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MASTER THESIS

Energy future for the new Indonesia's capital city: An energy modelling approach

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ABSTRACT

The plan of capital city relocation of Indonesia to East Borneo has been enacted to encounter many problems carried by the current capital, Jakarta. A good energy planning, especially in the power sector, is entailed to make sure any policy or measure taken still complies with the national target of energy share without neglecting any trade-off or threat. This research aims to analyse the energy model scenario for the power sector of the East Borneo where the new Indonesia's capital city is located until 2050 in accordance with the Paris Agreement and National Energy General Plan in order to give its implication to the government as the future plan for the new capital city development. LEAP energy modelling tool will be used as the analytical tool with quantitative methods and design-based approach. Two model scenarios, Business-as-Usual and Capital City Relocation scenarios is designed to make comparison and analysis for the impact of capital city relocation in the power sector.

Keywords: capital city relocation, energy planning, power sector, LEAP.

ACKNOWLEDGMENT

This thesis research is made to answer the question that came to my head “What would be the future of the energy sector in Indonesia?” As I experienced how EU countries keep their strong commitment in promoting cleaner energy to tackle the issue of climate change, I look back at what my country has done towards this issue. As a “life-changing” step, the plan to relocate the capital city could give such an enormous impact to the country, especially in the energy sector. From this reason, I initiated to do my research on the planned new capital city related to its implication in the power sector and its correlation with climate change mitigation.

This thesis is dedicated to my mother, the strongest person I ever had. She gave me the reason to be strong and keep my chin up even in a tough situation. For this reason, I have the willingness to finish my thesis and eventually end my master program in MEEM. My greatest honour to present my work to you.

I would like to give my deepest appreciation and gratitude to my first supervisor, Dr. Maarten Arentsen, who supported me the most from the beginning until the finalization of this thesis. My great appreciation also for my second supervisor, Professor Joy Clancy, for her thoughtful understanding and invaluable insight during the making of this thesis. Likewise, I would also like to thank all of the MEEM members: teachers, staff, and not to mention, my supportive cohorts MEEM 20/21 who made all of this process more meaningful.

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Finally, I also want to thank my father, brother, and all of my family and friends who supported me since I made the decision to go abroad to pursue my study.

In the end, I hope this thesis would be helpful for those who read and could give a small meaningful contribution to my country, Indonesia.

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LIST OF ACRONYMS/ABBREVIATIONS

ACRONYM	DEFINITION
BAU	Business as Usual
BPS	Badan Pusat Statistik (Central Statistic Body)
CCR	Capital City Relocation
DEN	Dewan Energi Nasional (National Energy Council)
ESDM	Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources)
GHG	Greenhouse Gas
GWP	Global Warming Potential
IKN	Ibu Kota Negara (planned new capital city of Indonesia)
NDC	Nationally Determined Contributions on Climate Change
IPCC	Intergovernmental Panel on Climate Change
LEAP	Low Emissions Analysis Platform
MMSCF	Million Standard Cubic Feet
NGCC	Natural Gas Combined Cycle
OSeMOSYS	Open Source Energy Modeling System
PLN	Perusahaan Listrik Negara (National Electricity Company)
PPN	Perencanaan Pembangunan Nasional (Ministry of National Development Planning)
PUPR	Pekerjaan Umum dan Perumahan Rakyat (Ministry of General Works and Public Housing)
RUED	Rancangan Umum Energi Daerah (District General Plan of Energy)
RUEN	Rancangan Umum Energi Nasional (National Energy General Plan)
RUKN	Rencana Umum Ketenagalistrikan Nasional (National Electricity General Plan)
RUPTL	Rencana Usaha Penyediaan Tenaga Listrik (Business Plan of Electricity Supply)

CHAPTER 1 INTRODUCTION

In Chapter 1, the background and problem statement related to the relocation planning of the capital city of Indonesia are introduced. Furthermore, the research objective and (sub) research question(s) are presented based on this background. Additionally, a brief explanation of methodology, ethical statement, concept definition, and overview of this thesis are explained in this chapter.

1.1 BACKGROUND

The urgency of capital city relocation of Indonesia has arisen since the current capital, Jakarta, faces many problems. With a population of more than 10 million people, Jakarta should deal with traffic congestion which is estimated to give economic loss up to 2.6 billion USD per year (Julita, 2019). Massive grey infrastructure along with the increasing population does not go along with the green measures. From the 30% target of green area based on National Constitution No. 26/2007 about Spatial Planning (Indonesia, 2007), only 9% of total area of Jakarta are covered in green infrastructure.

One prominent issue that must be faced by the city is climate change. As it is located in the coastal zone in the northwest of Java Island, Jakarta is facing the issue of sea level rise along with the land subsidence which are projected to inundate almost all Jakarta's coastal zone in 2100 (Indonesia Climate Change Sectoral Roadmap (ICCSR), 2010). ICCSR (2010) has predicted the area will be flooded with an elevation between 0 to 3 m or 3 to 4 m in intensified extreme weather. Abidin (2010) analysed the land subsidence in the coastal area of the city will occur in between 1 to 15 cm per year. The situation is exacerbated with the seawater infiltration and the weakening river flow due to the altitudinal difference between the river and the sea level. As a result, groundwater and surface water quality will be decreased significantly.

The relocation is amplified with an inevitable condition of the geographic characteristic of the city. Jakarta is located in a volcanic archipelago which is flanked between the Indo-Australian oceanic plates and Eurasian plate. This tectonically active region has a high potential risk of earthquake as the subduction of these two plates is placed only 200 km northward from Jakarta (Isburhan et al., 2019).

In response to the extensive issues of sociological, economic, topographical, and climate change risks, Joko Widodo as the President for the Republic of Indonesia has announced plans to relocate its capital city from Jakarta to Borneo, potentially in the District of Penajam Paser Utara and Kutai Kartanegara, East Borneo (see Figure 1). Nur Azhar, Putri Fatima, and Tamas (2020) offer several reasons why this location is chosen, in which it is located near two major international airports, has access of Balikpapan-Samarinda toll road and Port of Semayang, abundant access to energy (both fossil and renewable) and clean water resources, and also it crosses the Indonesia Archipelagic Sea Lanes. One of the prominent reasons is it has relatively low seismic activity and is far from a subduction zone which means it is safer than Jakarta in terms of natural hazard risks.

Figure 1.1 Location of the current and new capital cities of Indonesia

1.2 PROBLEM STATEMENT

The concept of a forest city (or "Nagara Rimba Nusa") has been revealed as the new capital city is located in the largest forested area in Indonesia and considered to be one of the cores for the global biodiversity (Post, 2019). Consequently, the development of the infrastructure is rather focused more on the green measures and clean energy. The latter should be considered with a conscientious planning in supporting the national target to reduce greenhouse gas emissions to 29% compared to Business As Usual (BAU) in 2030 (DEN, 2017).

It is apparently seen that the government of Indonesia has tried to be more adaptable in response to the considerable climate change risks, environmental issues, pollution and traffic problems, and sociological influences. Nevertheless, the relocation plan could be questionable in regards of the sustainability of the new capital and its repercussions to the surrounding area. Van de Vuurst and Escobar (2020) warned about a major biodiversity catastrophe that could be happened as the effect of the relocation without multidisciplinary and sustainable transition. Borneo island itself has already lost around 30% of its forest within 50 years with primary forest being the most heavily affected (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014; Van de Vuurst & Escobar, 2020). Moreover, Borneo also has a few numbers of endemic species which have been categorized as critically endangered fauna such as Bornean Orangutan (*Pogo pygmaeus*) (Ancrenaz et al., 2008; IUCN, 2020). For these reasons, studying the relocation plan compounded with the climate-change and sustainability causes should be carefully put in the first place in order to bring a nurturing effect to the affected area rather than to be even more damaging.

The concept of sustainability is closely linked to the access of sustainable energy. Energy services have a profound effect on any elements of a city, such as productivity, health, education, food and water security, and communication services (Vezzoli et al., 2018). On the other hand, there are implications connected to energy, especially related to developing countries. Access to energy, availability of renewable resources, social, politics and economics issues become the hindrance in the development of sustainable energy. Thus, a sustainable energy development and energy planning is important to realise the concept of sustainable city for the new capital without overlooking all of these hindrances. Hitherto, there is no study or analysis that concerns the energy planning for the new capital city. Nur Azhar, Putri Fatima, and Tamas (2020) examined the environmental aspects of the relocation in accordance to disaster mitigation using a mental model approach. Van de Vuurst & Escobar (2020) gave their perspective of mass migration expected to occur linked to the biodiversity impacts. Nonetheless, no study specifically put the energy planning of the relocation at the first place. Thus, there is a need to account this aspect in order to comply with the national target of energy share without neglecting any trade-off or threat.

