

In contrast to other energy storage units, according to Mousavi G et al. (2017), The flywheel has many advantages, including high energy efficiency, quick response time, high instant power, low maintenance, long service life and environmentally friendly features. Meanwhile, the disadvantages of the flywheel technology are considered as follows: instantaneous output is not very high because it uses devices with a permanent magnet in the rotor to remove the losses based on the magnetic coupling in the device.

2.5.3 Lithium-Ion Batteries

Lithium-ion (Li-ion) batteries are powered by lithium-ion motions between positive and negative electrodes. The lithium ions de-intercalate from the positive electrode when charging, and then intercalate through the electrolyte into the negative electrode; at the time, the negative electrode is in a lithium-enriching state. The lithium ions travel in the opposite direction, when the battery is discharged (Zhang et al.,2018). According to Zhang et al. (2018), the high initial capital cost is an important factor that limits the extensive application of Li-ion batteries in grid energy storage. Moreover, in cases where there are substantial charge-discharge randomness and repeated charging, the insufficient cycle life restricts the application of the lithium-ion battery. The fundamental advantage of lithium-based batteries is having a higher potential for energy storage (Zubi et al., 2018).

2.6 HOMER Software

HOMER (Hybrid Optimization of Model with Multiple Energy Resources) is a programme for optimising on-grid and an off-grid hybrid combination of power or microgrid design in all sectors, from small villages and grid-connection islands to military bases and community-scale. In addition, this software evaluates the financial and technical aspects of each possible scenario, allowing users to consider a large number of appropriate options for the availability of energy resources and other variables (HOMER, 2020). HOMER Pro includes the consideration of environmental aspects such as carbon dioxide, sulphur dioxide emissions and particulate matter, which make this tool more efficient in the analysis of the power system even with some limitation in the simulation components.

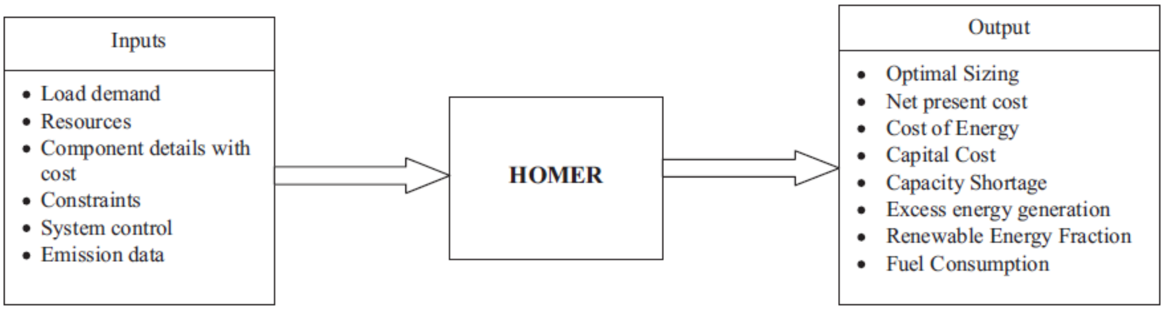


Figure 2.13 HOMER software schematics (Sinha and Chandel, 2014)

Based on a review by Bahramara, Moghaddam and Haghifam (2016), HOMER software is a versatile tool for the design and preparation of the Hybrid Renewable Energy System to assess the optimum size of its components through a techno-economic analysis. Many technologies are modelled in HOMER, such as wind turbine, PV collection, fuel cells, small hydropower, biomass, converters, batteries, and traditional generators. Still from the same review study, HOMER software has been used in developing countries more than other regions. The software itself can handle a wide range of load from 0.626 kW to 2,213,000 kW.

Another study review by Sinha and Chandel (2014) demonstrate that Among the nineteen software tools for the hybrid renewable energy system, HOMER is found to be most widely used, and has a maximum combination of renewable energy systems. The software also capable of performing optimisation and sensitivity analysis; hence it is easier for a user to evaluate many different possible configuration or scenario. In conclusion, HOMER is selected to be the software for simulations as the aim of this project is to find suitable hybrid renewable energy system combination design in order to accomplish the objective of evaluate and suggest the best system option in regard to environmental and economic aspect.

Chapter 3: HOMER Simulation Inputs and Parameters

As it is already mentioned in Chapter 2.6 that HOMER will be used in this study to examine the suitable hybrid renewable energy system combination to electrify Indonesia's new capital in East Kalimantan, it is necessary to determine the input data for modelling the future energy system. HOMER requires four types of data to do the simulation and optimization. These data are electricity load profile, renewable resources, energy generation components and storage technology. The study will use input data that applies to the new capital city project in East Kalimantan carried out from Chapter 2. Relevant assumptions and constraints obtained from the literature review are employed to the simulation due to difficulties to get primary renewable resources data and detailed technical components specification. Some parameters in HOMER are also adjusted to match the possible realistic result.

3.1 Simulation Input Data

The electricity load profile is the key input data to start the simulation; hence the daily electricity demand in the project area is the first criteria to explore before deciding the hybrid combination model. Following that, the model was designed by HOMER based on provided energy generation component data such as solar PV, wind turbine, biomass power plant, and hydropower. Other than renewable energy component, conventional generation from natural gas is also taking into account for the combination, in this case, the gas turbine was chosen. All this generation outputs are backed up by storage technology. This chapter will explain the configuration of components to simulate the new capital city energy system.

3.1.1 Electricity Load Profile

The electricity load profile is a representation of electricity demand in the project area. This study used one-year Jakarta city demand data from 2019 obtained from PLN, the only electricity distributor in the country. Jakarta is the current capital city of Indonesia, and its demand was chosen because it can reflect the future energy demand of new capital. However, the new capital is designed to have less resident and only serve as centre governmental offices without involving too much business activities. While Jakarta has 10 million residents, the new capital will only have one-seventh of Jakarta's population, or roughly about 1.5 million. It is assumed that electricity consumption will follow the total population number and their activities; hence the new capital city will consume much less electricity than Jakarta.

Since the study investigates the hybrid renewable energy system to accommodate the new capital city demand, Jakarta electricity demand during 2019 is used as the basis to calculate future demand. With the East Kalimantan annual demand growth rate of 7.1% for the next ten years, the future demand is determined by the equation below.

$$V2 = \frac{1}{7} V1(1 + r)^n$$

Where r = annual growth rate

n = number of periods (e.g., years)

$V1$ = Jakarta 2019 demand

$V2$ = future demand

Microsoft Excel performed the calculation as the raw data is presented in excel file with one-hour time step. The justification for calculating the demand up to ten years period is because it is likely that the city will attract newcomer resident from the surrounding area and increase electricity consumption. Moreover, 30 per cent energy reserve must be achieved; hence the new capital city demand is calculated using the equation below.

$$NCdemand = V2(1 + 30\%)$$

Where 30% = percentage of energy reserve

$V2$ = future demand

$NCdemand$ = new capital city demand

The calculation results then fed into HOMER as time-series data so the detail consumption within one hour every day in one year can be specifically simulated. As it is mentioned in Chapter 2.2, East Kalimantan electricity demand pattern is influenced by climate, time, and type of the day, Jakarta is no exception. Consequently, the new capital city demand replicates Jakarta's pattern as can be seen in Figure 3.1. The average daily demand in the new capital city forecasted to be 1,387,013 kW, and the peak demand is in October, where the demand reaches 1,939,599 kW.

It is clear that there is a distinctive anomaly in June and August shown in Figure 3.1. In June, the average daily demand, as well as minimum electricity demand, is lower than the rest of the other month. This anomaly was due to the two weeks festive holiday season of Eid Al-Fitr. During that time, most of the townspeople left the city to celebrate the moment in their hometown or went on vacation. Another reason is many offices, and commercial buildings were closed during the holiday. As a result, electricity consumption was drastically decreased. The consumption went back to normal in July.

Meanwhile, in August, the average daily consumption is equal or slightly higher than July, indicating it is normal. But the minimum electricity consumption dropped to zero. The cause that responsible for this discrepancy was Jakarta hit by a massive power outage for almost full day from midday of August 4^{th} to the early day of August 5^{th}. The blackout is the largest in more than two decades caused by disruption of high voltage transmission line in Central Java (Andapita and Sulaiman, 2019). These two occurrences can be another good sample for the model apart from the seasonal variation.

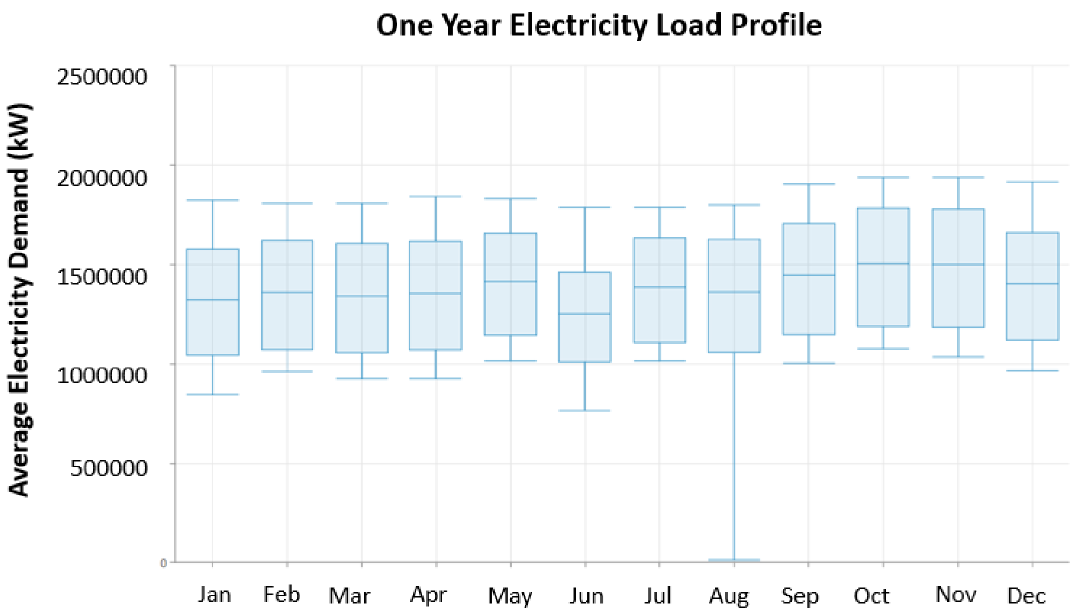


Figure 3.14 one-year new capital city electricity monthly average demand

For the seasonal variation, the average demand is lower in the rainy season than in dry season. The rainy season start from October to March as the pattern is pictured in Figure 3.1, the average daily demand begins to decline in November and drop gradually until January, then increase slightly until March. When dry season starts in April, the electricity consumption begins to climb until reach the highest point at the peak dry season in September. Two typical days in January and September are chosen to demonstrate the daily load pattern of each season for the next ten years. Figure 3.2 shows that for each season, the load pattern has a similar shape where the demand begins to incline rapidly from 5 am in the morning until 11 am. It is then declining mildly from 11 am to 12 pm and start to rise again until it reaches the peak demand at 2 pm. After that, the consumption is decline steadily until tip the lowest point at 4 am in the morning. The peak demand for the dry season is 1,875,668 kW and the rainy season is 1,685,033 kW. Obviously, the demand in the rainy season is lower than in dry season as less extensive air conditioner usage in many buildings and houses due to cooler temperature.

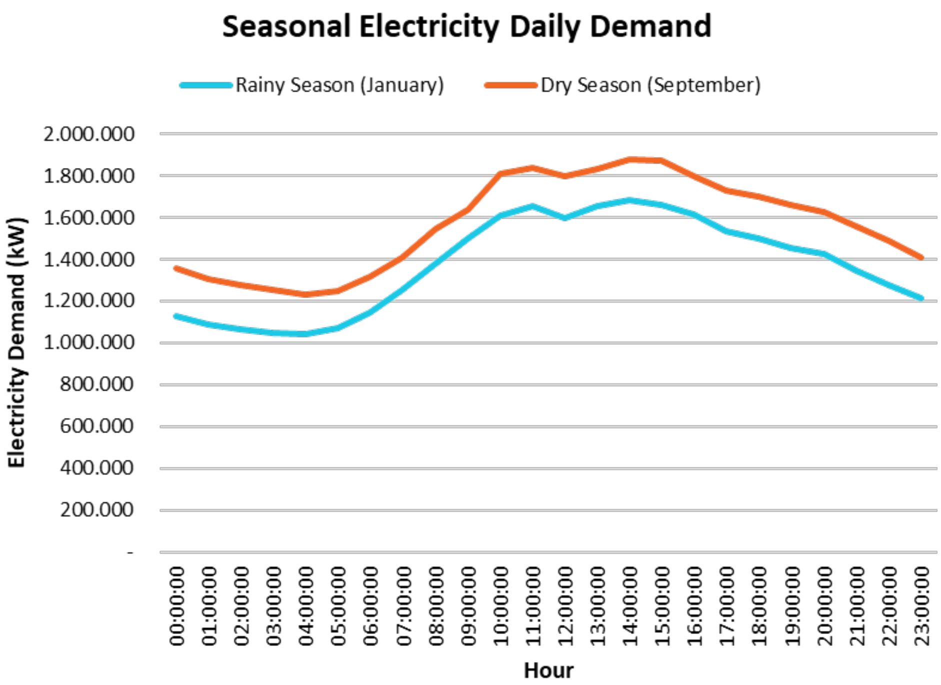


Figure 3.2 daily electricity demand pattern

It is mentioned in Chapter 2.2 that electricity demand pattern is usually unique and has its own characteristics depending on the place, activity and climate. The load pattern is shown in Figure 3.2 indicates that the pattern is heavily influenced by commercial and offices use. For commercial and office buildings, the timing and amount of energy use are the most significant indications of the building's operating patterns (Luo, 2017). Clearly, the heaviest load demand follows the most of commercial workhour building from 9 am to 5 pm, and governmental building from 7 am to 2 pm.

Additionally, the electricity consumption value between office hour and non-office hour does not rapidly decrease, signifies that there is another type of consumer outside the usage of business purposes. Residentials electricity consumptions are high enough to make the load shape not fall abruptly after office hour. As the new capital city most likely will have a lot of office buildings for governmental work as well as houses for the civil servant, the load pattern is suitable for the modelling purpose.

3.1.2 Combined Cycle Gas Turbine (CCGT)

Combined cycle gas turbine is selected to be the conventional resources energy generator for this study. Given the fact that natural gas produces less carbon per unit of energy than coal, a modern CCGT plant that operates optimally at full capacity in baseload mode will generate electricity at a thermal output of 55 per cent compared to a traditional coal or oil plant operating at 35 per cent efficiency. Resultantly, a modern CCGT plant generates just only 40% of the CO_2 generated by a traditional coal-fired power plant and 75% of the CO_2 emitted by a traditional oil-fired power plant for the same amount of electricity production (Bower, 2003). CCGT plant also works well to support peak demand when needed due to its ability to spin the turbine constantly. Another reason is East Kalimantan has the potential of primary energy sources from 11,713.9 billion of standard cubic feet of natural gas that can be used for electric power generation.