1.3 RESEARCH OBJECTIVES

This research aims (i) to analyse the energy model scenario for the power sector of the new Indonesia’s capital city until 2050 in accordance with the Paris Agreement and National Energy General Plan; (ii) to provide recommendations to the Indonesian government on the preferred power system of the planned new capital.

1.4 RESEARCH QUESTION

Main research question

How will the power system of East Borneo develop until 2050 with the relocation of the capital of Indonesia to the region if the system will be designed in accordance with the Paris Agreement on Climate Change? **(RQ)**

Sub research questions

1. How will the newly planned capital of Indonesia look like in terms of location, size, functions and activities? **(sRQ1)**
2. How would the energy system for the power sector of the new capital of Indonesia look like? **(sRQ2)**
3. What are the estimated CO_2 equivalent emissions impacts for East Borneo of the relocation of the capital of Indonesia? **(sRQ3)**
4. What are the implications of the relocation of the capital to East Borneo for the costs of power production in East Borneo? **(sRQ4)**

1.5 METHODOLOGY

Two scenarios of the East Borneo region will be built and compared with the help of the LEAP model in order to answer the research question and sub research questions. The two scenarios are 1) the power system of East Borneo without the newly planned capital (the Business-As-Usual (BAU) scenario) and 2) the power system of East Borneo with the newly planned capital (the Capital City Relocation (CCR) scenario). The perspective is analytical in its comparison of both scenarios to find out the impact of the newly planned capital on the power system in the East Borneo region. An in-depth explanation about the data analysis using LEAP is written in Chapter 3.

1.6 ETHICAL STATEMENT

This research is subject to ethical considerations concerning the purpose and methods to be deployed as it may contain some data privacy (i.e. from National Energy Council) and this research also may affect related stakeholders or institutions. This research upholds the principle of research integrity based on Netherlands Code of Conduct for

Research Integrity: honesty, scrupulousness, transparency, independence, and responsibility (KNAW et al., 2018). Therefore, confidentiality and transparency of data is upheld during accessing all of the research material.

1.7 DEFINING CONCEPT

The following key concepts are defined for the purpose of this research. These definitions are mentioned in consideration with the context of Indonesian government stipulation in purpose to be closely applied to Indonesia's situation:

Energy planning: the process of approaching national or regional targets through policies and strategies which derived from the analysis of energy sector scenarios.

Energy modelling: the process of formulating or simulating a model that focuses on energy as an economic resource and associated directly or indirectly with the decision-making process.

Energy mix: the group of different primary energy sources from which secondary energy for direct use is produced (% of ton oil equivalent).

Electricity generation mix: the group of primary energy sources contributes in the total electrical energy production (% of Megawatt hour).

New energy resources: energy resources that could be produced from a new technology, both from renewable or non-renewable energy resources, such as nuclear, hydrogen, coal bed methane, liquified coal, and gasified coal (Indonesian Government, 2014).

Renewable energy resources: energy resources that could be produced from sustainable energy resources that is not depleted when used, such as geothermal, wind, bioenergy, solar, hydro, and ocean thermal (Indonesian Government, 2014).

Capital city relocation: the movement of the national capital city, fully or certain part of it, to another geographical area within the country.

1.8 OVERVIEW OF THE THESIS REPORT

The thesis report is divided into five chapters. This chapter gives the information about the background, research objectives, and research questions of the research. The next chapter answers the first sub research question about the planning for the capital city relocation and also introduces the energy modelling tool. Chapter 3 explains the concept and method for the research design. Moreover, chapter 4 develops the energy modelling for the planned new capital city, answering the second, third, and last sub research questions. Lastly, chapter 5 summarize the content of the research based on the modelling result in chapter 4.

CHAPTER 2 PLANNING FOR THE CAPITAL CITY RELOCATION

This chapter is introduced with some past experiences of capital city relocations in other countries. Moreover, it elaborates the concept of the planned new capital city in East Borneo from the current condition to its planning concept in regards of the function and population. In the end, this chapter answers the first sub research question of this thesis (SRQ1).

2.1 INTRODUCTION: LEARNING FROM THE PAST

Displacement of a capital city is a remarkable case that happened in some countries during civilization throughout centuries. More than 30 countries have run the risk of relocating their capital cities. Rossman (2017) argued that capital city relocations are rather a typical theme in political development and were taken as the part of history of most nations rather than something extraordinary. He indicated four big groups of factors of placing a capital city: geographical, military, cultural, and political. Nevertheless, capital city movement turned into a more exceptional condition in the modern states as more contemporary and properly urban decisions were taken into account. Table A.1 in Appendix A shows the list of capital city relocations after World War II (Quistorff, 2015). It is shown from the table that some capitals were purposely built and some others only moved several functions partially to the new capital, namely Brazil, Pakistan, Belize, Nigeria, Malaysia, Myanmar, Palau, and South Korea. Brazil has moved its capital city from Rio de Janeiro to Brasilia in 1960. The city was specifically planned and built in four years to be the capital of Brazil in order to serve the needs of the whole population of this giant nation as it is sparsely populated and located more in the central compared to the overcrowded coastal city of Rio. The capital city relocation to the centre in order to be more neutral was also taking place in Nigeria, where the country had devised the new area in the centre of the country as the new capital, replacing Lagos in the coast which was already overpopulated. In other cases, Canberra as the new Australia’s capital was rather built in a political situation where the federation was commenced in 1901 and Melbourne was still the temporary capital at that time. To compromise a long dispute over whether Sydney or Melbourne should be the permanent capital, Canberra which is geographically located between them was chosen.

The latest capital city relocation and presumably most similar with Indonesia's planning is in Malaysia. Putrajaya was a planned city designed as the new federal administrative centre of Malaysia following the government's decision to relocate its federal capital in June 1993. The reason behind the relocation from Kuala Lumpur is to alleviate traffic congestion and overcrowded population in the former city (Chin, 2006). The area was chosen as it has a good accessibility to major transportation networks, pristine natural vegetation and land form, and also minimal negative impact to local communities. The construction of Putrajaya commenced in October 1996 and the seat of government started to shift to the new area in 1999. Entitling "City in a Garden – Intelligent City", Putrajaya tried to adopt the concept of sustainable urban city by integrating metropolitan parks with wetland, botanical garden, vegetation, and water bodies while also combining integrated neighbourhood and community by providing public transportation such as buses and monorail and also bicycle trails, efficient accessibility, intelligent telecommunication and information technology, and dynamic, lively and economic vitality. At that time, the city was planned to accommodate 335,000 inhabitants on 4,400 hectares of land.

Looking at the past experiences, the realisation of capital city relocations is varied among other countries. The duration from the conception to the realisation usually takes years or even decades. The conception of Brasilia started in 1827 and just realised by construction in 1956 until the capital was inaugurated in 1960 (Quistorff, 2015). During this period, the relocation plan was hindered and changed many times by political interests and unstable condition of the government (Quistorff, 2015). In other hand, the conception of Putrajaya only took around three years until it was realised in 1996 (Moser, 2010), while Nigeria need fifteen years to build its new capital in Abuja (Reva, 2016) and ten years for South Korea (Hur, Cho, Lee, & Bickerton, 2019). By this point, no study or evidence shows the energy policy or planning taken as concern in the relocation of capital city. The concept of green city with the consideration of energy transition to renewable and clean energy is undiscovered as the concept of sustainability and climate change adaptation are rather new and countries still put the economic development as the top priority at that time. Giving example to Putrajaya. Even though this new capital claimed itself as a sustainable urban city, Putrajaya is still using natural gas as the fuel source for its district cooling system. Furthermore, this city is also failed to actualise the concept of green city as it could not overcome the main shortcoming of its climatic condition (Moser, 2010). Lack of innovative and resourceful microclimatic features, ecological footprint minimisation, and correct green measures (shade trees or green roofs instead of decorative shrubs and trimmed hedges) in the design has resulted in weak resistance to intense heat during daytime. As the result, extensive usage of air conditioning which leads to GHG emissions cannot be avoided. In terms of mobility, there is little evidence of green and sustainability reflected in the public transportation as it still uses natural gas as the main fuel. Bicycles are also encouraged more as a recreation rather than as a mode of transportation.

Reflecting to a few preceding capital city relocations, it is going to be a big challenge for the government of Indonesia to realise its new capital city with the ideal conception which will be explained in the following sections. Thus, a proper and careful planning and urban design along with the support from the government and related stakeholders is needed with the concern of time and financial management.

2.2 EAST BORNEO IN A NUTSHELL: ENERGY CURRENT CONDITION AND GENERAL PLAN

East Borneo is a province in Borneo Island consisting of seven districts and three big cities (see Figure 2.1). As the fourth lowest population density in Indonesia with 439 trillion Rupiah of GDP (2015) and 3.7 million inhabitants (2019) in 127,347.92 km^2 of total area, East Borneo has some issues that are generally faced by low-populated provinces outside the Java-Bali region (DEN, 2019a). Most of the resources for electricity comes from conventional non-renewable resources which derived of 372 million litres of petroleum and 2,791 mmscf of natural gas (DEN, 2019a). Almost all areas within this province have been electrified, while some small villages in remote areas still use self-subsistent oil-fuelled generators to generate the electricity. Normally, the generator is operated from 6 to 10 PM every day. In this case, the fuel transportation becomes a concern as it takes a lot of effort to transport the fuel with inadequate road system. Solar energy is utilized in limited households and villages, especially in remote area where electrification from PLN is not reached. Until the end of 2017, there are 5,998 units of solar generators installed across 72 villages with total capacity of 479,840 W (DEN, 2019a). Another renewable resource utilized are micro-hydro and biogas. in 2015 to 92.43% in 2017 (DEN, 2019a). To summarize, energy resources potential and energy mix in East Borneo is presented in Table 2.1 and Figure 2.2.

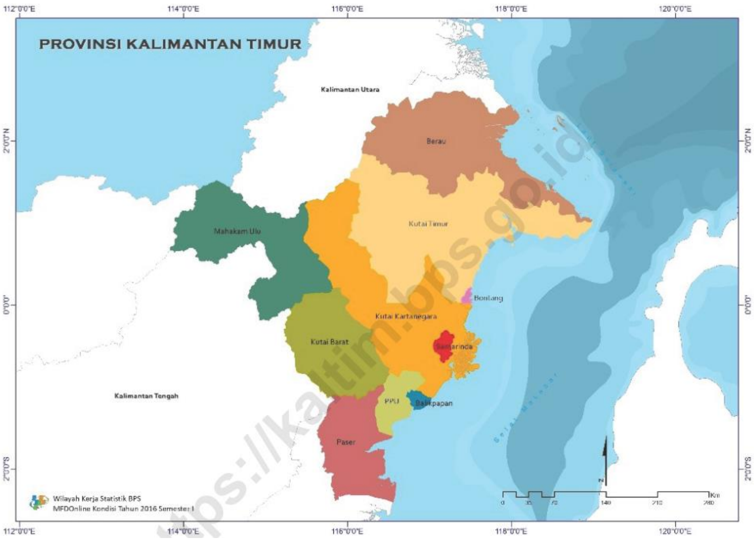


Figure 2.1 East Borneo district map

Table 2.1 Potential energy capacity of East Borneo (2015)

Resources	Potential Capacity	Unit
Petroleum	787,844,828	MWh
Natural gas	3,433,005,209	MWh
Coal	515,219,467,000	MWh
Geothermal	18	MW
Hydro	2,118.8	MW
Solar	13.479	MW
Bioenergy	1,086,14	MW
Wind	212	MW

Source: (DEN, 2019a)

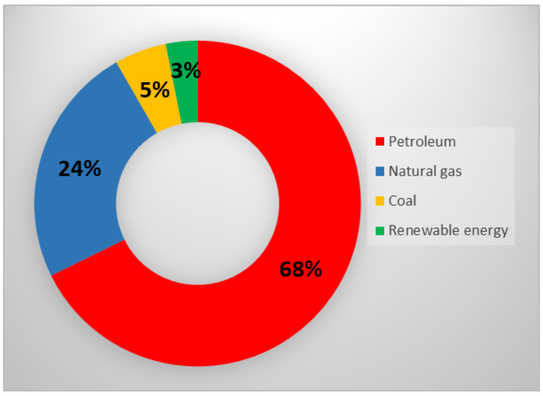


Figure 2.2 Energy mix of East Borneo (2015)

Source: (DEN, 2019a)

In power sector, electricity consumption is 880 kWh per capita and the total energy consumption is 2.18 TOE per capita. Hitherto, not all inhabitants in East Borneo have access to electricity. However, it shows improvement over time, which is indicated by electrification ratio (excluding off grid system) increasing from 87.55% (2015) to 92.43% (2017) (DEN, 2019a).

Based on current condition and energy modelling using LEAP conducted by the Department of Energy and Mineral Resources, the government of East Borneo has made energy general plan until 2050 to increase the utilization of renewable energy resources with 12.4% share in 2025 and 28.7% share in 2050 (DEN, 2019a). This target is enhanced with incentives for the utilization of renewable energy and energy conservation even though its framework is not put in detail yet to this moment. The electrification ratio is also planned to reach 100% in 2025 which means electricity is accessible for all inhabitants in the province.

In conclusion, conventional non-renewable energy resources still take the major part of electricity in East Borneo. With domination of non-renewable resources, the government took a tough decision way before the new capital city plan to apply energy transition and increase renewable portion in a very short period of time. Moreover, the capital city relocation will obviously be increasingly a burdensome for the government. The new planned capital should take more effort to consider the target of the district energy general plan in order to increase the utilization of renewable energy in their planning concept which will be explained further in section 2.3.

2.3 PLANNING CONCEPT

The planning concept for new capital city of Indonesia (IKN) was prepared based on New Capital City Relocation Plan by the Ministry of National Development Plan (PPN/BAPPENAS). The plan is limited in basic information on land use planning and zonation, regulation, function, and economical analysis, as the masterplan is still on progress and the law provision has not been enacted yet by the government.

The new capital city is designed with the ideal concept of “the best city on earth” (BAPPENAS, 2019). One of the main principles of the concept is to uphold the values of smart, green, beautiful, and sustainable. The concept of forest city is applied in these values as Kalimantan is the centre of biodiversity in Indonesia with 262 of 386 species of dipterocarp trees found in this island (FAO, 2011). With more than 1285 endemic tree species and some endangered faunas such as orangutans, Sumatran rhinoceros, pygmy elephant, and dugong, Borneo has lost a significant portion of its forest due to deforestation with only half of its forest remains today (Kieft & Liu, 2019). Therefore, the development of the forest city is expected to increase the quality of the forest in Kalimantan by enhancing the restoration of endangered species in the rainforest due to deforestation (BAPPENAS, 2019).

As part of the concept, the development of renewable energy is enhanced in the initial concept design of the new planned capital city. The government, through the National Energy Council (DEN), has enacted the National General Plan of Energy (RUEN), which adapted by each province with their District General Plan of Energy (RUED). In these documents, the government clearly stated the acceleration of renewable energy development as the strategy of climate change mitigation in order to meet Paris Agreement target, which is to control the increasing of the earth temperature not more than 2^{o}C (DEN, 2017). Through the Constitutional Law no. 30 of 2009 on Electricity, the government of Indonesia has set the share of new and renewable energy in the national energy mix up to 23% in 2025 and 31% in 2050 (Handayani, 2019). Besides that, the Constitutional Law no. 16 of 2016 about Paris Agreement Ratification states the commitment of the government to reduce greenhouse gas emissions up to 29% in 2030, with sector energy itself has the contribution to reduce GHG emissions up to 11% in 2030 (ESDM, 2015).

2.4 LOCATION

As it is mentioned in chapter 1, East Borneo is chosen as the province where the new capital city would be located. The criteria of the relocation area are explained by PPN Ministry as follow (BAPPENAS, 2019):

- Heterogeneity of population structure with low potential conflict. An harmonious social relations between the ethnic social groups in East Borneo and migrants has been constructed based on the value of cooperation or working together for mutual benefit without undermining the land distribution and equal access to economic resources (Wartiharjono, 2017). Despite the acceptance from the ethnic groups, indigenous territory mapping should be applied carefully to prevent the potential social conflicts (Putra, 2019).
- High accessibility of the location as the new capital is placed nearby two big cities in Borneo, Balikpapan and Samarinda. This gives benefit to the new capital city in regards of infrastructure. Some existing main infrastructure are Balikpapan-Samarinda and trans Kalimantan Highway, Syamsudin Noor and Aji Pangeran Tumenggung Pranoto International Airport, and the Port of Kariangau and Semayang.
- Low risk of natural disaster. The geographic features of Borneo which include being surrounded by the other large islands could aid in protecting the city from destructive coastal storm (Van de Vuurst & Escobar, 2020). The national agency for meteorological, climatological, and geophysics (BMKG) also claims the relatively low seismic activity in Kalimantan as it is far from the subduction zone (Nur Azhar et al., 2020).
- The availability of extensive government-owned land for the future economy growth. East Borneo has an extensive amount of forest land with 36% and 35% portion respectively for tree farming and limited tree farming (Borneo, 2016).
- The availability of water supply and soil for construction. The water bodies consist of three water reservoir, four rivers, and four watersheds. The soil characteristic is also qualified for building construction.