However, there is no option for a CCGT plant model in HOMER. Therefore, a gas engine from General Electric (GE) Jenbacher type 6 is selected as the base model; then the specification is modified to replicate a CCGT power plant. The 9HA.02 gas turbine specification from GE is picked as the modifier. The reason why this specific type of gas turbine was chosen is that recently Indonesia installed the 9HA.02 gas turbine to their biggest CCGT plant project as reported by Asian Development Bank (2019) and General Electric (2020). Thus, the assumption is Indonesia capable of affording and implementing this technology. Also, 9HA.02 gas turbine classified as H-class, which means it is an advanced class turbine with better efficiency and fewer emissions.

The capacity of the CCGT plant is 1680 MW and reduce to 571 MW when running in simple cycle mode. These capacities of CCGT plants were applied for four scenarios. According to the US Energy Information Administration report (2019), an H-class turbine combined cycle initial capital cost is 958 $/kW. Still from the same report, the operating and maintenance (O&M) cost of this type of turbine depends on its operating hours. Further assumptions are 1 $/hour for the O&M cost, and replacement cost is fifty per cent of initial capital cost. The 9HA.02 gas turbine detail specification and properties are presented in Table 3.1.

Table 3.4 Combined cycle gas turbine plant model specifications

Specification	Value	Source
Type	Gas Turbine 9HA.02	
Manufacturer	General Electric	
Capacity (MW)	571 (simple cycle) 1680 (combined cycle)	General Electric (2020)
Initial capital cost ($/kW)	958	US Energy Information Administration (2019)
Replacement cost ($/kW)	479	
O&M cost ($/hour)	1	
Minimum load ratio (%)	15	General Electric (2020)
Efficiency (%)	64	General Electric (2020)
Lifetime (hours)	120,000	General Electric (2020)
Fuel type	Natural gas	
Fuel price ($/m^3)	0.2	MEMR (2020)
Fuel curve slope (m^3/hour/kW)	0.1760	HOMER (2020)
Emissions		
Carbon monoxide (g/m^3 of fuel)	Below 25 6.42 (assumption)	Vandervort, Leach and Scholz (2016) HOMER (2020)
Nitrogen oxides (g/m^3 of fuel)	Below 15 13.47 (assumption)	Vandervort, Leach and Scholz (2016) HOMER (2020)
Particulate matter (g/m^3 of fuel)	0.181	HOMER (2020)

3.1.3 Biomass Power Plant

The biomass power plant is one of the renewable energy technologies that already established long enough in Indonesia. From a total of 1.6 GW of bioenergy power capacity, mainly generated from residues and waste in the palm and paper industries, 92 MW was connected to the grid in 2014 (IRENA, 2017). As it is mentioned in Chapter 2.4.1, Kalimantan has a potential of 8,812 MW equivalent from palm oil waste. Particularly for East Kalimantan, 964 MW can be generated from bioenergy. The new capital city can tap this potential to give electricity for the city needs.

According to a report from East Kalimantan Provincial Plantation Service (2019), palm oil production in 2018 is 13,398,363 tonnes. However, based on Abdullah and Sulaim (2013) research on palm oil wastes in Malaysia, 51 per cent from total production available are residues in the form of empty fruit bunch, shell, palm kernel and fibre. Therefore, the assumption is 6,833,165 tonnes of palm oil residues were produced in 2018. As a result, the average biomass availability of 569,430 tonnes per day for each month in one year is fed into HOMER. The number is needed for HOMER biomass resources input data. HOMER assumes the biomass feedstock is fed into a gasifier to create biogas. One or more generators then consume the biogas to produce electricity. Assumption of 1.33 kg/kg gasification ratio is considered from Li et al. (2009) study.

Three different capacity of biomass plants were applied in four scenarios to find optimum power system combination, which are 50 MW, 100 MW, and 200 MW. Based on IRENA (2020) report, the global average bioenergy projects total initial capital cost was 2,141 $/kW in 2019. Likewise, O&M costs are between 2% and 6% of the total capital costs per year. For this study, 4% of the total initial capital cost is selected for O&M costs. Replacement cost is assumed to be half of the initial capital cost. The biomass power plant detail specification and properties are presented in Table 3.2.

Table 3.5 Biomass power plant model specifications

Specification	**Value**	**Source**
Type	Generic biomass	
Capacity (MW)	50, 100; 200	
Initial capital cost ($/kW)	2,141	IRENA (2020)
Replacement cost ($/kW)	1,071	
O&M cost ($/hour)	24.5	IRENA (2020)
Minimum load ratio (%)	50	
Efficiency (%)	32	
Lifetime (hours)	175,200	IRENA (2020)
Fuel type	Palm oil wastes and residues	
Gasification ratio (kg/kg)	1.33	Li et al. (2009)
Carbon content (%)	45	Li et al. (2009)
Fuel price ($/kg)	1	HOMER (2020)
Fuel resources (tonnes/day)	569,430	East Kalimantan Provincial Plantation Service (2019)
Fuel curve slope (kg/hour/kW)	2	HOMER (2020)
Emissions		
Carbon monoxide (g/kg of fuel)	2	HOMER (2020)

Table 3.5 Biomass power plant model specifications

Specification	Value	Source
Nitrogen oxides (g/kg of fuel)	1.25	HOMER (2020)

3.1.4 Hydropower

Chapter 2.4.2 explain that in East Kalimantan, two studies regarding the hydropower potential was conducted. With the information from the study, the input for the hydropower model in HOMER is feasible. Hydropower selection in HOMER is based on a hydroelectric turbine. The turbine is assumed to be Francis turbine in an impoundment (dam) type hydroelectric plant. When well designed, a Francis turbine can capture 90%–95% of the energy in the water (Breeze, 2019). Because HOMER can only consider a single size of the hydro system, data from both literature studies are combined into the model. There are two hydroelectric models in this study. The first one replicates Tabang hydroelectric from Windarta et al. (2020) research, the second one based on Kayan hydroelectric project by the Indonesian government in North Kalimantan. The nominal capacity for these two models is 340 MW and 848 MW respectively and will be applied in four scenarios.

Table 6.3 Belayan river monthly average stream flow rate

Month	Average Stream Flow (L/s)
January	480,100.526
February	458,872.632
March	434,628.947
April	468,775.789
May	460,655.263
June	379,702.632
July	320,176.842
August	295,461.053
September	274,919.474
October	296,691.053
November	440,987.368
December	486,276.842

HOMER needs hydro resources in monthly streamflow rate data. The input data are based on the monthly average discharge generation data in 1990-2008 of Belayan river, one of the main Mahakam river tributaries. These data are provided by the East Kalimantan River Region

III Agency and available in Windarta et al. (2020) paper. Both models use the same resource data because of a lack of available flow rate data for the Kayan River. The average monthly data is presented in Table 3.3. According to Breeze (2019), The Francis turbine design has been used with head heights ranging from 3 to 600 m. Still, it delivers the best performance between 100 and 300 m. Tabang hydroelectric available head height is 80 m based on Windarta et al. (2020) calculation. At the same time, Kayan hydroelectric available head height is 200 m.

Especially for Kayan hydroelectric, the available head height is an assumption refers to Upper Karnali hydropower Project in Nepal since it has a similar capacity with the Kayan hydroelectric model. However, HOMER does not calculate power output from available head height. The available head height is the total available vertical drop between the intake and the turbine. Due to friction losses in the pipeline between the intake and the turbine, the effective head is less than the available head. The pipe head loss is assumed to be 15 per cent.

Based on IRENA (2020) report, the initial capital cost of a hydroelectric project in a country like Indonesia with a capacity of Tabang hydro is 1,630 $/kW, and for Kayan hydro capacity is 1,086 $/kW. For O&M cost of Tabang hydro is 3% of total initial capital cost or 552,624 $/year while Kayan hydro as a larger project have O&M costs of 2% average or 613,651 $/year. Whereas replacement cost is assumed to be half of its initial capital cost. The hydropower plant detail specification and properties are presented in Table 3.4

Table 3.7 hydropower plant model specifications

Specification	Value	Source
Type	Francis turbine hydroelectric	
Capacity (MW)	340 – Tabang hydro 848 – Kayan hydro	Windarta et al. (2020)
Initial capital cost ($/kW)	1,630 – Tabang hydro 1,086 – Kayan hydro	IRENA (2020)
Replacement cost ($/kW)	815 – Tabang hydro 543 – Kayan hydro	
O&M cost ($/year)	552,624 – Tabang hydro 613,651 – Kayan hydro	IRENA (2020)
Available head (m)	80 – Tabang hydro 200 – Kayan hydro	Windarta et al. (2020) The World Bank (1992)
Pipe head loss (%)	15	
Design flow rate (L/s)	480,000	
Efficiency (%)	90	Breeze (2019)
Lifetime (years)	30	IRENA (2020)

3.1.5 Solar PV Panel

Generic flat-plate PV panel option in Homer is selected as the model in this study. Flat-plate PV is a PV array or assembly consisting of flat solar panels. This technology uses direct and diffuse sunlight. In literature review chapter explained that the largest renewable resource in East Kalimantan is from solar energy. As no darker or brighter part of the year was observed in Indonesia and the solar resource is fairly stable throughout the year, the application of photovoltaic technology (PV) to convert these resources into electricity will benefit the future power system.

The utility-scale PV system price in Indonesia is 1,192 $/kW with 15 $/kW for annual operation and maintenance cost (IRENA,2020). Replacement cost is assumed to be fifty per cent of initial system price or 596 $/kW with fifteen years system lifetime. Based on Kunaifi, Reinders and Veldhuis (2020), Indonesia's grid-connected PV performance ratio (PR) is estimated at 75 per cent for urban centres and 80 per cent for suburban areas. Owing to higher temperatures and environmental shading, the PR for urban centres is expected to be 5% lower than for suburban areas. For this study, 80 per cent PR is considered as input parameter since the new capital city most likely will not have a lot of skyscrapers in its first ten years of development. HOMER needs average monthly global horizontal solar radiation and clearness index as the resource data for calculating the output power of PV panels. In the simulation, these resource data are provided by NASA Surface meteorology and Solar Energy database. The resource data is extracted from monthly averaged values over twenty-two years period from July 1983 to June 2005, which are presented in Figure 3.3 below.

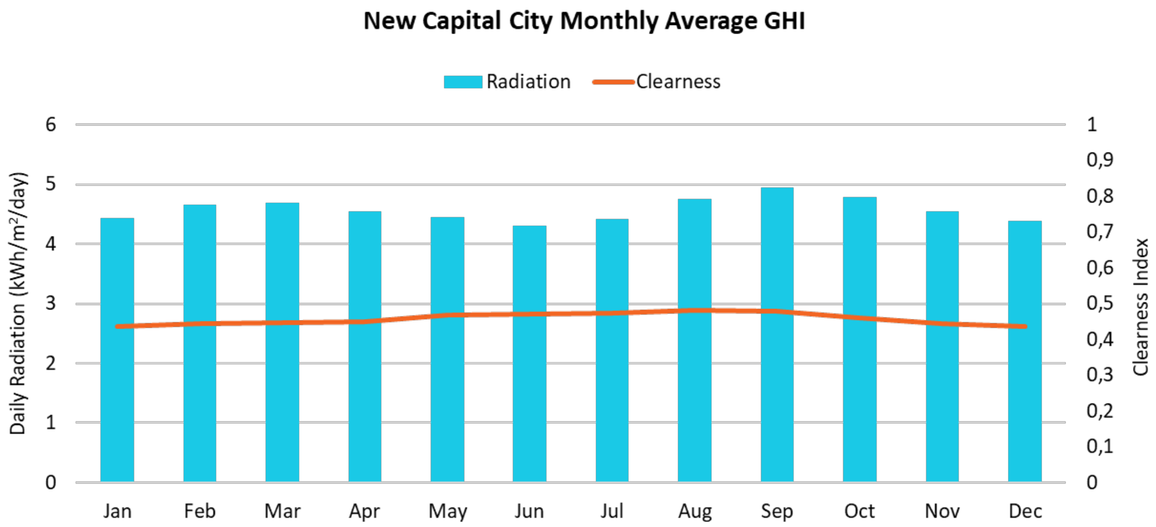


Figure 3.3 Monthly average solar Global Horizontal Irradiance (GHI) data (NASA, 2020)

Global Horizontal Irradiance (GHI) is the total incident to horizontal surface solar radiation. This is the sum of DNI, Diffuse Horizontal Irradiance and ground-reflected radiation. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. The clearness index is a level measurement of the clear atmosphere in a particular area. The value clearness index is determined from 0 to 1 range and defined as the ratio between surface radiation and extra-terrestrial radiation. A higher value indicates clear sunny conditions and the lower value indicates cloudy conditions (HOMER, 2020). The area in the new capital city has fairly stable daily radiation and clearness index throughout the year. Clearly, in the dry season, the daily radiation and clearness index are slightly higher than in the rainy season, but the difference is not significant. With average daily radiation of 4.58 $kWh/m^2/day$ and average clearness index of 0.46. This condition is ideal for solar PV to generate electricity in a decent amount.

3.1.6 Wind Turbine

There are many options for wind turbine model in HOMER. For the simulation in this study, Enercon E-53 800 kW is selected as one of the renewable technology components in a hybrid power system. Initial capital cost and O&M cost are based on research from Open Energy Monitor (2020). Replacement cost is assumed to be half of the initial capital cost same with other components in this study. The wind turbine detail specification and properties are presented in Table 3.5.

Table 3.8 wind turbine model specifications

Specification	Value	Source
Type	Enercon E-53	
Capacity (kW)	800	
Initial capital cost ($/kW)	3,628	Open Energy Monitor (2020)
Replacement cost ($/kW)	1,814	
O&M cost ($/year)	111,200	Open Energy Monitor (2020)
Hub height (m)	73	
Lifetime (years)	20	

Enercon E-53 selection background is because the cut-in speed is lower than the other option, and the hub height is high enough to get faster wind speed. This combination is suitable for new capital city surrounding area with low wind speed, as explained in the literature review, Kalimantan as a whole has a marginal prospect of wind speed.

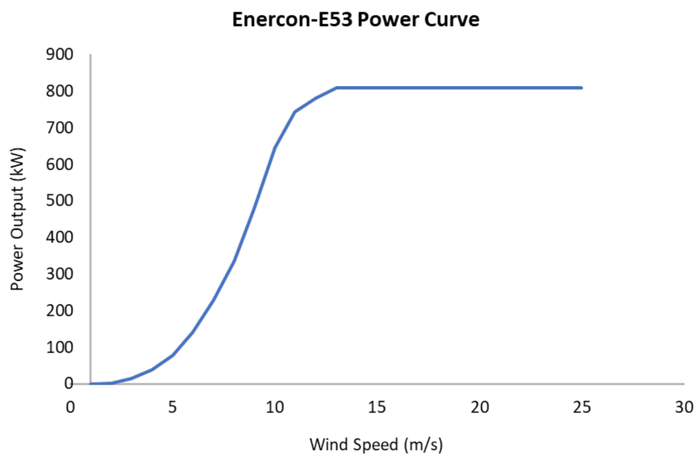


Figure 3.4 Enercon-E53 power curve

Figure 3.4 above illustrates the power curve of the Enercon E53 wind turbine. The turbine begins to generate power when speed exceeds 1 m/s. The output power increases rapidly until it hits maximum power output at 13 m/s and remain static at an output power of 810 kW. It stops produces power when the wind speed blows more than 25 m/s to fulfil the safety aspect. Wind speed resource data is needed by HOMER to simulate the wind turbine model. The data is provided by NASA Surface meteorology and Solar Energy database similar to solar GHI data in the previous section. The new capital city average wind speed data is shown in figure 3.5.