The new capital city will be located in two adjoining districts, Penajam Paser Utara and Kutai Kartanegara. The total area of the new capital city is 56,180.87 hectares. The planned centre area for the government itself is 5,644 hectares. The capital has a total authority area of 256,142.74 hectares, in which the expansion plan will be carried out in the future. This total authority area will include part of the tree farms in Penajam Pasir Utara and conservation area (Bukit Soeharto) in Kutai Kartanegara. The map for this new capital city is shown in Figure 2.3.

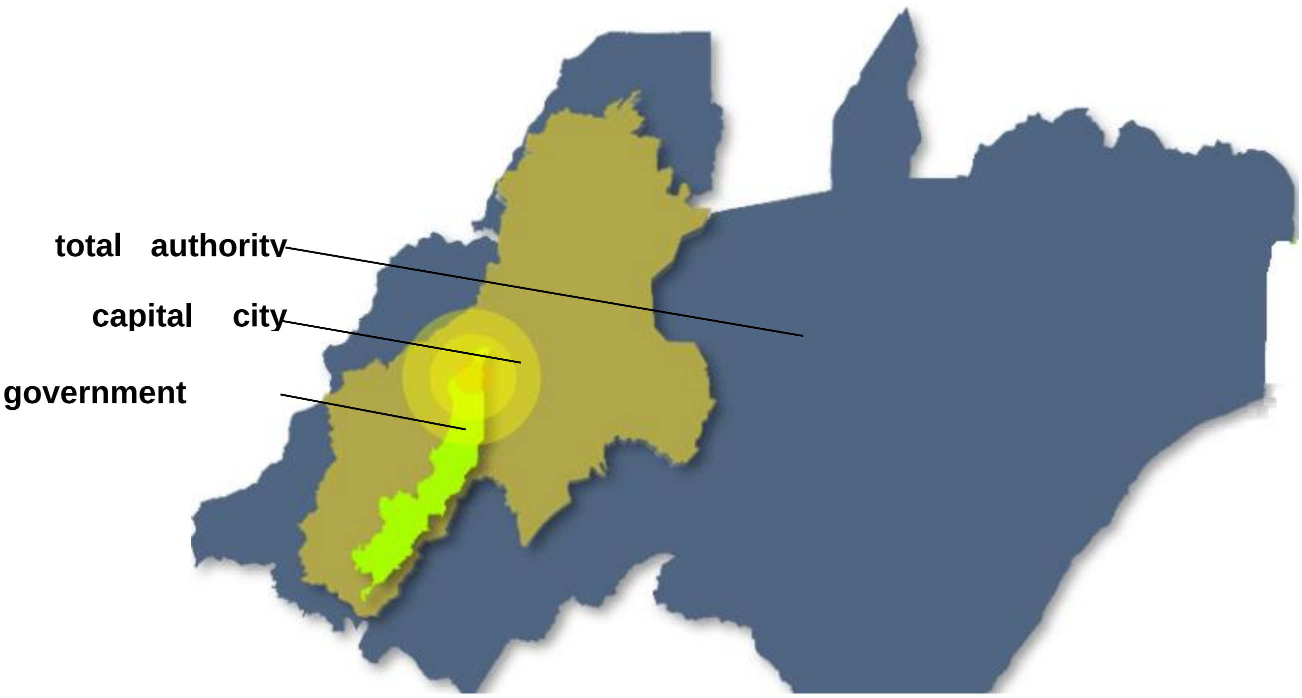


Figure 2.3 Area mapping of the new capital city

Source: (BAPPENAS, 2019)

2.5 FUNCTION

As it is shown in Table 2.2, the plan for the city functioning is divided into two consecutive period with four main categories: households, business, industry, and general. The first period (2021-2024) mainly focuses on the construction of the main function of the government. Thus, the building for the presidential palace, executive, legislative, and juridical committees are prioritized along with the headquarters for defence institutions (national army and police). Subsequently, the housing for government officials and civil servants are built. Moreover, the infrastructure for business centre and public facilities are developed within this stage. In the second period (2025-2029), the business and industries sectors will be started to build. There is no detail yet about what kind of industries will be developed but it is stated that the industries should combine the aspects of high technology and clean energy in their operation. Households for embassies and other public places such universities, sport centre, museum, cultural park, and national park will be constructed within this period (BAPPENAS, 2019).

There were six utilities services planned for the new capital city: water supply, drainage, waste processing, sewage treatment, power plant, and grid system. Two new water reservoirs will be built to accommodate the new demand of water, while 500 MW of power plant is estimated to be generated to meet the increasing demand of electricity. As it is stated before, new and renewable energy resources will be the first option for the technology of the power plant in order to meet RUEN and RUKN target in compliance with the Paris Agreement (BAPPENAS, 2019).

The application of smart grid for electricity distribution is included in the planning concept along with the value of a modern, smart, and high-tech city. The national electricity general plan (RUKN) defines smart-grid as a digital technology that enables two-way communication between the electricity companies and its customers, and it also enables the sensing along power transmission and distribution networks (ESDM, 2015). With its approaches such as integrated storage system or demand side management mechanisms, a smart grid can handle the intermittent and hard to control nature of renewable energy generation. Moreover, this kind of technology can give solutions for demand growth, energy access, and renewable integration (Römer, Julliard, Fauzianto, Poddey, & Rendroyoko, 2017).

Table 2.2 Functioning planning for the new capital city

	2021-2024	**2025-2029**
Households	• VIP housing • Civil servants housing • Public housing	• Diplomatic compound
General	• Government's building (presidential palace, executive, legislative, and judiciary building) • Headquarters of national army forces and police • Green open space	• University, science and techno park • Sport centre • Museum • Cultural park • National park

	• Airport and port refurbishment
	• Military base
	• Utilities:
	  ○ Water supply
	  ○ Drainage system
	  ○ Waste processing
	  ○ Sewage treatment
	  ○ Power plant and grid systems	

Business	-	• Shopping mall • Business centre • Convention hall
Industry	-	• High tech and clean industries

Source: (BAPPENAS, 2019)

2.6 POPULATION

As the initialization, the new capital city is designated as the new administration seat of the government of Indonesia. There will be around 182,462 of civil servants will be relocated from Jakarta to East Borneo, with 79 % comes from the ministries and 21% from other government bodies/institutions. The ministries/bodies/institutions to be relocated will be defined in the national constitutional law. Besides that, around 53,483 national army forces and polices is likewise moved to the new capital. Along with families and other related personnel, 1.5 million of people will be migrated to be the inhabitants of the new capital city within the first period of the relocation (BAPPENAS, 2019).

2.7 EVALUATION

An ex-ante evaluation of the new capital city is conducted by using the Plan-Process-Results (PPR) methodology focuses on the plan proposed by Oliveira and Pinho (2015). This method provides a strong morphological dimension evaluation with a sound and substantiated judgment to a built environment which now linked to the purpose-built new capital city (Oliveira & Pinho, 2015). The method consists of three main criteria – rationality, conformance, and performance – in which each criterion corresponds to a few specific criteria. In this stage, only rationality and conformance can be assessed as the plan has not been implemented yet. Each criterion is then assessed and resulted in attributed sub-criteria value. The value is divided into four levels: letter D corresponds to a highly negative result, C to a negative result, B to a positive result, and A to a highly positive result. These sub-criteria values are then being averaged for each main criterion to be averaged again until it gets the final value. Below is the description of the assessment for each criterion for the relocation plan.

1. Plan rationality
    a. Interpretation of the legal context. In this case, the plan hitherto has not had a legal framework yet. It is developed under the coordination of PPN/Bappenas and PUPR ministries while still waiting for the draft bill of president to be enacted. Under this circumstance, the relocation plan has no legal power which resulted in a very weak indicator value (D).
    b. Relevance of the plan to the main objectives. Reflecting in the plan target to overcome the natural disaster threat due to climate change and geographical condition, the relocation plan offers a sound solution to maintain the stability of administrative function as it offers a strategic location that is safe from the threat of sea level rise and volcanic eruption. However, the new capital cannot address the issue of high population density, traffic congestion, and air pollution as it only moves partial function of the government. The issue will still occur if there is no measure to the remaining function and population in the current capital. By these reasons, the relevance gives a weak indicator value (C).
    c. Internal coherence. This means the relevance and linkages between the main components of the plan, such the objectives, planning concept, the location and classes of areas, infrastructure and the mechanism for plan implementation (Oliveira & Pinho, 2015). The latter is not discussed further as it is still not described yet in the plan. The relationship between the objectives and planning concept shows a positive coherence as the value of smart, green, and sustainable in the city can enhance the objectives of the new capital city. Meanwhile, the choice for the location of the new capital is in line with the

objective. Nevertheless, the correlation between the location and the planning concept is still questionable as it could be a threat for the conservation area without an environment protective measure and mechanism. By these reasons, the internal coherence gives a weak indicator value (C).

d. External coherence. The external plan discussed here is referred to the district general plan of energy (RUED). The conception of sustainable city for the new capital is placed on the coherence between the RUED plan and the relocation plan as it goes along with the plan to enhance renewable energy. Hence, the external coherence gives a good indicator value (B).

e. Participation in plan making. Hitherto, the local government has been actively involved in the plan making with the assistance by Bappenas/PPN and PUPR ministries. Public participation has been initiated by PUPR through an open urban design contest for the new capital city. There is also an open discussion and socialization through social media for people to get informed and engaged with the issue of the new capital. Nevertheless, directly affected people, which in this case are the citizen of Penajam Paser Utara and Kutai Kartanegara, has not yet been involved in the city plan (Hamdani, 2020). In his journal, Hamdani (2020) also found that there is no platform for indigenous people to give opinions and suggestions. Lack of participation of public in the affected area gives a weak indicator value for this criterion (C).

2. Plan conformance

a. Effectiveness. The effectiveness of this plan is shown in how the development of the plan can be realised as expected. The concept of sustainable city seems hard to realise reflecting from the past experiences of capital city relocation from other countries which showed no evidence of success story to implement this concept. This is further compounded with the fact that conventional fuels, especially coal, are still relied upon the primary fuels. Even though DEN and ESDM have created strategic plan through RUED for increasing the renewable resources portion in the electricity mix, the development of non-renewable power plant is still included in this plan. Hence, the effectiveness criterion gives a weak indicator value (C).

b. Commitment of resources. The resources here are referred on the planning staff and the financial resources available (Oliveira & Pinho, 2015). By this point, Bappenas/PPN as the main planner has actively contributed to the plan making and coordination with the local government and related functions. In regards of the financial resources, the new capital city is budgeted with 34 billion USD or equal to 3.27% of annual GDP (Shimamura & Mizunoya, 2020). This is a sound budget if compared to 20 billion USD of projected cost in Sejong City (Hur et al., 2019) and 3% of GDP for Brasilia (Quistorff, 2015). However, the government heftily put more than half of the budget in public-private partnerships scheme and private sector, while only around 20% budget is subsidized by the government (Shimamura & Mizunoya, 2020). This brings more uncertainty to this point as there is hitherto no fixed partnership strategy that can guarantee the funding for the new capital. This reason gives a weak indicator value for the criterion (C).

The empirical results gathered in this evaluation point to a weak/negative assessment of the relocation plan (see Table 2.3). The specific criteria with the highest score is the external coherence while the lowest score is the interpretation, both in the general criterion of rationality.

Table 2.3 Evaluation results for the relocation plan

General criteria	Specific criteria	Score	Average Score
Rationality	Interpretation	D	**C**
	Relevance	C	
	Internal coherence	C	
	External coherence	B	
	Participation in plan making	C	
Conformance	Effectiveness	C	**C**
	Commitment of resources	C	
			C

2.8 CONCLUSION

The planning for the new capital city of Indonesia is hitherto under preliminary study from the ministry of PPN/BAPPENAS. Up and until this thesis report was written, the information published about the new capital is limited, consisting a brief explanation of the location, area, function, and population. The new capital will be located in East Borneo, precisely in the district of Penajam Paser Utara and Kutai Kartanegara. The total area of the new capital city is 56,180.87 hectares, with 5,644 hectares is allocated for the centre area of the government. The capital has a total authority area of 256,142.74 hectares, in which the expansion plan will be carried out in the future. Around 1.5 million people are estimated to be relocated from Jakarta to the new capital. There will be two periods of relocation stage. The first period will be taken in 2021-2024, in which the government function is prioritized along with some critical infrastructure, such as airport and port, and utilities. The function of business and industries will be constructed in the second period, 2025-2029, along with some public facilities such as university, shopping mall, and museum. With the increasing number population and the construction of some infrastructure, the demand for electricity will certainly rise in the following years. Additional power plant is planned to meet the electricity demand of the new capital with capacity up to 500 MW. However, the new capital city is designed without neglecting the national and district energy plan target to reduce GHG emissions and increase the share of renewable energy in compliance of the Paris agreement.

Reflecting to past experiences of capital city relocations from other countries, realising the new capital into green and sustainable city is a tough challenge for the government as there is no evidence where new capital succeeded in implementing sustainable concept in their city. Moreover, the relocation plan is still considered weak because there is no legal framework and lack of rationality and conformity regarding to the current condition of Indonesia in general and East Borneo in particular.

CHAPTER 3 MODELLING APPROACH

3.1 INTRODUCTION: ENERGY PLANNING AND ENERGY MODELLING

There are a few definitions of energy modelling. It was defined a long time ago as the process of formulating a model that focuses on energy as an economic resource and associated directly or indirectly with the decision making process (Samouilidis, 1980). Rebelatto & Frandoloso (2020) described energy modelling as a way to boost the performance and control of an energy system. Energy modelling can be used to explore the energy setting in regional or global scale (Urban, Benders, & Moll, 2007) with time scale in the near future or to a reasonable long term (Pokharel et al., 2012). Kydes, Shaw, & McDonald (1995) defined the long term in a time period between 25 to 50 years ahead.

Energy models can be categorized into several categories based on different approaches. Van Beeck (2003) characterized energy model based on analytical approach (top-down and bottom-up), future perspective (forecasting, scenario analysis, back casting), special purposes (energy demand, energy supply, impact assessment, appraisal), underlying methodology (econometrics, macroeconomics, economic equilibrium, optimization, simulation, spreadsheet, and multi-criteria methods), mathematical approach (linear programming, mixed integer programming, and dynamic programming), data requirements (qualitative and quantitative, desegregate and aggregate), time horizon (short, medium, and long term), and geographical coverage (local, national regional, and global).

In regards of long-term energy forecasting, Ouedraogo (2017) divided the modelling tools into several categories: simulation (e.g. RAMSES, BALMOREL, LEAP, WASP, etc.), scenario (e.g. MARKAL/TIMES, MESSAGE, LEAP, etc.), equilibrium (e.g. MARKAL, PRIMES, etc.), top-down (ENPEP-BALANCE, LEAP, etc.), bottom-up (HOMER, RAMSES, MARKAL/TIMES, MESSAGE, LEAP, etc.), operation optimization (BALMOREL, MESSAGE, RAMSES, etc.), and investment optimization tools (MESSAGE, MARKAL/TIMES, RETScreen, etc.). As these models provide insights of how the energy system would evolve in the future, they become more developed to comply with what the user needs.

Modelling energy system in developing countries is quite challenging and complex as there are some distinctive factors possessed within developing countries. High reliance on conventional non-renewable energy resources, the existence of large informal sectors, inefficient energy sectors, poor performance of power sector, supply shortages, energy poverty, inequity in energy access, rapid increase in electricity demand are many characteristics of energy sectors in developing countries (Ouedraogo, 2017). Many scholars have reviewed these characteristics in regards to the relevance of the energy model to the targeted countries. The fundamental differences between developed countries and developing countries may preclude the adoption of many existing energy models in developing countries as most of them are replications of energy system in developed countries (Irsyad, Halog, Nepal, & Koesrindartoto, 2017). Urban et al. (2007) suggest a simulation model in which a bottom-up approach is preferred as it does not assume the perfect market and optimal behaviour compared to the optimization approach do and it overcomes the contradictory economic assumptions that the top-down model offers. On the other hand, Pandey (2002) and van Ruijven et al. (2008) suggest to still use the top-down approach by modifying the model's assumption in accordance with developing country's characteristics. Therefore, an analysis with a more country-specific or regional focus is preferred with some indicators relevant to most developing economies such as resource management, assessment of energy alternatives, economic and technical challenge in accordance with the transformation of the energy infrastructure from centralized to decentralized, and financial vulnerabilities in households (Debnath & Mourshed, 2018). Nevertheless, integrating both top-down and bottom-up approaches in conventional energy modelling will improve the robustness of the result in conducting energy model analysis (Irsyad et al., 2017).