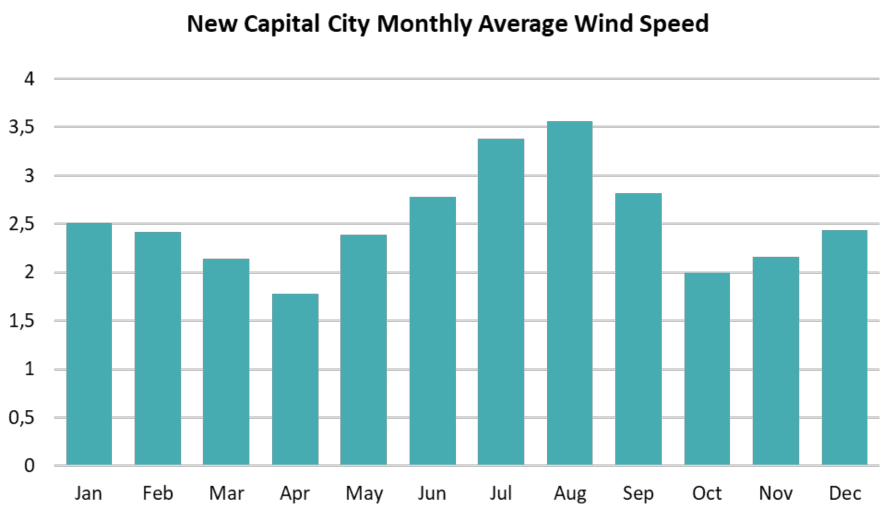


Figure 3.5 New capital city average wind speed (NASA. 2020)

Figure 3.5 presents the monthly average wind speed in the new capital city. It is worth mention that the anemometer height was 50 m when measuring the wind speed data. The wind turbine in this model is higher than the anemometer; hence it gets the faster speed to generate electricity. From this data, it can be concluded that the wind turbine will generate more electricity in the dry season for four months from May to August. However, likely, the wind turbine power output will not be at the maximum level of 800 kW for the whole year due to the available wind speed is lower than the specification needed. Nonetheless, it still produces higher power output than another option in the HOMER with lower cost and lower cut-in speed. Hence it is the most balance between performance and financial aspect.

3.1.7 Storage Technology

Pumped hydro storage option in the HOMER is selected for the simulation in this study. From the initial simulation to determine which the better performance to cost ratio between pumped hydro storage and Lithium-ion battery, the pumped hydro storage gave a better result.

According to Immendoerfer et al. (2017) pumped hydro storage, tends to hold large volumes, has far higher energy to performance ratios than a battery, and is able to provide long-term services, to compensate some degree inter-seasonal fluctuations.

The other justification to choose pumped hydro storage is based on research by Devi et al. (2018) that utilize ex-coal mining pits to become pumped hydro storage. According to BBC Indonesia (2019), there are at least five hundred ex-coal mining pits claimed by the Indonesian government in East Kalimantan. With this potential site, it is assumed that pumped hydro storage can be built more than one. The generic model in the HOMER is modified to replicate Devi et al. (2018) pumped hydro storage performance with 150 MWh capacity. The pumped hydro storage detail specification and properties are presented in Table 3.6.

Table 3.9 Pumped hydro storage specifications

Specification	Value	Source
Type	Pumped hydro storage	
Initial capital cost ($)	1,342,314	IRENA (2020)
Replacement cost ($)	30,507	IRENA (2020)
O&M cost ($/year)	122,029	IRENA (2020)
Lifetime (years)	50	Immendoerfer et al. (2017)
Reservoir (m^3)	1,417,570	Devi et al. (2018)
Pipeline (m)	755	Devi et al. (2018)
Operation Time / Cycle (hrs)	10	Devi et al. (2018)
Energy Produced (MWh)	150	Devi et al. (2018)
Energy Needed by Pump (MWh)	233	Devi et al. (2018)
Roundtrip Efficiency (%)	64	Devi et al. (2018)
Assumption Generator (V)	240	
Max. Charge Current (A)	62,285	
Max. Discharge Current (A)	62,285	

3.1.8 Converter

A converter is a device that converts alternative current (AC) to direct current (DC) or vice versa. Because the solar PV and pumped hydro storage are on the DC side, and power generations are on the AC side in the power system, hence the system requires a converter. The generic system converter is chosen in HOMER to simulate the model. The initial capital cost and replacement are set to $300 with fifteen years lifetime and 95 per cent efficiency.

3.2 Economic Parameters

The project lifetime is determined to be 20 years for all hybrid system simulation scenarios. The nominal discount rate is assumed to be 8.5% with the expected inflation rate for this study is set to 3.47% based on Bank Indonesia (2020) inflation data from 2015 to 2019. From these two parameters, the real discount rate for the simulation is calculated at 4.86%. The real discount rate is aligned with Bank Indonesia average discount rate data from 2016 to 2019.

3.3 Project Constraints

The simulation constraints of the minimum renewable fraction are set to 23%, 50%, and 100% for each designated hybrid system simulation scenario. Operating reserve is determined to 10% from peak demand in all hybrid system scenarios, although the electricity load input itself already added with 30% reserve.

3.4 Energy System Simulation Scenarios

In order to get the most suitable and optimum hybrid energy system, four different configurations scenario are simulated in this study. The first scenario uses only conventional power generation and follows business as usual arrangement from PLN electricity procurement plan, as already mentioned in Chapter 2. This scenario fully utilizes CCGT as the main source of electricity in the new capital city. However, this scenario is not an option for the solution of this study, and the sole purpose of this scenario is only just as a base model to be compared with another scenario. The second scenario follows the 2025 government target to achieve 23% energy generation from renewable resources. Investigation of suitable hybrid energy system if the government renewable energy target increase to 50% is where the third scenario simulation is based on. The last or fourth scenario follows the recommendation from Indonesia Renewable Energy Society, where the new capital city power is fully supported by renewable energy. The scenario is summarised in Table 3.7 below.

Table 3.10 Summary of modelling scenario

Scenario	Configuration	Summary
Scenario 1: Business as usual (base model)	CCGT power plant	Based on the Electricity Procurement Plan 2019 by PLN.
Scenario 2: Hybrid energy system with 23% renewable fraction	CCGT power plant Biomass power plant Hydropower plant Solar PV panels	Based on the 23% target in National Electricity General Plan 2019 by Ministry of Energy and Mineral Resources.

Table 3.10 Summary of modelling scenario

Scenario	Configuration	Summary
Scenario 3: Hybrid energy system with 50% renewable fraction	Wind turbines Pumped hydro storage Converter	Scenario if the renewable energy target increase in the future.
Scenario 4: Fully renewable energy system	Biomass power plant Hydropower plant Solar PV panels Wind turbines Pumped hydro storage Converter	Based on the recommendation by Indonesia Renewable Energy Society that the new capital city can be supported by one hundred per cent renewable energy (Harsono, 2019).

Chapter 4: Results and Discussions

This chapter presents the results and discussions of the HOMER simulations in this study. As already mentioned in Chapter 3, three different simulation scenarios and one base model scenario were created to investigate the suitable energy system in the new capital city. Each scenario then analysed to find the optimum result. These four power generation options will be subsequently presented and then compared, to obtain the most optimum performance, economic and environmental aspects. The performance of the energy system was analysed by two elements, capacity shortage and excess electricity. A capacity shortage is a shortfall that occurs between the operating capacity required and the actual operating capacity the system can provide. Excess electricity is extra or surplus electricity that must be discarded (or reduced) because it cannot serve a load demand or stored in storage technology.

The financial factors taken into consideration were initial capital cost, cost of energy (COE) and net present cost (NPC). Initial capital cost is the total cost of the component installed at the project start. Cost of energy is the average cost per kWh of useful electrical energy produced by the system. The net present cost is the present value of all the cost the energy system incurs, including capital costs, replacement costs, O&M costs minus the present value of revenue earn over its lifetime. The environmental evaluation is taken by CO_2 emissions generated by the hybrid energy system compared to the conventional energy system in the base model.

The last section on this chapter consists of the answer to the research questions based on the result and discussion of each scenario as well as the environmental impact assessment of proposed area selection for the nominated energy system.

4.1 Business as Usual Scenario (Base Model)

This scenario is based on the Electricity Procurement Plan 2019 by PLN as it is reported that PLN will increase the power plant capacity in East Kalimantan dominantly still by fossil fuel. As coal-fired power plant model is not available in HOMER, CCGT is selected for this scenario. The reason behind CCGT selection is because, on the Electricity Procurement Plan 2019, PLN planned to utilise more natural gas for their future power plant besides by only using coal. Natural gas will become the second-highest fuel utilisation. This scenario is considered to be standard to compare with other scenarios with a renewable energy mix, especially for the CO_2 emission since this scenario use one hundred per cent conventional energy from natural gas. The business as usual scenario consists of two CCGT power plants with each capacity of 1680 MW to supply electricity load.

4.1.1 Business as Usual Scenario Results

Table 4.11 Business as usual scenario detail results

Electricity Production	Value
CCGT-1 (MW)	1,307 (94.2%)
CCGT-2 (MW)	252 (5.79%)
Economic	**Value**
Initial capital costs ($)	3.22 billion
NPC ($)	11.4 billion
COE ($/kWh)	0.074
System Performance	**Value**
Renewable fraction (%)	0
Capacity shortage (%/year)	0
Excess electricity(kWh/year)	1,454,196 (0.012%)
Unmet Electric Load (kWh/year)	0
Emissions	**Value**
CO_2 production (tonnes/year)	4.13 million

4.1.2 Business as Usual Scenario Discussion

Based on the result of the business as usual model scenario, the average daily consumption of 33,288,312 kWh is proven can be supplied by two CCGT power plant. As for electricity production, CCGT-1 produced 94.2% of the total capacity, while CCGT-2 only take 5.79%. The CCGT power plants give an excellent performance to accommodate load variation throughout the year since it can vary the power output instantly when needed at peak demand and also can generate stable energy supply. Hence, the capacity shortage and unmet demand are zero in this scenario. Despite the excellent performance, the CCGT-2 capacity is not fully utilised and only running in simple cycle mode with 252 MW power generation.

Meanwhile, CCGT-1 is almost running in full capacity with 1,307 MW electricity production. As a result of massive blackout replicates in the electricity load model, this scenario has an excess capacity of 1,454,196 kWh/year or only 0.012%. The illustration of the CCGT power plant generation is shown in Figure 4.1.

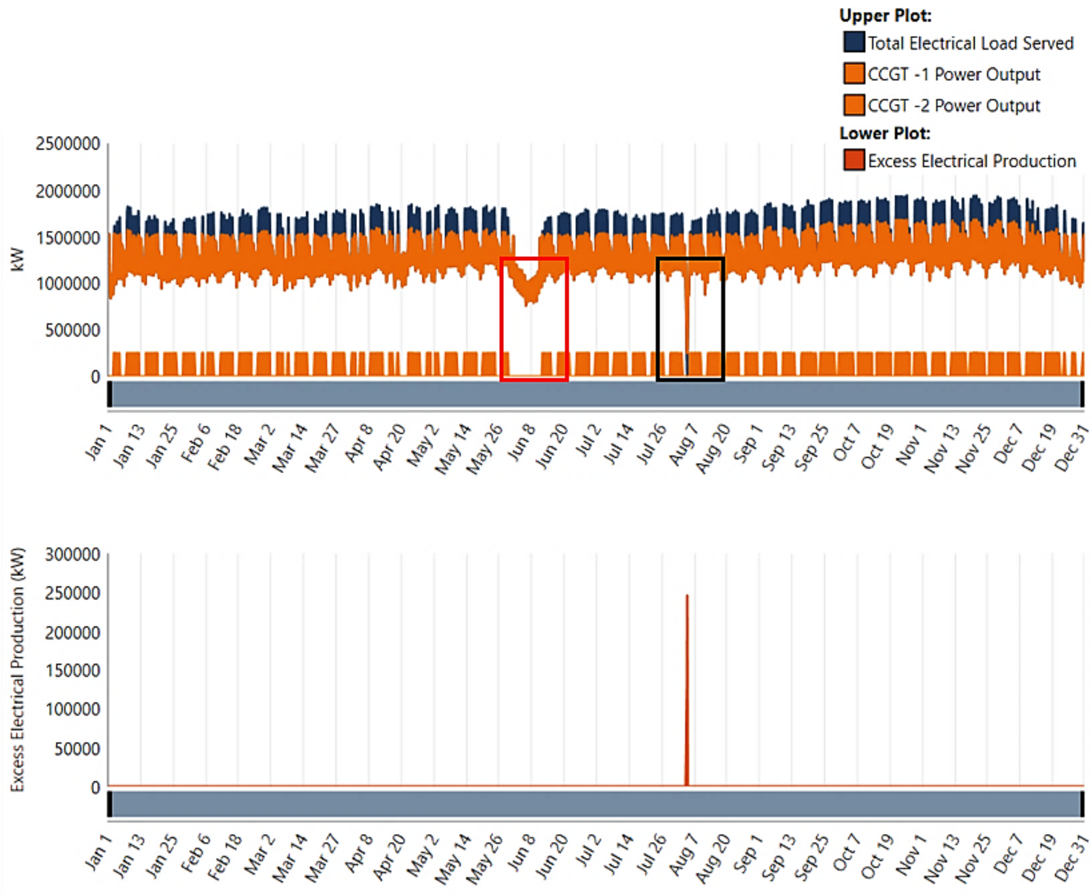


Figure 4.15 Scenario BAU power output in one year

As it can be seen in Figure 4.1, CCGT-1 power output varies throughout the day and resemble the electricity load pattern, while the CCGT-2 responsible is to support when the electricity load reaches its peak demand with additional 252 MW. The red box indicates two weeks holiday season, and the electricity demand decreases greatly with no peak demand observed. In this condition, CCGT-2 does not generate power and CCGT-1 lower its production. The black box shows massive power outage in the electricity load model. As the CCGT plant runs with a minimum load ratio of 15%, consequently during the power outage where zero load is produced, the CCGT plant yields excess electricity due to the demand being below its intended minimum load ratio.

In regards of COE, in December 2019, the price of electricity in Indonesia is 0.100 $/kWh for households, 0.071 $/kWh for businesses, and the average is 0.094 $/kWh. The COE of this scenario is 0.074 $/kWh, only fraction higher than the electricity price for businesses but its decently cheaper than the average price of electricity in the country even from household's electricity price. The new capital city inhabitant will get benefit from the cheaper COE as most likely the place will be occupied by civil servants who have just been transferred and plan to settle permanently.