The Low Emissions Analysis Platform (LEAP) is an energy model tool developed by the Stockholm Environment Institute (SEI) which combines both bottom-up and top-down approaches with simulation-based methods and has been used in 190 countries. Bottom-up models describe current and prospective technologies in detail and top-down models more determine the energy system in terms of the broader economy and aggregate relationships which derived empirically from historical data. Combination of both approaches in LEAP gives more advantage than other models as it creates an integrated energy-economy model by connecting the technological details in bottom-up models with the reliance on real market data in top-down model (Böhringer & Rutherford, 2011; Rivers & Jaccard, 2005). Moreover, LEAP has been analysed to address a large number of developing countries' characteristics (Urban et al., 2007), making it becoming the de facto standard for energy modelling tools in the developing world (Heaps, 2020). Indonesia became one of the 32 countries which use LEAP as their energy planning tools in the basis for their Nationally Determined Contributions on Climate Change (NDC) in order to comply with the Paris Agreement. Another benefit that LEAP offers is its low initial data requirements and free-subscription for developing countries users, making it easier to use in the case of Indonesia.

3.2 LEAP DATA ANALYSIS

Combination of quantitative and qualitative methods is applied in analysing the data. Quantitative methods take a significant role as all of the data are inputted and analysed in the LEAP energy modelling which is used as the primary tool in this research. The detail of the LEAP structure and how it is used this research is explained in research framework.

3.2.1 Research Framework

The scheme of research framework of this research is elaborated in Figure 3.1.

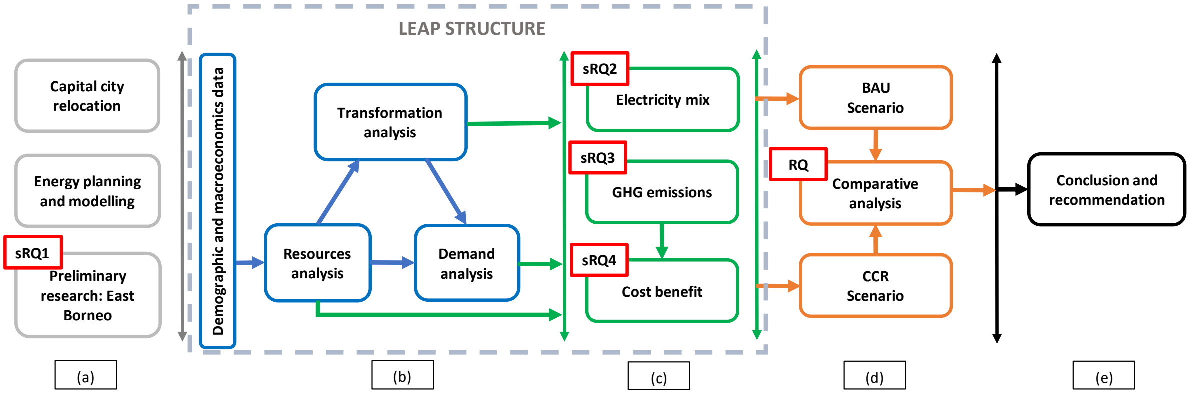


Figure 3.1 Research framework

The LEAP structure is shown in the dashed box in Figure 3.1. It is consisting of three components of analysis: resources, transformation, and demand. The model input consists of demographic and macroeconomics data along with electricity data of the technology used in the analysis. The input of this data is then calculated by LEAP with the algorithm explained in Appendix B. The model output of the analysis is then divided into three components: the technology added capacity which is interpreted as electricity mix, GHG emissions, and cost benefit.

In general, the research framework of this research is conducted in the following sequences:

(a) First step is conducting the literature review and preliminary research of the current condition of the research target in regards to energy and electricity planning. In this step, the basis for the CCR scenario is made using scientific and logical assumptions to answer the first sub research question (sRQ1). Review on energy models is also carried out to determine the best model for the analysis and research material needed. This step is already covered in chapter 2.

(b) Analysis of electricity mix is taken into two scenarios, Business-as-Usual (BAU) scenario and Capital City Relocation (CCR) scenario. Both scenarios are analysed using LEAP in which all related data consisting of demographic and macroeconomic data are inputted into several steps within the model. Resources analysis will be focused on the supply side for the primary energy used, such as petroleum, coal, natural gas, or solar and wind. Output of the resources is carried out in transformation analysis where electricity generation and distribution are taken place. Moreover, outputs of both resources and transformation are the input for demand side analysis which includes all sectors related to electricity usage. Validation of LEAP is conducted prior the scenario analysis using historical data from the past.

(c) Result of the LEAP model for both scenarios is separated into three aspects: electricity mix, GHG emissions, and cost analysis. All of these aspects answer the remaining three sub research questions.

(d) Comparative analysis is conducted between both scenarios.

(e) Implication of the capital city relocation is concluded based on the result of the comparative analysis. Recommendation is then carried out in this final step.

3.2.2 Validation of Data Analysis

The LEAP model for East Borneo's power system is validated using the data from 2010 as the base year and then the expansion of power generation capacity is simulated within the period time between 2011 and 2018. The validation is conducted by using the optimization function in LEAP. This function is intended to get the capacity of the power generation addition with the least-cost technology at the end of the period based on the electricity demand in the base year. The output from the simulation is then compared with the actual data of electricity generation. The input and output parameters for this validation step are summarized in Table 3.1. The input for the electricity demand is the actual data of counted electricity consumption from 2010 to 2018 which is derived into four sectors: households, business, industrial, and general/public. Other parameters such as transmission and distribution losses, and economical costs are also based on actual data. Meanwhile, planning reserve margin, interest rate, and characteristics of the technology mix are assumed based on the literature (see Appendix C). Energy load shape data is gathered using the data from Java-Bali model from Kamia Handayani's thesis (2019) with that assumption that the load shape of East Borneo and Java-Bali is similar. All of these inputs will then be calculated by LEAP to get two outputs, the additional capacity of the electricity generation and the composition of technology mix for the additional capacity. The detail of this calculation is explained in Appendix B.

The technology mix during this period still mainly came from conventional fuels. Based on PLN statistical report (PLN, 2011), coal (steam turbine), natural gas (gas turbine), natural gas combined cycle (NGCC), and diesel are the technology used for power generation in East Borneo in 2010. Diesel power plants have the largest capacity, generating 65% of the total electricity mix. This is because during this period, exploration of oil was still enhanced with some productive wells along with the high demand of oil consumption as the effect of fuel subsidy from the government (Akhmad & Amir, 2018).

Table 3.1 Parameters for LEAP validation

Input parameters	Model outputs
Electricity demand (2010 – 2018)	Additional capacity for electricity generation (2018)
Transmission and distribution losses	Technology mix for additional capacity (2018)
Energy load shape[a]	
Planning reserve margin[b]	
Characteristics of technology mix for the electricity generation	
Capital cost[c]	
Fixed[d] and variable[e] operation/maintenance cost	
Fuel cost	
Interest rate	

[a]Energy load shape: seasonal and time-of-day variation in the energy consumption in a specific period of time (Heaps, 2020).

[b]Planning reserve margin: amount of reserved electricity generation capacity available against peak loads (%) (PLN, 2019a).

[c]Capital cost: fixed, one-time expenses incurred to build a power plant.

[d]Fixed operation/maintenance cost: non-avoidable cost incurred in the operation of the plant, including the planned and unplanned maintenance (IESR, 2019).

[e]Variable operation/maintenance cost: variable costs other than fuel costs including consumables (IESR, 2019).