This model COE can be a representation of Indonesia's current energy system price where it is still dominated by fossil fuel, mainly coal. It is found to be interesting by using more advance type of fossil fuel generator like an H-Class CCGT power plant in this model. The detail specification can be seen in Chapter 3.1.2. The COE difference is not significantly higher. Even though the model has some assumptions, but it is worth for PLN to consider at least to use more natural gas instead of coal as a future energy system in the new capital city. With the initial capital cost of $3.22 billion and in return of $11.4 billion NPC, the investment surely turns to high profit as revenue surpass the cost throughout the project lifetime.

In contrast with the advantages of stable power generation and economic gain, the environmental aspect clearly took a hit with 4.13 million tonnes/year of CO_2 emission. This result makes the business as usual scenario is not the first option for the new capital city electrification as the government design the city with an eco-friendly concept with green energy initiative. Public acceptance will be violated if this scenario gets nominated.

4.2 Hybrid Energy System with 23% Renewable Fraction Scenario

This scenario follows the 23% target of renewable energy generation in National Electricity General Plan 2019 by Ministry of Energy and Mineral Resources. The scenario configuration composed of power generation technology both from conventional and renewable resources, storage technology, and converter. Conventional power generation is from CCGT; renewable power generation consists of biomass, hydropower, solar PV, and wind turbines. Pumped hydro storage represents storage technology.

This scenario has both alternating current (AC) and direct current (DC) side in the system. All of the power generations are on the AC side except for solar PV. Along with pumped hydro storage, solar PV is on the DC side where together, both AC and DC side is connected by the converter. The converter can act as an inverter to change DC input from both solar PV and pumped hydro storage to AC output and then feed into the electric load. The converter also can perform as rectifier where AC supply from the power generation is converted into DC output and then use the power to operate the pumped hydro storage if the surplus electricity is available.

4.2.1 Hybrid Energy System with 23% Renewable Fraction Scenario Results

Table 4.12 Scenario 23% renewable fraction configuration detail

Components	Quantity	Rated Capacity	Mean Production (MW)	Capacity Factor (%)
CCGT	1	1,680 MW	1,068 (76.9%)	63
Biomass power plant	1	50 MW	50 (3.6%)	100
Tabang hydropower	1	340 MW	240 (17.3)	70.8
Solar PV	198,322	198 MW	30 (2.18%)	15
Wind turbine	50	800 kW	1 (0.02%)	3
Pumped hydro storage	49	150 MWh	-	-
Converter	2,381	100 kW	-	-

Table 4.13 Scenario 23% fraction renewable detail results

Economic	Value
Initial capital costs ($)	2.68 billion
NPC ($)	7.17 billion
COE ($/kWh)	0.047
System Performance	**Value**
Renewable fraction (%)	23
Capacity shortage (%/year)	0
Excess electricity(kWh/year)	1,576,666 (0.013%)
Unmet Electric Load (kWh/year)	0
Emissions	**Value**
CO_2 production (tonnes/year)	3.18 million

4.2.2 Hybrid Energy System with 23% Renewable Fraction Scenario Discussion

As presented in Table 4.2, in order to achieve 23% renewable energy generation in the new capital city, the configuration that will be needed to extract electricity consists of one CCGT power plant, one 50 MW biomass power plant, Tabang hydropower with a capacity of 340 MW, 198,322 of solar PV panels, 50 units of wind turbines, 49 pumped hydro storage sites, and 2,381 of converters. Electricity generation still dominated by the CCGT power plant with 76.9% or 1068 MW from total system production. Tabang hydropower comes second with 17.3% portion worth of 240 MW. It is followed by the biomass power plant with 3.6%, then solar PV, and the least is the wind turbine. When it comes to capacity factor, biomass is fully utilised in this scenario with 100% capacity or all of 50 MW available. Tabang hydropower use only 70.8% of its total capacity and followed by the CCGT power plant with 63%. In this scenario, solar PV average production is 30 MW per day for one year and only exploits fifteen per cent of its total capacity. For the wind turbine, the average electricity output is 1 MW per day and its capacity factor only three per cent. The reason why electricity production by wind turbine and solar PV is smaller than other types of renewable technology is due to intermittent resources during the day. The specific reason for the wind turbine, the high wind speed to generate significant power only last four months from June to August and also in January the high wind speed only decent.

For the economic investigation, The COE in this scenario is significantly cheaper than the conventional energy model. With the COE at the price of 0.047 $/kWh, it is even more economical than the actual cost of electricity in Indonesia. This scenario would benefit the government as well as the new capital city resident. With a lower cost of energy, the new capital city would have the bargain to bring other people outside civil servants who have just been transferred. This condition could lead to a better economy and development in the new capital city, the initial capital cost to build this system also lower with only $2.68 billion compared to $3.22 billion on business as usual scenario. However, the NPC is lower than the base model with only $7.17 billion. Still, the investment turns to profit, but with more complex renewable technology overall costs, particularly O&M costs, it affects the revenue gain during the project lifetime.

In term of system performance, this scenario achieves zero per cent capacity shortage. Excess electricity as a result of replicated massive blackout in the electricity load model is only 0.013%. The environmental aspect also gets better with the introduction of 23% renewable energy to the system. As a result, the CO_2 emission reduces to 3.18 million tonnes/year. The hybrid combination between CCGT power plant and 23% renewable energy is proven to give power supply with no shortfall and insignificant excess electricity. The characteristics of this scenario energy system with seasonal variation are presented in Figure 4.2 and 4.3.

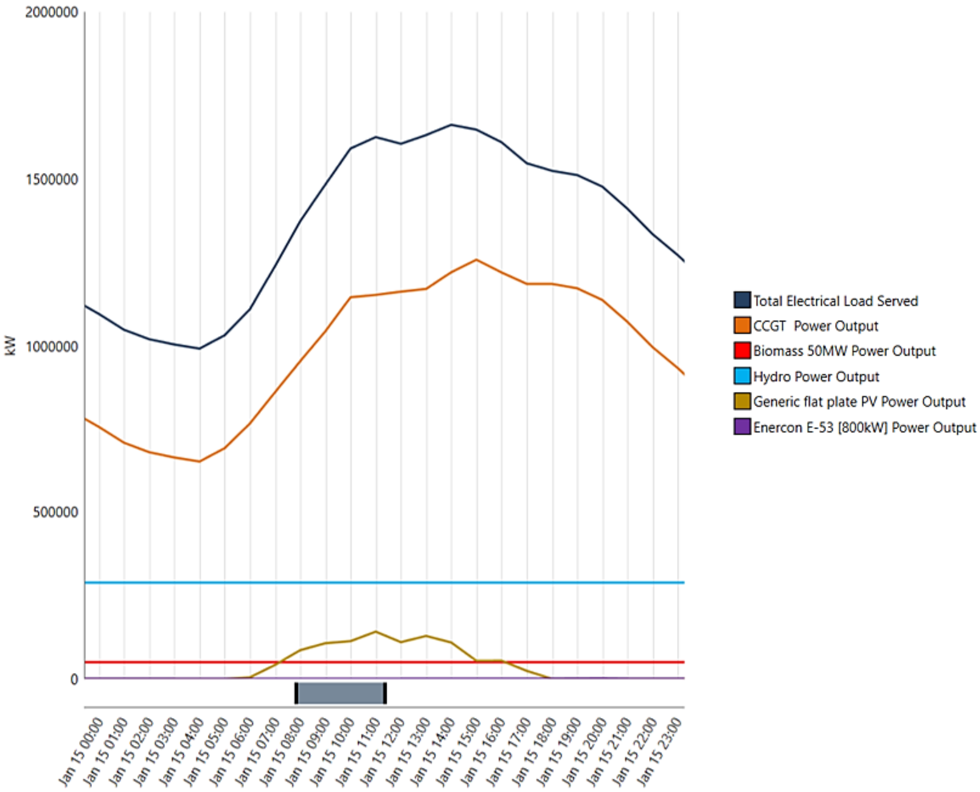


Figure 4.16 Characteristics of Scenario 23% fraction renewable in the rainy season

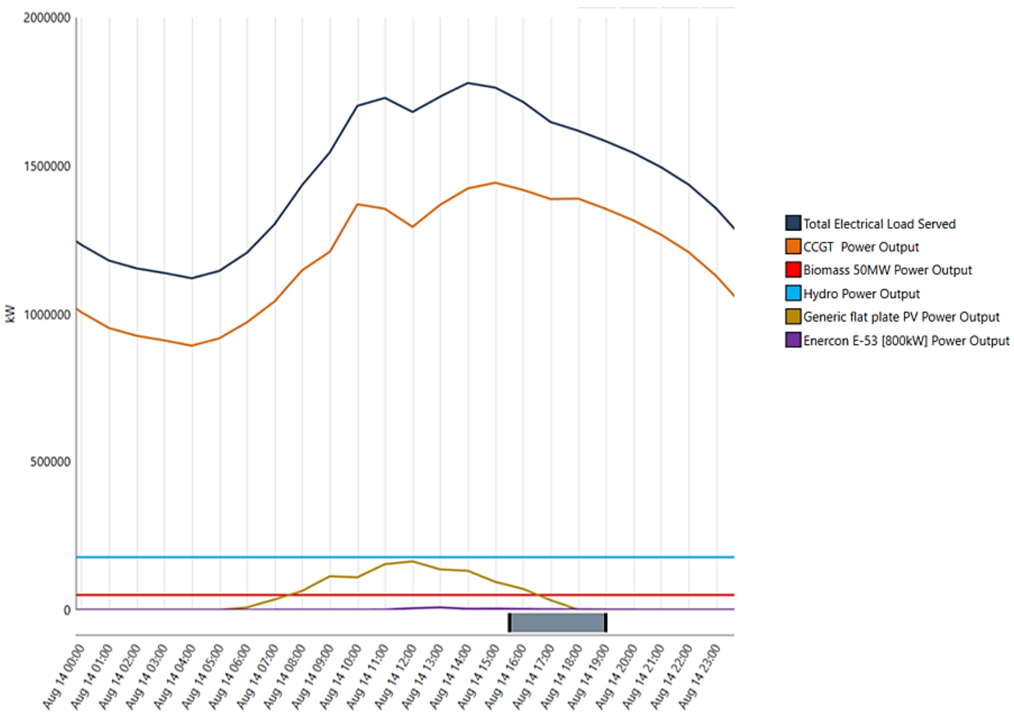


Figure 4.17 Characteristics of Scenario 23% fraction renewable in the dry season

As can be seen in Figure 4.2 and 4.3, typical days in the rainy and dry season are selected. In this scenario, the power generation mainly still generated from CCGT. However, the role of renewable energy is vital to balance and compensate for the peak demand from 11 am to 3 pm, similar to the second CCGT power plant in the base model. Therefore, the CCGT power output can be reduced, and as a result, lower fuel is needed. The consequence of lower fuel usage is emission curtailment.

Solar PV panels start to produce electricity from 6 am in the morning until 5 pm in the afternoon for both seasons. Solar PV panels reach a peak in electricity production at 12 pm midday. For the rainy season, the peak production is 120 MW and 175 MW in the dry season. Due to solar resources are relatively stable throughout the year, the difference is not significant. The energy produced by solar panels profoundly affected the reduction of dependency on CCGT.

Biomass power plant continuously generates 50 MW and no influence from seasonal variation because monthly resources are assumed to be the same. Tabang hydropower production is higher in the rainy season due to higher streamflow availability. 288 MW of electricity is generated in the rainy season whereas in the dry season Tabang hydropower produces 178 MW of energy output. Both biomass and Tabang hydropower serve as baseload power plant and always ready to fulfil the electricity demand alongside CCGT power plant.

Wind turbine energy output is minimal in the rainy season with only 6 MW in total daily production, but the condition is different in the dry season where the wind turbine capable of generating 30 MW of total daily electricity.

Although the power output from the wind turbine is small compare to other forms of generation, it still can supply one or two districts in the new capital city. The role of pumped hydro storage in the system is minor because the energy dispatch strategy is in cycle charging. Under this strategy, whenever CCGT is required, it operates at full capacity and surplus production charges the storage. Hence, in Figure 4.4 and 4.5, the line of pumped hydro storage sits in zero kilowatts as its always in charge mode. Cycle charging strategy is optimal in a system with little renewable energy.

4.3 Hybrid Energy System with 50% Renewable Fraction Scenario

This scenario tries to investigate if the target of renewable energy generation fraction in National Electricity General Plan 2019 is increased to 50%. As the tendency to satisfy Paris agreement is unlikely if the new capital city still follows the 23% target by the government. Similar to the previous scenario, the configuration composed of power generation technology from both conventional and renewable resources, storage technology, and converter. Conventional power generation is from CCGT; renewable power generation consists of biomass, hydropower, solar PV, and wind turbines. Pumped hydro storage serves as energy storage. All of the power generations are on the AC side except solar PV. Along with pumped hydro storage, solar PV is on the DC side. The converter connects both AC and DC. The converter can act as an inverter as well as a rectifier.

4.3.1 Hybrid Energy System with 50% Renewable Fraction Scenario Results

Table 4.14 Scenario 50% renewable fraction configuration detail

Components	Quantity	Rated Capacity	Mean Production (MW)	Capacity Factor (%)
CCGT	1	1,680 MW	695 (48.2%)	41
Biomass power plant	1	100 MW	99 (6.53%)	94
Tabang hydropower	1	340 MW	240 (16.7)	71
Solar PV	2,676,486	2,676 MW	408 (28.4%)	15
Wind turbine	100	800 kW	3 (0.02%)	3
Pumped hydro storage	128	150 MWh	-	-
Converter	666,284	100 kW	-	-

Table 4.15 Scenario 50% fraction renewable detail results

Economic	Value
Initial capital costs ($)	5.94 billion
NPC ($)	9.49 billion
COE ($/kWh)	0.062
System Performance	**Value**
Renewable fraction (%)	50
Capacity shortage (%/year)	0
Excess electricity(kWh/year)	382,270 (0.003%)
Unmet Electric Load (kWh/year)	0
Emissions	**Value**
CO_2 production (tonnes/year)	2.07 million

4.3.2 Hybrid Energy System with 50% Renewable Fraction Scenario Discussion

For the scenario hybrid energy system with 50% renewable fraction as presented in Table 4.4, in order to obtain intended renewable energy generation in the new capital city, the configuration that will be needed to produce electricity consists of one CCGT power plant, one 100 MW biomass power plant, Tabang hydropower with a capacity of 340 MW, 2,676,486 of solar PV panels, 100 units of wind turbines, 128 pumped hydro storage sites, and 666,284 of converters. Electricity generation now split into half. Where the CCGT power plant portion now only 48.29% or 695 MW from total system production. Solar PV takes the second-highest energy producer in this scenario with 408 MW or 28.4%. Tabang hydropower still producing 240 MW of electricity or 16.7% of total system production. It is followed by the biomass power plant with a 6.53% contribution, and the least is still the wind turbine.

When it comes to the capacity factor, biomass is still the most utilised in this scenario with 94% capacity or 94 MW from 100 MW available. Tabang hydropower used 71% of its total capacity and followed by the CCGT power plant with 41% much less than the previous renewable fraction scenario. In this scenario, solar PV average production is 408 MW per day for one year and still fifteen per cent of capacity factor. For the wind turbine, the average electricity output is 3 MW per day and its capacity factor still three per cent. Signify the intermittent resources.

For the economic aspects, the COE is 0.062 $/kWh in this scenario. The cost is still cheaper than the base model and also from the actual average electricity price in Indonesia. This condition could lead to a better economy and development in the new capital city. Not only that but also the government able to decrease or even stop their subsidy for electricity generation based on fossil fuel that comes at an expensive cost such as diesel and diverts their budget to renewable technology. The initial capital to build this system is $5.94 billion, double from the 23% renewable fraction scenario targeted by the government. However, the NPC is still positive, with a value of $9.49 billion. The investment is still lucrative, but with more components required and renewable technology high O&M costs, it lessens the generated revenue.

System performance-wise, this scenario success to get zero per cent capacity shortage. Excess electricity as a result of replicated massive blackout in the electricity load model now reduce to only 0.003% or equal to 382,270 kWh/year. The environmental aspect gets more enhanced with the upsurge of 50% renewable energy to the system. Consequently, the CO_2 emission reduces to 2.07 million tonnes/year. Therefore, it can be concluded that a 50% hybrid system with a combination of CCGT and renewable technology along with pumped hydro storage optimum enough to maintain balance and accommodate the system's electricity load. The characteristics of this scenario energy system with seasonal variation are presented in Figure 4.4 and 4.5.

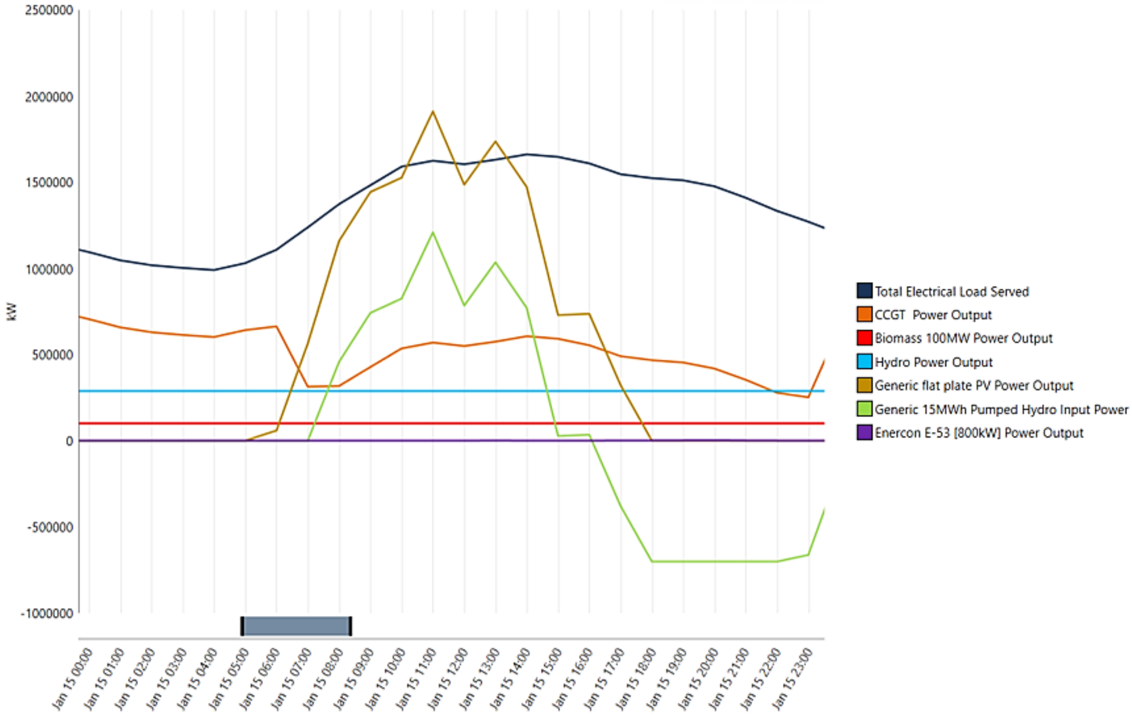


Figure 4.18 Characteristics of scenario 50% fraction renewable in the rainy season

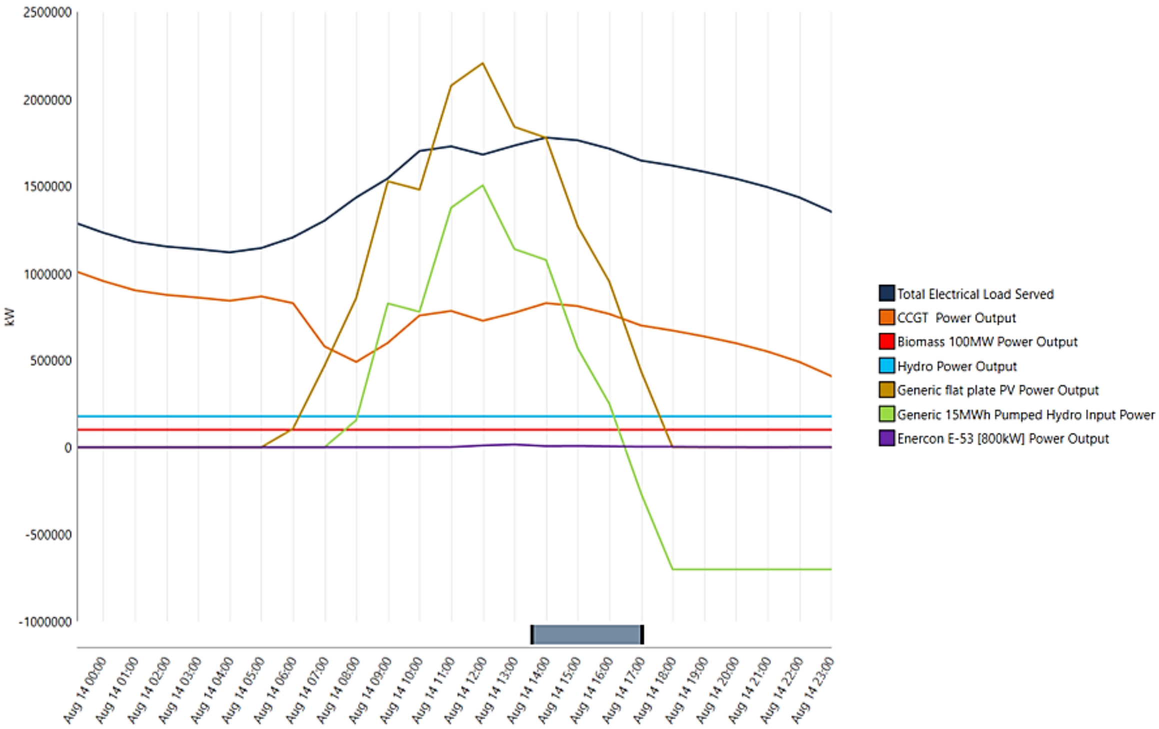


Figure 4.19 Characteristics of scenario 50% fraction renewable in the dry season

As illustrated in Figures 4.4 and 4.5, typical days in the rainy and dry seasons are selected to present the characteristics of the scenario energy system. In both seasons, Solar PV panels start to produce electricity from 6 am in the morning until 5 pm in the afternoon. Solar PV panels reach a peak in electricity production at 12 pm midday. For the rainy season, the peak production is 1,955 MW and 2,256 MW in the dry season. Due to power output exceeds demand during this period, the hydro pump storage stores electricity by using this energy to run the pumped hydro storage. As can be seen in Figure 4.4 and 4.5, the hydro pump storage input follows the solar PV output pattern.

The CCGT power plant still supports the system by reducing its power production to the minimum load ratio when renewable energy production is high or during the discharge condition of pumped hydro storage. The pumped hydro storage begins discharge electricity to cover demand in the evening approximately from 4 pm to 8 pm when renewable generation, especially from solar PV, is not sufficient enough to meet the demand. Similar to the previous scenario, biomass power plant continuously generates 100 MW and no influence from seasonal variation because monthly resources are assumed to be the same. Tabang hydropower production is higher in the rainy season due to higher streamflow. 288 MW of electricity is generated in a rainy season whereas in the dry season Tabang hydropower produces 178 MW of energy output. Both biomass and Tabang hydropower serve as baseload power plant and always ready to fulfil the electricity demand alongside CCGT power plant.

Wind turbine energy output is still minimal compare to others. But the power output from the wind turbine in the rainy season increase to 11 MW in total per day, it is even higher in the dry season where the wind turbine can generate 59 MW of total electricity per day. The role of pumped hydro storage in the system is maximised because of the energy dispatch strategy in load following type. Under this strategy, whenever CCGT is required, it operates at only enough capacity. This dispatch strategy works optimally in a system with abundant renewable production that sometimes exceeds the demand.

4.4 Energy System with 100% Renewable Fraction Scenario

This scenario tries to investigate the recommendation by Indonesia Renewable Energy Society that the new capital city can be supported by one hundred per cent renewable energy (Harsono, 2019). The configuration composed of power generation technology only from renewable resources, storage technology, and converter. Renewable power generation consists of biomass, hydropower, solar PV, and wind turbine, with pumped hydro storage functions as a storage technology in the system. All the power generation are on the AC side except solar PV. Along with pumped hydro storage, solar PV is on the DC side where together, both AC and DC side is connected by the converter. The converter can act as an inverter, also a converter.

4.4.1 Energy System with 100% Renewable Fraction Scenario Results

Table 4.16 Scenario 100% renewable energy system configuration detail

Components	Quantity	Rated Capacity	Mean Production (MW)	Capacity Factor (%)
Biomass power plant	1	200 MW	182 (0.03%)	0.3
Kayan hydropower	1	848 MW	600 (33.6%)	71
Solar PV	7,740,697	7,740 MW	1,180 (66.1%)	15
Wind turbine	250	800 kW	5.5 (0.3%)	3
Pumped hydro storage	530	150 MWh	-	-
Converter	1,983,193	100 kW	-	-

Table 4.17 Scenario 100% renewable energy system detail results

Economic	Value
Initial capital costs ($)	11.9 billion
NPC ($)	13.9 billion
COE ($/kWh)	0.090
System Performance	**Value**
Renewable fraction (%)	100
Capacity shortage (%/year)	0.091
Excess electricity(kWh/year)	12,142,371,840 (14.3%)
Unmet Electric Load (kWh/year)	7,862,014 (0.065%)
Emissions	**Value**
CO_2 production (tonnes/year)	10.45

4.4.2 Energy System with 100% Renewable Fraction Scenario Discussion

In this scenario, the configuration detail is presented in Table 4.6. The optimum configuration to manage full renewable energy generation in the new capital city consists of one 200 MW biomass power plant, Kayan hydropower with a capacity of 847 MW, 7,740,697 of solar PV panels, 250 units of wind turbines, 530 pumped hydro storage sites, and 1,983,193 of converters. Since the CCGT power plant not included in this scenario, solar PV is the primary energy producer in this scenario with 1,180 MW or 66.1%. Kayan hydropower produces 600 MW of electricity or 33.6% of total system production. Wind turbines follow it with a contribution of 0.3%, and then the least power producer in this scenario is the biomass power plant. When it comes to capacity factor, the most utilised components in this scenario is Kayan hydropower with 71% capacity factor, followed by solar PV, wind turbine and biomass power plant.

The COE in this scenario increase to 0.090 $/kWh makes it the costliest energy system in term of the price of electricity. However, it is slightly cheaper than the actual average electricity price in Indonesia, which is at the price of 0.094$/kWh. Combine with the initial capital cost of $11.9 billion and NPC value of $13.9 billion makes the economic rate of this system is the priciest among others scenario. This result is due to the extensive quantity of renewable components, especially solar PV panels and wind turbines so that O&M costs exponentially incline. Hence, the revenue generated cuts down a lot by running costs throughout the project lifetime.

System performance-wise, this scenario capable of achieving near-zero per cent capacity shortage with only 0.091%/year. However, excess electricity reaches 14.3% or equal to 12,142,371,840 kWh/year, which is significantly higher than any renewable energy scenario in this study. In addition, there is quite an amount of 7,862,014 kWh/year unmet electric load or 0.065% from total generation. Clearly, the energy balance in this system is not accomplished perfectly and a higher chance of electricity shortfall lingering around.

Nonetheless, the environmental aspect gets a lot of advantage with the implementation of a fully renewable energy system as the CO_2 emission reduces to only 10.45 tonnes/year. There is still a small emission generated from the biomass power plant. Hence even it is a fully renewable energy system it still emits CO_2. The characteristics of this scenario energy system with seasonal variation are presented in Figure 4.6 and 4.7.

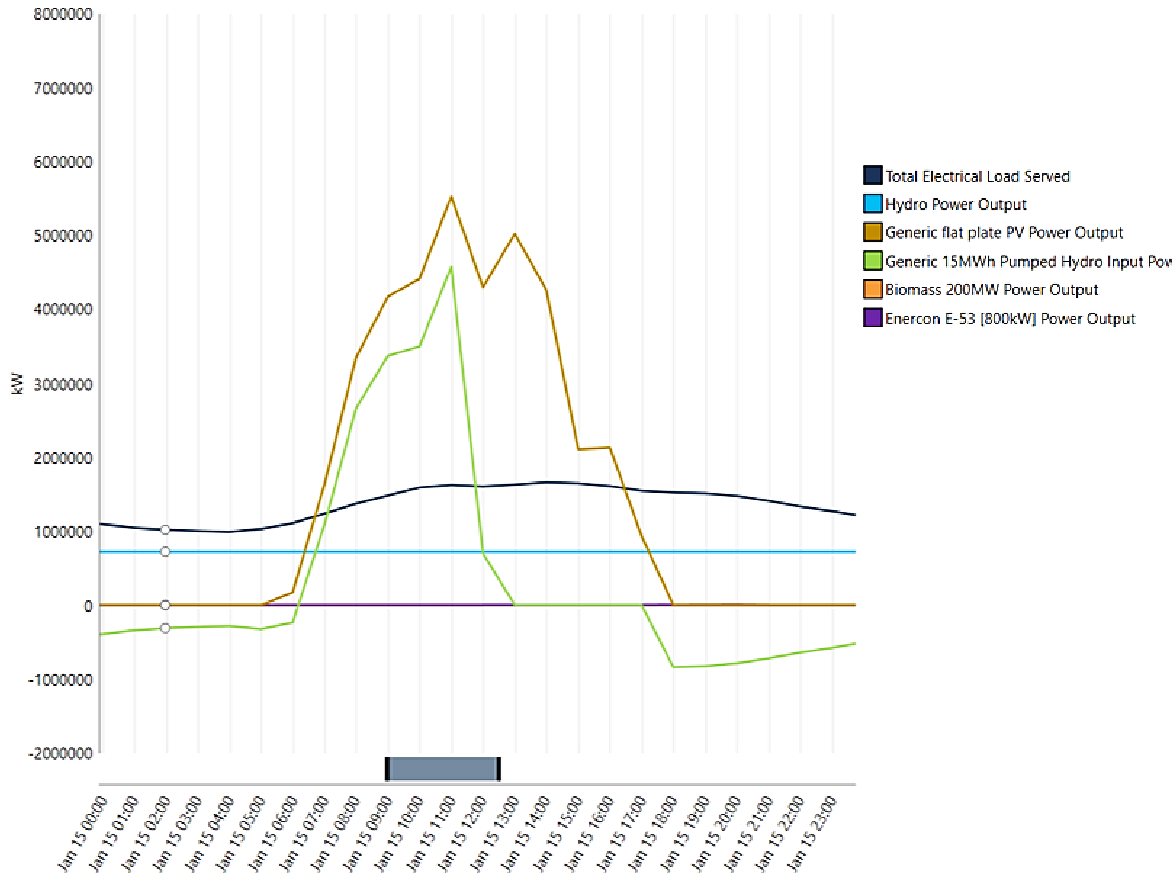


Figure 4.20 Characteristics of scenario 100% fraction renewable in the rainy season