Handayani, Krozer, & Filatova (2017) explained the optimization setting in LEAP which is divided into two steps. The first step is the capacity addition where the input data of additional capacity from different technology within the period is added. Using the OSeMOSYS solver[1], LEAP controls the type of the new capacity added and the year when it will be added based on annual demand and cost optimization. In calculating

[1]OSeMOSYS solver is a type of optimization model for long-run energy planning using open-source programming language which initially design for developing countries.

an optimal system, LEAP takes into account all of the relevant running costs and benefits incurred in the system such as capital costs, decommissioning costs, fixed and variable operating and maintenance costs, fuel costs, and environmental externality values (Heaps, 2020). The decommissioning costs and environmental externality values such as pollution damage or abatement costs are neglected in this research as there is no reference available. The second step is the electricity dispatch from each type of power supply. In this step, LEAP controls the dispatch of electricity from each technology based on the output of the solver for the running cost. Finally, the combination of the technology with the least cost available will be shown as the result.

The optimization setting for the electricity generation capacity in East Borneo from 2010 to 2018 shows an accurate result. As it is shown in Table 3.2, LEAP gives the added capacity for the electricity generation from 2010 to 2018 slightly below the actual capacity with only 2.07% difference. Meanwhile, the technology mix resulting from the LEAP shows 100% coal as the technology added, compared to the actual mix where coal only gives 79% portion of the electricity mix. This is due to the fact that the operating and maintenance cost of coal power plants inputted on LEAP is much lower than the other technology. Borneo island is the biggest coal producer in Indonesia. Thus, the distribution cost of coal within this island is cheaper. This is also the reason why coal power plants are still used in RUED as the primary fuel for electricity generation in East Borneo. Nevertheless, the LEAP calculations are still reliable and can be accepted to be used in this research in regards of some limitations in data input and assumptions.

Table 3.2 LEAP validation result

	Actual data	**LEAP optimization settings**	**Difference**
Cumulative electricity generation capacity added 2010 - 2018	662.3 MW	648.6 MW	2.07%
Technology mix of the added capacities	Coal: 79% Natural gas: 21%	Coal: 100%	

3.2.3 Conclusion

LEAP is chosen as the energy modelling tool used in this research as it combines bottom-up and top-down approaches which gives more integrated technical-economy model. LEAP also well-known to be used in developing countries and it is commonly used for energy modelling in Indonesia as it is available with free-subscription for developing countries. LEAP is structured in this research as the primary tool to analyse the resources, demand, and transformation of electricity. Later on, LEAP will calculate the input of demographical, economic, and technology data and generate the output into three categories: electricity mix, GHG emissions, and cost benefit. These outputs furthermore will answer the last three sub research question. Moreover, A series of historical data of East Borneo electricity is used to validate the data analysis using LEAP. The results of the validation show an acceptable deviation between the LEAP simulation output and actual data which implies that the tool can be used reliably for this research.

CHAPTER 4 ELECTRICITY MODEL ANALYSIS RESULTS

4.1 THE BUSINESS AS USUAL SCENARIO

4.1.1 Demand side analysis

Electricity demand in East Borneo in this scenario is analysed based on the data from The National General Plan of Electricity 2019-2038 which derived into five sectors: households, business, industrial, general/public, and transportation (ESDM, 2019). 2019 data is inputted in LEAP as the base year while the data from 2020 until 2050 is inputted in the BAU scenario. As it is provided only until 2038, the data is extrapolated to 2050 using a polynomial second order equation in Microsoft Excel. The equation for the electricity demand per sector is shown in Table 4.1.

Table 4.1 Equation for electricity demand 2019-2050

Sectors	Equation	R^2 value
Households	$y = 8.31x^2 - 33539.46x + 33823647.41$	1.00
Business	$y = 2.70x^2 - 10874.54x + 10952613.59$	1.00
Industrial	$y = -3.83x^2 + 15603.25x - 15901459.88$	0.96
General	$y = 8.46x^2 - 34201.39x + 34559321.29$	0.99
Transportation	$y = 6.82x^2 - 27589.79x + 27883283.18$	1.00

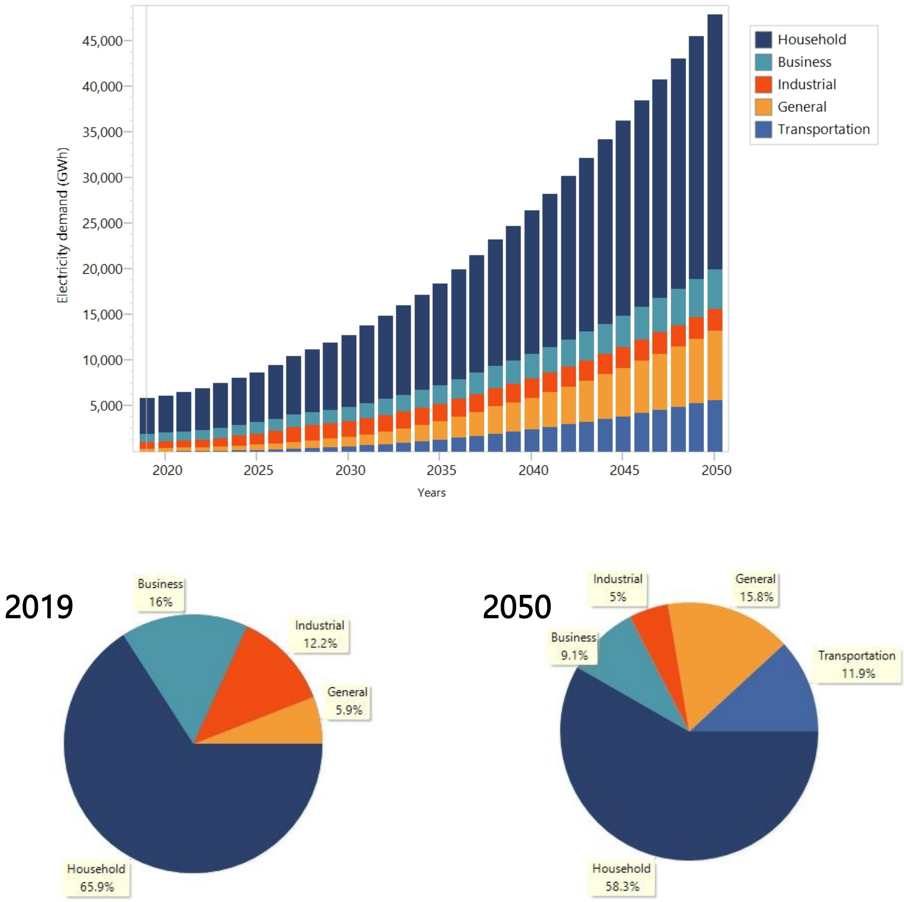


Figure 4.1 Electricity demand 2019 - 2050 (BAU scenario)

The electricity demand trends from 2019 to 2050 is presented in Figure 4.1. The electricity demand in East Borneo is projected to grow by around 7.4% per year. Based on this projection, the demand is estimated to be increased from 5,783 GWh in 2019 to 47,924 GWh in 2050.The household sector dominates the portion of the demand with 65.9% in 2019 and 58.3% in 2050. The second fastest growing sector is the general/public sector, which is started in 5.9% in 2019 after which it will grow until 15.8% in 2050. Business sector portion is 16% in 2019 but the portion then reduced to 9% in 2050. Industrial sector is also reduced in terms of portion with 12.2% in 2019 and 5% in 2050, giving it the least portion in 2050. Transportation sector takes a new role as it will be introduced in 2020 with the initialization of electric cars program and grows until it reaches 11.9% portion in 2050.

4.1.2 Electricity mix analysis

The electricity mix is defined with the data of electricity demand from section 4.1.1. and some assumptions shown in Appendix D. Some data parameters such as planned reserve margin, interest rate, load shape, capital cost, and characteristic of technology mix is assumed to be the same with the data from LEAP validation. However, other parameters such as transmission and distribution losses, operation and maintenance cost, and fuel cost is updated based on the newest data in 2018. The added capacity of power generation is inputted based on the scenario of District General Plan of Energy in East Borneo 2019 where renewable energy resources such as hydropower, solar PV, and biomass are started to be introduced in the electricity mix along with other non-renewable resources (DEN, 2019b). The added capacity is calculated internally by LEAP which is then called the endogenous capacity. The calculation of the endogenous capacity is processed in order to maintain a minimum planning reserve margin (Heaps, 2020). LEAP adds the endogenous capacity along with the current capacity (called exogenous capacity) in a specific year within the time period based on how quickly the electricity demand increases and the initial reserve margin.