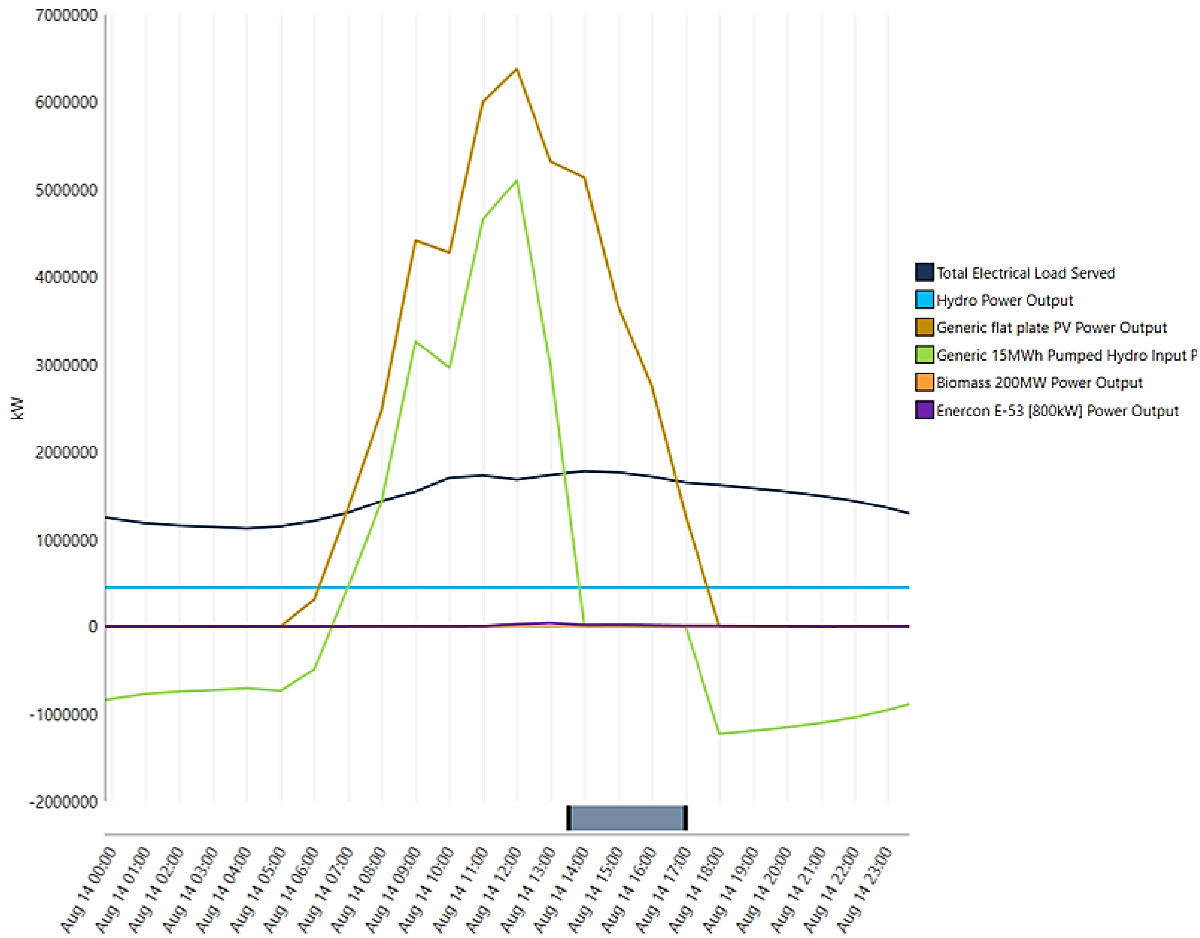


Figure 4.21 Characteristics of scenario 100% fraction renewable in the rainy season

As illustrated in Figures 4.6 and 4.7, typical days in the rainy and dry seasons are selected to present the characteristics of the energy system scenario. In both seasons Solar PV panels start to produce electricity from 6 am in the morning until 5 pm in the afternoon. Solar PV panels reach a peak in electricity production at midday. For the rainy season, the peak production is 6,032 MW and 6,960 MW in the dry season. Due to power outputs exceeds demand during this period, the pumped hydro storage stores electricity by using this energy to run the pump storage. As can be seen in Figure 4.6 and 4.7, the hydro pump storage input follows the solar PV output pattern. The pumped hydro storage begins discharge electricity to cover demand in the evening from 6 pm to 12 am and in the morning from 1 am to 6 am when renewable generation is not sufficient enough to meet the demand since solar PV as the biggest electricity produces is unable to generate electricity.

Similar to the previous scenarios, biomass power plant continuously generates 200 MW and no influence from seasonal variation because monthly resources are assumed to be the same. Kayan hydropower production is higher in the rainy season due to higher streamflow availability. 721 MW of electricity is generated in a rainy season whereas in the dry season Kayan hydropower produces 296 MW of energy output. Both biomass and Tabang hydropower serve as baseload power plant and always ready to fulfil the electricity demand.

Wind turbine energy output is small compare to others. But the power output from the wind turbine in the rainy season increases to 28 MW in total per day while in the dry season the wind turbine can generate 149 MW of total electricity per day. The role of pumped hydro storage in the system is maximised because the energy dispatch strategy in load following. However, even though the number of hydro pump storage already reach 530 sites, excess capacity still emerges as the pumped hydro storages are unable to absorb it all.

4.5 Research Questions Answer

4.5.1 Can renewable energy resources fulfil the 1.555 MW electricity shortage in the new capital city?

Table 4.18 System performance comparison

Scenario	Capacity shortage (%/year)	Unmet Electric Load (%/year)	Excess electricity (%/year)
Hybrid Energy System with 23% Renewable Fraction	0	0	0.013
Hybrid Energy System with 50% Renewable Fraction	0	0	0.003
Fully Renewable Energy System	0.091	0.065	14.3

The new capital city can be supplied safely with renewable energy resources. As can be seen in Table 4.8, hybrid energy systems have zero unmet electric loads throughout the year. However, if the new capital city power production wants to be generated from fully renewable energy, a higher chance of power outage is unavoidable. Hybrid energy systems give more stable and well-balanced electricity output. The full renewable energy system generates 14.3% of excess electricity and has 0.065% unmet electricity demand or equal to 7,862,014 kWh/year. Where the excess electricity yields by both hybrid energy systems are minimal. The detail components of each scenario for better judgement to choose the most feasible system are presented in Table 4.9.

Table 4.19 Each scenario components summary

Components	Hybrid Energy System with 23% Renewable Fraction	Hybrid Energy System with 50% Renewable Fraction	Fully Renewable Energy System
CCGT (MW)	1,680	1,680	-
Biomass power plant (MW)	50	100	200
Hydropower (MW)	340	340	847
Solar PV (MW)	198	2,676	7,741
Wind turbine (units)	50	100	250
Pumped hydro storage (units)	49	128	530
Converter (kW)	238,076	666,284	1,983,193

As presented in Table 4.9, hybrid energy system with 23% renewable fraction scenario is the most achievable in term of components quantity followed by hybrid energy system with 50% renewable fraction scenario. The main drawback of fully renewable scenario is the number of pumped hydro storage units. It is unlikely to build 530 the storage facility because the reported ex-coal mining pits as the pumped hydro storage reservoir is only 500 pits. In addition, not all 500 pits are feasible to be transformed into a pumped hydro storage reservoir.

Another difficulty in implementing a fully renewable energy scenario is the number of required solar PV panels. It will need a lot of space to arrange millions of PV panels as a solar farm, and usually, they are developed in rural areas. Local community or villagers around the new capital city would be impacted. It could lead to refusal from them and stall the capital city development. Hence, the government most likely will choose the achievable scenario, which means 23% hybrid renewable energy scenario will be the nominated system. Although the 50% hybrid renewable energy system is still possible, more components are required. Back again, it depends on which target the government want to focus on when building the capital city. If COP-21 Paris agreement is the first national priority, then 50% hybrid renewable energy system is a better option. But with the fact that 23% renewable target already stated in the 2019 national general electricity plan, 23% hybrid renewable energy scenario is the more solid option. The next section will explain the government budgeting capability within these energy system scenarios.

4.5.2 Is the fulfilment of electricity shortages with a hybrid renewable energy system still meet the limit of government budget?

According to Medina (2019), if the Parliament accepts the move, the project is expected to cost an estimated $33 billion to build a green city starting in 2021. But the project will require massive investment: the government expects state-owned entities and the private sector to share 80 per cent of the total costs, with the rest financed by the government. With the assumption that the government allocate its 20% from $33 billion only for power generation in the new capital city, then the government budget limit is set to $6.6 billion.

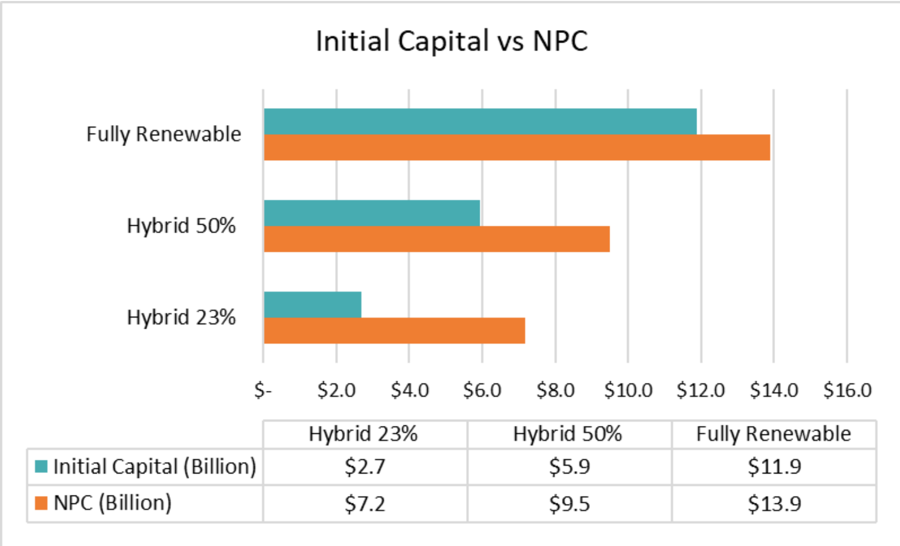


Figure 4.22 Summary of each scenario economic aspect

As can be seen in Figure 4.8, the scenario that can be afforded by the government are 23% hybrid renewable energy system and 50% hybrid renewable energy system. This means that implementing fully renewable energy technologies into the energy systems is not cheap, as it needs significant higher initial capital cost. Nevertheless, it can be seen from the NPC that total costs to implement and run hybrid energy system are calculated at $7.17 billion for the 23% renewable fraction, and $9.49 billion for the 50% renewable fraction. Clearly, in the long-term costs needed to run 23% hybrid renewable energy is cheaper than 50% hybrid renewable energy system. The government could consider 50% hybrid renewable energy system if their budget limit is increased by co-financing with the private sector or state-owned company. At the moment, 23% hybrid scenario is the realistic choice for the government, as the remaining budget can be allocated development of the new capital city.

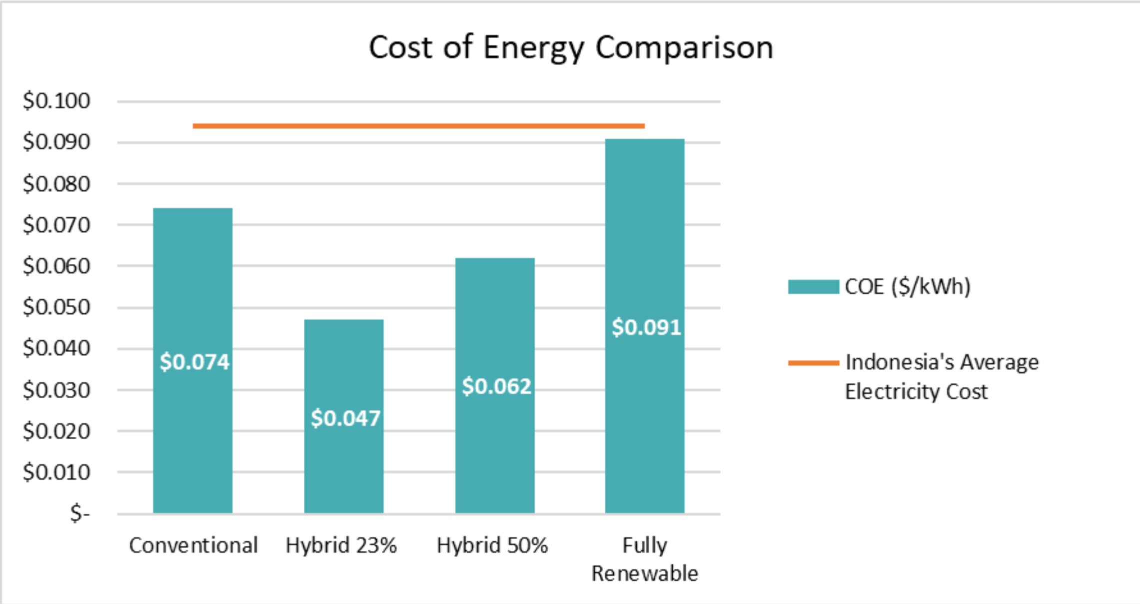


Figure 4.23 Comparison of Each scenario COE

As presented in Figure 4.9, the implementation of the of 23% hybrid renewable energy resulting cost of energy in a price of 0.047 $/kWh and become the most affordable compare to another scenario. The hybrid 50% renewable fraction scenario COE is the second cheapest with 0.047 $/kWh. Both hybrid systems generate the cost of energy below the price of business as usual scenario as the base model of this study, where power generation only comes from conventional resources. The fully renewable scenario has the highest cost of energy, with 0.091 $/kWh.

On the other hand, all scenario in the study generates the cost of energy below the average electricity cost in Indonesia. It means that the price of electricity from the current energy system where it is dominated by coal that supposed to be cheap, in fact, does not. The government currently gives a subsidy to electricity price to make it cheaper. It can be concluded that the implementation of hybrid energy system scenario able to lower the cost of energy in this study, compared to business as usual scenario and fully renewable scenario.

With the 23% hybrid energy system implementation, the government could stop or decrease their subsidy for electricity generation based on fossil fuel price and divert their budget to improve renewable technology in the country. As a result of the lower cost of energy, the new capital city would have the bargain to bring other people outside civil servants who have just been transferred. This condition could lead to a better economy and development in the new capital city.

4.5.3 Can carbon emissions in the new capital city be lower with the entry of renewable energy?

The entry of renewable energy into the energy system is proven to reduce the CO_2 emissions in the new capital city. As can be seen in Table 4.10, the business as usual scenario which only utilise a conventional energy system with the configuration of two CCGT power plant produces 4.13 million tonnes of CO_2 equivalent. When renewable energy technology introduced into the energy mix, it reduces the CO_2 emissions to 3.18 million tonnes/year for hybrid 23% scenario and 2.07 million tonnes/year for hybrid 50% scenario. Specifically, for a fully renewable scenario, the reduction is significantly higher to only 10.45 tonnes/year. If the government not considering budget and system performance, the fully renewable scenario is the best option. The 50% hybrid scenario should be the ideal choice. However, the hybrid energy system with 23% renewable fraction still gives a good result as the realistic choice for the government.

Table 4.20 Summary of each scenario carbon emissions

Scenario	**CO_2 Emissions (tonnes/year)**	**Reduction from Conventional Energy System Model**
Conventional	4,134,382	-
Hybrid 23%	3,182,628	23.02%
Hybrid 50%	2,068,296	49.97%
Fully Renewable	10.45	99.99%

4.5.4 What type of energy storage that fittingly well for new capital city area?

As presented in the literature review chapter and simulation input data chapter, the type of storage that will be suitable for the new capital city is pumped hydro storage by using ex-coal mining pits as the reservoir. It is cheaper than the battery, and it also uses an abandoned area, so the land acquisition is not needed. Pumped hydro storage utilisation is maximised in 50% hybrid scenario while in 23% hybrid scenario this storage system is in charging mode most of the time. As illustrated in Figure 4.10, this is the example of ex-coal mining pits that can be transformed into a pumped hydro storage facility based on the study by Devi et al. (2018). The upper reservoir has deeper crater and smaller volume but both reservoirs situated at the same height. The upper reservoir is filled by 1.5 million metre cubic of rainwater and will be full at 2028. Piping and pump hydro turbine system will be developed in the underground level. The 3D cross-section of this coal mining shows the different depth between the two-reservoir presented in Figure 4.11 below.

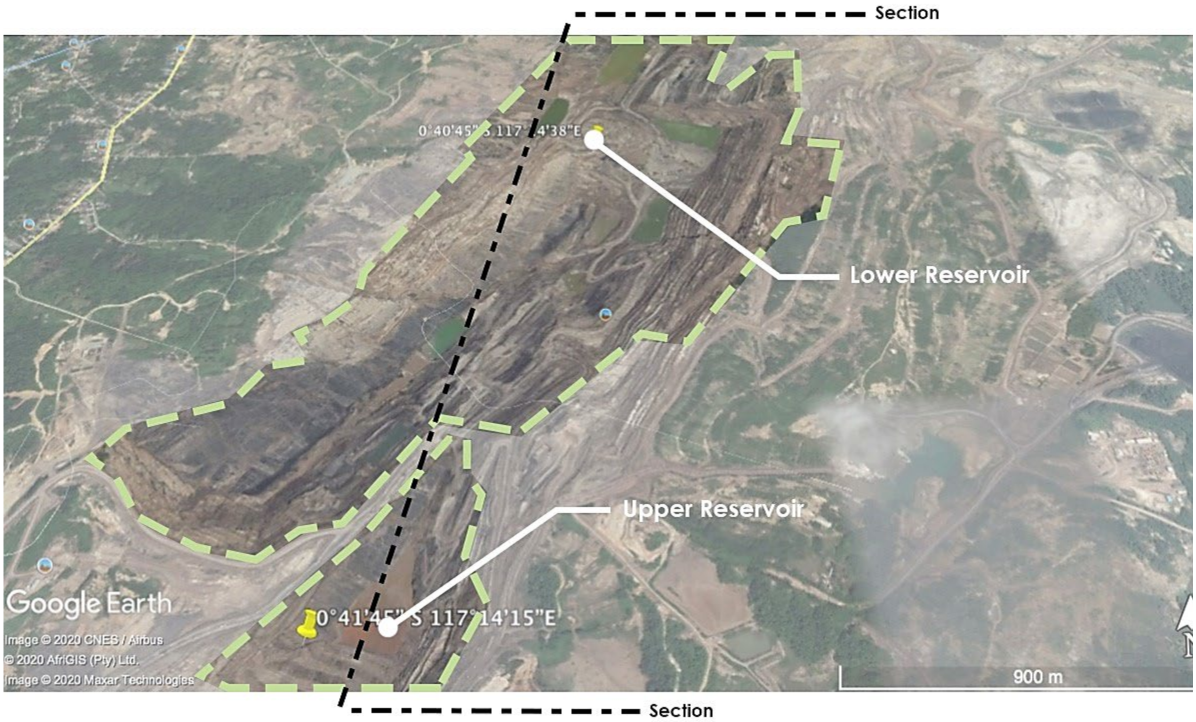


Figure 4.24 Aerial view of a pumped hydro storage site at ex-coal mining pits

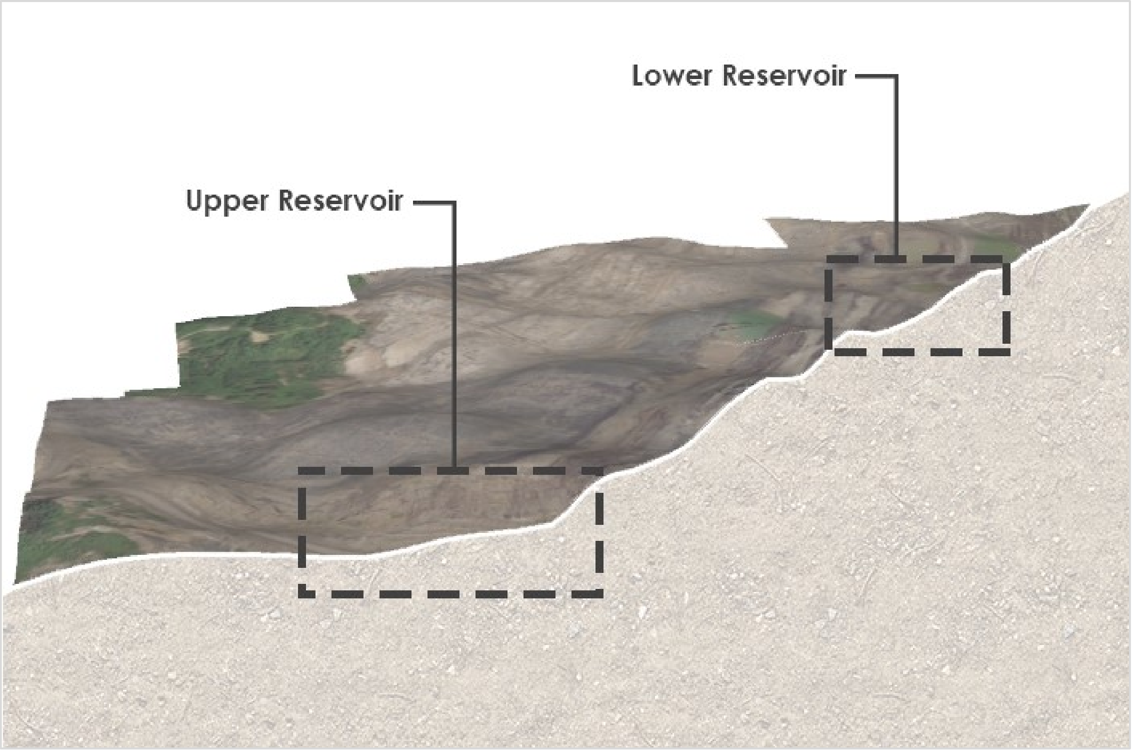


Figure 4.25 Cross-section view of a pumped hydro storage site at ex-coal mining pits

4.5.5 Where is the right land selection for renewable energy technology without having to disrupt the socio-ecological system on a large scale?

The land selection for renewable energy technology that will not disrupt the surrounding environment in the new capital city is ex-coal mining field in Semboja East Kalimantan. The coordinate of the study place is 1° 2'51.00"S 117° 0'58.32"E. This place used to be an illegal coal mining and then abandoned. The Semboja area is presented in Figure 4.12. As can be seen in Figure 4.12, most of the area is damaged indicates by greyish land colour instead of green. On the west part of the area is a residential area with access to provincial road. The mining pits are marked by dark blue colour on the aerial view of the Semboja area.

It is an open area with small peat vegetation, hence layout design considering peat and hydrological characteristics of the site project to enable avoidance of environment degradation will not take extensive resource and time. As peat excavation is one of the carbon emission large contributor, careful treatment is prioritised. When peat being released, and then dry out, it is easy to be burned. Hence, the minimisation of displaced peat being dry out is essential. For the wind turbine base excavation, opening barrow pits will not much impact the area as it has been exploited before. Environment management framework plan including waste management; sediment management; water ingress to turbine excavations calculation are also taking into account to minimise the land disturbance during the construction phase (Viking Energy Company, 2009).

Figure 4.26 Aerial view of Semboja ex-coal mining area

During the construction phase for the PV panels installation, it is likely to do soil excavation for cable trenching, construction compound and PV panels platform ground anchors. Where this soil degradation occurs in the topsoil and subsoil should be stripped, processed and replaced separately in order to mitigate soil damage and to establish optimum conditions for the regeneration of the site. For ground-based PV arrays, ground maintenance to tackle overgrown bush is prioritised. Mining pits that already filled with water can be used as floating PV space to maximise the area utilisation. Unsupervised mining pits are dangerous, and it is reported that some people were found drowned into the unmarked hole. The area should be safer as it becomes a restricted area of solar farm or wind farm with proper boundary fencing. Area rehabilitation with soft landscaping and habitat creation will improve the area condition at least to pre-mining activity. The rehabilitation also can reduce the visual impact of the project development. PV arrays can also be capable of providing environmental benefits, such as building ecosystems by undisturbed grassland for several years, wildflower meadows, higher hedges and forests, etc. (The National Solar Centre, 2013). Noise control by working hours arrangement where restrictions extend to any activity where noise and vibration emissions can have a negative effect on a residential area near the project site is applied. It is a pivotal thing to keep surrounding community disturbance at a minimal level. Traffic management also has an important role in ensuring efficient transport of components and materials to the site, thus reducing inconvenience to other road users. The renewable technology components such as wind turbine blade and hub have a large dimension. Long wheelbase vehicle and big truck likely will pass over the local road.

Community involvement is an integral part of the project development process, developing a regular communication to the public to provide consistent update can give trust to the project stakeholder. Maximisation of local resources also could bring a positive impact to the community. For example, the development of the project will bring employment to the local community. Local contractors even able to get part in the project and transfer knowledge likely to happen. It is a good sign for renewable technology growth in the new capital city if local contractor also has the skill to operate and maintain the technology. Figure 4.13 and 4.14 are the 3D mock-up to illustrate if solar farm and wind farm are built in the area. The 3D model uses an actual size of wind turbine and solar panel. As can be seen in Figure 4.13, space availability is abundant, and further expansion is possible in the future if needed.

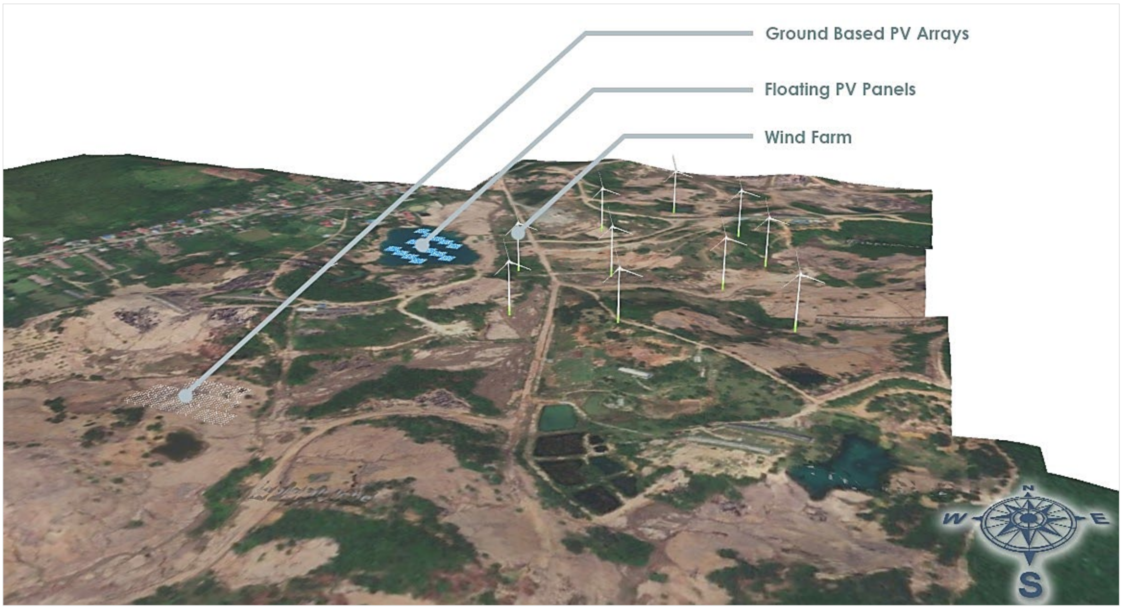


Figure 4.27 Semboja ex-coal mining area in the 3D model

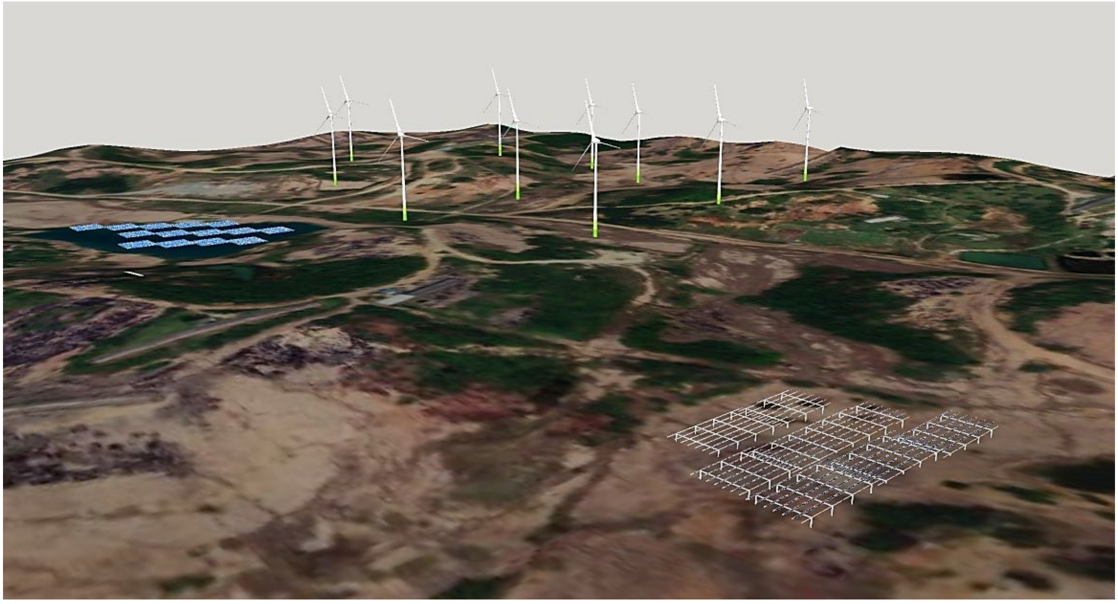


Figure 4.28 Closer view of Semboja ex-coal mining area in the 3D model

Following that, the environmental impact of Tabang and Kayan hydropower implementation, in general, would include alteration of existing terrain at the dam site, alteration in river flows, and loss of vegetation and habitat. During the construction phase, the main impacts on the existing terrain and the surrounding physical environment will occur as a result of activities related to vegetation clearing and soil movement for road building, development of the transmission line, dam abutment, and excavation. Best-practice construction methods are implemented such as all activities must remain within the guideline of the development, minimise the land clearing with only excavated within the transmission line and temporary access roads, replanting the impacted area as appropriate as possible and also soil remediation.

Hydrological impacts specifically change of river stream could be avoided or minimised during the dam construction by building a diversion channel to carry upstream flows past the dam structure, therefore no water accumulation which causes flooding. Consequently, downstream flows will not be disrupted, although water quality can be affected by sediment discharge and other materials such as gasoline or chemical spill from construction activities. Silt screen and silt curtains usage at the diversion channel will trap the unwanted material and prevent it from mixing with the water.

For biological impacts, most likely it will impact on the fish population. During the construction phase, fish migration or movement pathway could be disrupted. With the installation of a bypass structure, this impact would be minimised. Increased soil erosion and silt material accidentally run into the water could lead to a respiratory problem for the fish population. Sediment increase also could be resulting in breeding activity disruption. Best construction practice combines with careful control of erosion would reduce the sediment runoff. Maintaining vegetation buffer and sediment curtains application also useful for reducing the impacts. Large amounts of vegetation will also be impacted because they have to be removed for construction activities. To minimise the impact, construction activities are limited only within the designated area. After the works are done, site rehabilitation by trees and grass replanting is performed.

The most impacting phase of hydropower is during the operational period. The hydrological aspect of upstream and downstream will be impacted. Upstream hydrological impacts include, increase groundwater level, increase sediment accumulation on the river bed, changes of river flow as it is converted into a standing reservoir. Downstream hydrological impacts mostly located below the dam structure such as changes in the flows, river bed configuration, and sedimentation. But it also possible changes happen in further downstream. These conditions can only be minimised since the inundation impacts on the river are inevitable. Watershed management is necessary to reduce sediment accumulation in the reservoir. During the operational phase, the ecosystem in the dam reservoir is changed from river to condition similar to a deep lake. Habitat diversity would be declined as food resources and nutrients that used to generate by seasonal changes of the high and low stream is now vanished. As it creates a seasonal drought-like situation. Likely this is the most significant impact of inundation of the river bed.

Tabang hydropower plant is situated in 0°40'04.4"N and 115°54'17.3"E. This hydropower plant will be utilised in the hybrid energy system with 23% renewable fraction. As it is explained in the previous paragraph, the development of this power plant will give some environmental impacts to the Belayan River. But with proper mitigation and rehabilitation, the impact could be minimised. The social impacts would also minimal due to no residential area or human settlement near the location. An endangered animal such as orangutan does not live in the Tabang area but further deep into the rainforest.

The 3D model presented in Figure 4.15 illustrates the condition of Tabang hydropower plant development when it finishes. The mock-up is constructed using satellite terrain data and dam specifications based on the study by Windarta et al. (2020). Due to the implementation of real data, it could be said that the depiction represents an actual condition, although not one hundred per cent is accurate. As can be seen in Figure 4.15, the inundation impacts on the upstream flow. The area is now flooded and transformed into standing reservoir. Reservoir water body height is estimated at 75 m. Loss of vegetation and habitat as a result of submersion visible in the reservoir part. As long as the environmental impacts can be minimised and contained with adequate mitigation, the benefit of Tabang hydropower to give stable and instant electricity should be prioritised by the government.

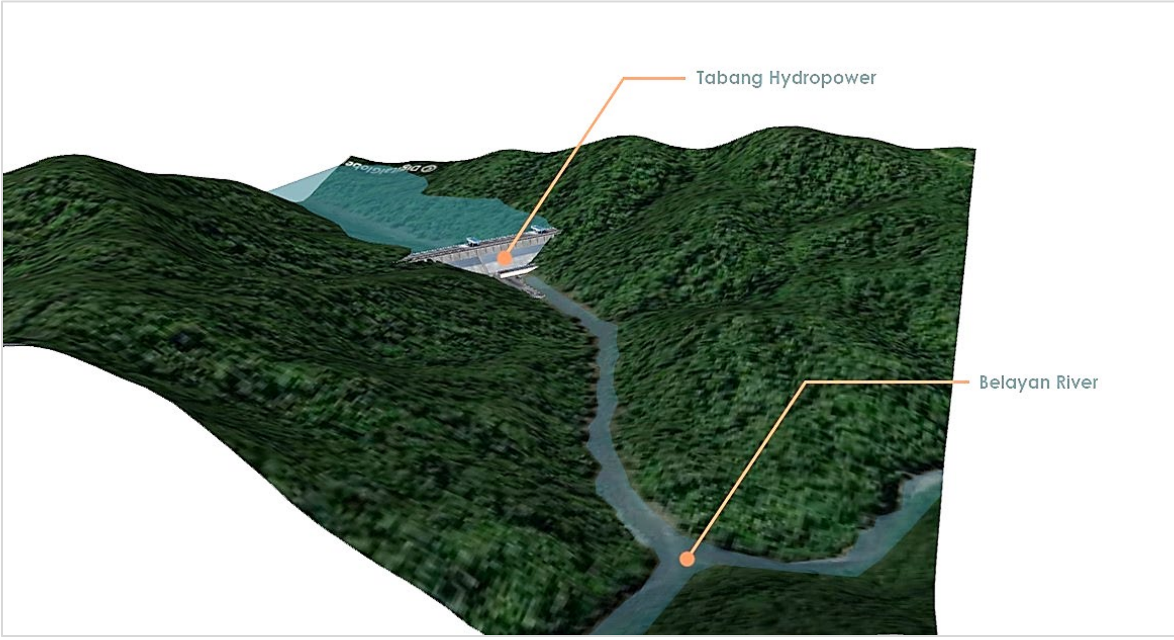


Figure 4.29 Tabang hydropower 3D model

The condition is different for Kayan hydropower plant, located in 2°40'37.4"N and 116°32'01.2"E. The proposed area is in North Kalimantan; hence it is far from the new capital city. But with the power output almost 900 MW just from the first phase, the government approved this project. Kayan hydro is claimed to be one of the largest dam type hydropower plant in South East Asia. This hydroelectricity is the model for simulation input in a fully renewable energy scenario of this study. As it is explained before, the development of such large dam construction will impact the surrounding environment. Naturally, as Kayan hydropower is much larger than the Tabang Hydro, the impacted area also exponentially increases.

Kayan River is a migration path for freshwater and marine fish species. Fish population in Kayan river definitely will be depleted with changes in the ecosystem in the dam reservoir. The surrounding rainforests are the habitat of orangutans, gibbons, and other endemic flora and fauna species. Damming the Kayan river would eliminate these endemic species habitats. The

Kayan River is also integral to the culture of the Kalimantan's indigenous peoples, including the Dayak Kayan who have lived along the river's banks for centuries (Esterman and Rochmyaningsih, 2016). The inundation impact will vanish their homes and livelihood. Their hunting ground and access to forest products would disappear as well. The resettlement of Dayak Kayan people would be problematic as they are native to the rainforest. If they are moved to the nearest village, there is a high possibility of social friction with local people.

The 3D model presented in Figure 4.16 illustrates the condition of Kayan hydropower plant development when it finishes. Using satellite terrain data, and dam specifications based on similar hydropower plant capacity. As can be seen in Figure 4.16, the inundation impacts on the upstream part of the river are massive as it is transformed into a reservoir. The estimation of water body height is 100 m. Loss of vegetation and habitat due to submersion clearly visible as part of the reservoir. The downstream also impacted by water discharge from the dam outlet. Obviously, these conditions are far from ideal to build Kayan hydro, and the government should consider the best mitigation available to minimise the impacts or even cancelled the project, which is unlikely.

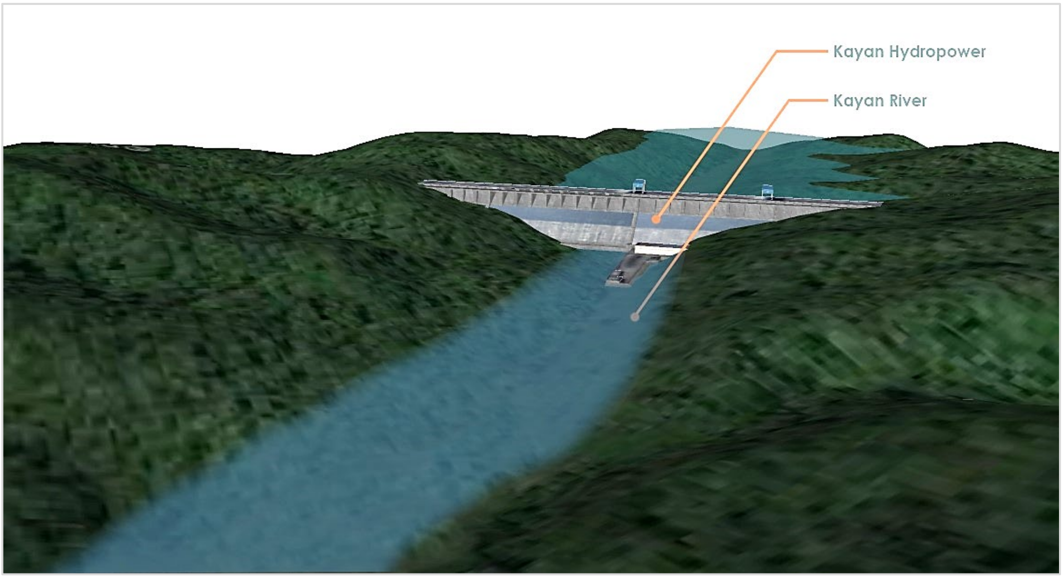


Figure 4.30 Kayan hydro power 3D model

Chapter 5: Conclusion

Jakarta capital city is one of the fastest-sinking cities in the world. It will submerge by 2050 if concrete action is not taken. To address this issue, In August 2019, the Indonesian government announced the new location of new capital would be in East Kalimantan. The government plans to develop a new capital city with a green and sustainable city concept. A crucial issue has emerged with a massive number of people moving to the new capital city, which is energy demand. The new capital city will need additional power plants if energy security wants to be achieved. The total estimated requirement is 1,555 MW. The government highly consider renewable energy option to provide electricity for the new capital city. For this reason, this study tries to investigate the feasible hybrid renewable energy system in terms of economic and environmental aspect through the modelling software.

HOMER is selected to be the modelling software. This study used one-year Jakarta city demand data from 2019 obtained from PLN as an electricity load profile input. The average daily demand in the new capital city forecasted to be 1,387,013 kW, and the peak demand is in October. Combined cycle gas turbine is selected to be the conventional resources energy generator for this study. Simulation of renewable technology includes the biomass power plant, hydropower dam type, solar PV and wind turbine. Relevant assumptions and constraints obtained from the literature review are employed to the simulation. Some parameters in HOMER are also adjusted to match the possible realistic result.

There are three scenarios that were simulated using HOMER to get the optimum hybrid renewable energy system and one scenario as the base model with only utilise conventional resources. The renewable energy system scenarios are classified by a renewable fraction of 23%, 50% and 100%. Below list will summarise the main finding from simulation result and analysis.

- Solar PV generates higher capacity than any other renewable technology, while wind turbine generates the least electricity in all scenarios. Hydropower and biomass power plant mostly served as a baseload power plant along with CCGT.
- Hybrid 23% and 50% renewable energy systems give more stable and well-balanced electricity output. In contrast, the fully renewable scenario has an unmet electric load and a high percentage of excess electricity.

- Hybrid 23% and 50% renewable energy systems have an achievable number of components required while a fully renewable system uses an extensive number of components.
- Only Hybrid 23% and 50% renewable energy systems that still within the government limit budget. The COE of hybrid 23% renewable energy system is the cheapest among another scenario.
- Fully renewable energy system reduces the highest number of CO_2 emission, but it falls in other performance categories.
- Pumped hydro storage is the suitable storage technology in the new capital city. By using abandoned ex-coal mining pits, pumped hydro storage is capable of storing excess electricity from renewable energy generation.

In summary, only hybrid 23% and 50% renewable energy systems than can be afforded by the government. The 50% hybrid scenario should be the ideal choice. However, the hybrid energy system with 23% renewable fraction still gives a good result, and at the moment, 23% hybrid scenario is the realistic choice for the government, as the remaining budget can be allocated to the development of the new capital city.

The land selection for renewable energy technology that will not disrupt the surrounding environment in the new capital city is ex-coal mining field in Semboja East Kalimantan. It is an open area with small peat vegetation. It is suitable to build a solar farm and wind turbine in the area. Necessary mitigation should be performed before or during the construction phase. Community involvement is an integral part that should be addressed. Tabang hydropower gives stable and instant electricity, and it should be prioritised by the government. As long as the environmental impacts can be minimised and contained with adequate mitigation, this hydropower dam type can be built by the government. Meanwhile, Kayan hydropower should be stopped as damming the Kayan river would eliminate endemic species habitats such as orangutan, gibbons etc. Also, the inundation impact will vanish homes and livelihood of Kalimantan's indigenous peoples, the Dayak Kayan.

Chapter 6: Future Work

Finally, this project may have some flaws and uncertainties from the limitation mentioned in previous chapters. Therefore, this chapter will identify the limitation of the current project and future work that needed as an improvement for the study. The distinguished uncertainty of this study related to the costs of components needed and the component specifications value. These values largely derived from some literature and reports. While in real-world condition, these values might vary from one project to another depending on the difficulty, scale, and place. The electricity load data input in the simulation has some uncertainty in the form of a power outage; hence excess electricity always emerges in every established simulation.

Another uncertainty is the land selection for the hybrid renewable energy system, as it is only based on terrain and map data. Further, inspection is needed to get an accurate condition of the area. The environmental impact assessment also based on similar project reports. The mitigation might be different and cannot be implemented in this study area. HOMER Software limitation appear when doing the simulation, it always chooses the lower cost components as the result of the simulation. Therefore, HOMER always chooses pumped hydro storage over the lithium-ion battery. Hence in the simulation, both storage system cannot be compared together in the energy system scenario.

As the limitations stated above, this project might be not one hundred per cent present an accurate result. In order to get a better result in the future, the following suggestion should be taken into consideration:

- More accurate parameter for simulation input and less assumption as the basis of simulation.
- Using primary data for the model instead of secondary data from the literature. Such as real-time solar GHI data and precise location wind speed data.
- Fieldwork and ground check for land selection to give more accurate condition in addition to GIS-based research.
- Survey and questionnaire to know the real social impact of the renewable energy development project.

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