The result of the calculation of electricity mix is shown in Figure 4.2. The capacity of electricity generation is increased from 1.2 GW in 2019 to 152.6 GW in 2050. Coal still gets the biggest portion of the electricity mix with 46.37% in 2050. As East Borneo is the province with the largest coal reserves in the country, it can be seen that the government will continue to try to harness the potential of coal in the future. However, the development of renewable energy power plants also takes part in this scenario. With 15.95% of biomass, 6.49% of hydropower, and 4.93% of solar, the electricity generation from renewable energy resources takes 27.3% of the total electricity mix in 2050. This result seems to imply that the national target of renewable energy mix of 31% in 2050 is not achieved. Nevertheless, the government has proportional targets for each province considering the economic and social aspects in developing renewable energy. Thus, this target already is set in compliance with the national target of electricity mix and furthermore, Paris Agreement target. The analysis about this target is discussed later in section 4.3.

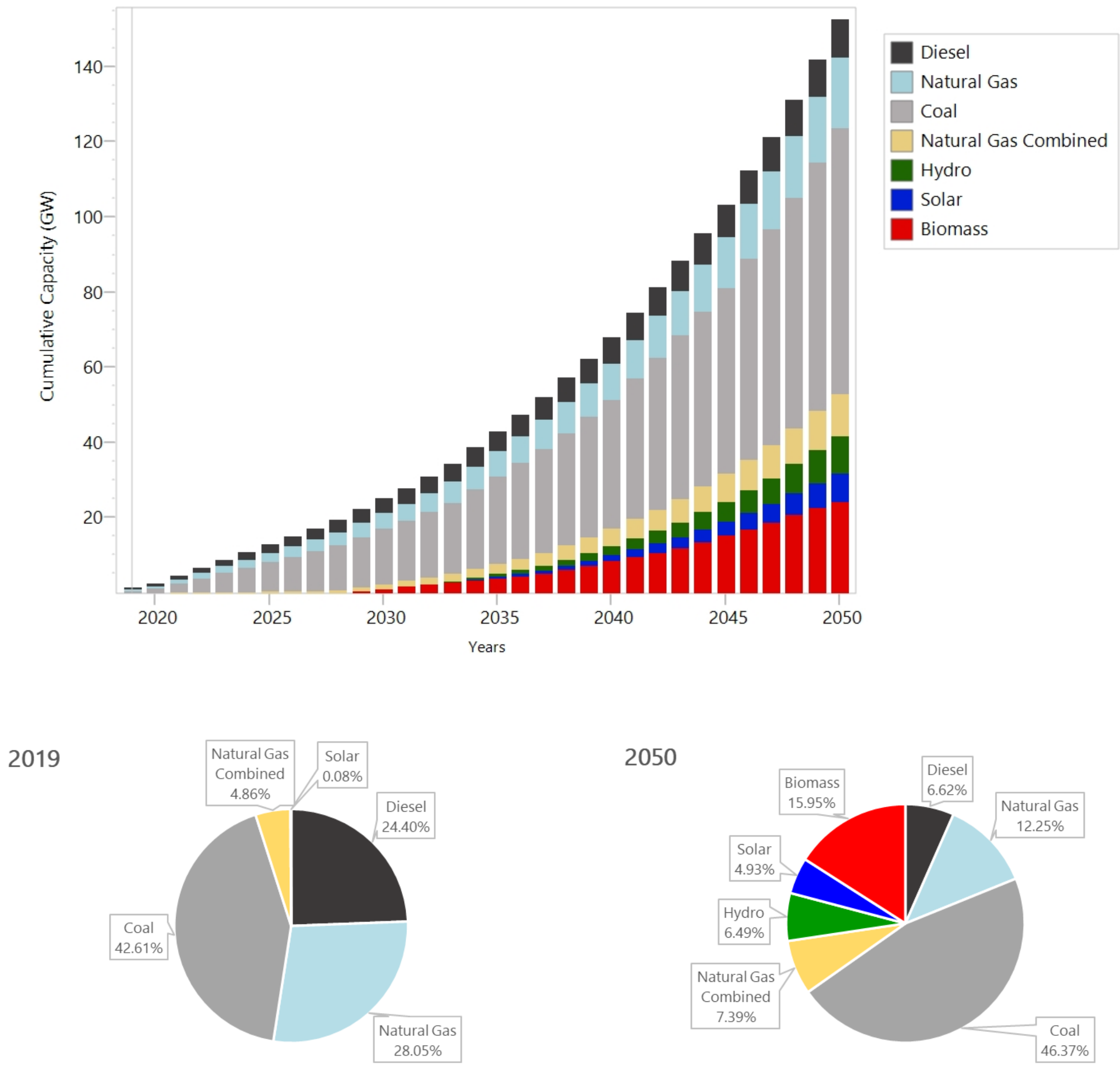


Figure 4.2 Electricity mix 2019 - 2050 (BAU scenario)

4.1.3 GHG emissions analysis

The environmental loadings for the electricity generation in each technology is calculated by LEAP based on the Intergovernmental Panel on Climate Change (IPCC) Tier 1 emission factors (Heaps, 2020). The emission factors in Tier 1 methods use readily available national or international statistics in combination that should be feasible for all countries (Rypdal et al., 2006). Based on IPCC Good Practice Guidance (Rypdal, Flugsrud, & Irving, 2000), Tier 1 should be chosen if there is no inventory data for more than one year and country-specific uncertainty estimates available. In this case, At the moment, Indonesia only has CO_2 data for emission factor to be used in Tier 2 methods (ESDM, 2017). Thus, Tier 1 methods with its default emission factors from IPCC are chosen in this analysis to comprise all other elements of greenhouse gas emissions alongside with the availability of the data in LEAP database.

The GHG emissions captured in the analysis are divided into three components: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The emissions are shown by measuring the Global Warming Potential (GWP) in CO_2 equivalent basis (Forster et al., 2007). The GWP was developed to allow comparisons of global warming impacts of different gases within the time horizon (US EPA, 2017). Direct GHG emissions are identified at the point where emissions are produced in 100 years of time horizon (Heaps, 2020).

The total GHG emissions in this scenario based on its technology is shown in Figure 4.3. It is shown that the emissions are increased drastically from 0.6 million metric Tonnes of CO_2 equivalent in 2019 to 4.9 million metric Tonnes of CO_2 equivalent in 2020 and then will reach 28.7 million metric Tonnes of CO_2 equivalent in 2050. The biggest contributor of total GHG emissions will be the coal power plant with 95.1% of total emissions in 2050, followed by NGCC (3.3%), biomass (0.8%), natural gas (0.5%), and diesel (0.3%). Most of the GHG emissions will come from CO_2 with 98.8%, followed by N_2O (0.8%) and CH4 (0.4%).

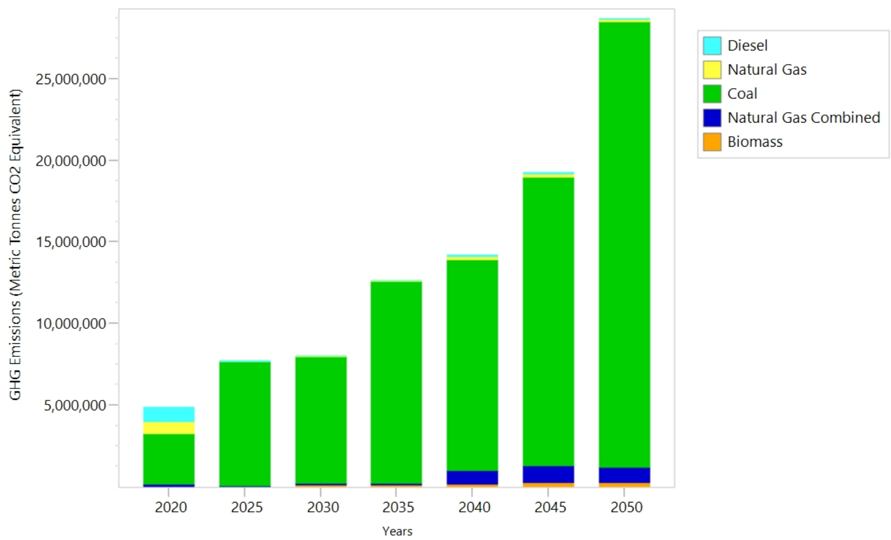


Figure 4.3 GHG emissions 2019 – 2050 (BAU scenario)

The trending of GHG per type can be seen in Figure 4.4, 4.5, and 4.6. Figure 4.4 displays the CO_2 emissions in 2019 – 2050. The emissions were dominantly produced by diesel in 2019 but then coal takes the major contributor of CO_2 emissions in 2020 with 3 million metric tonnes CO_2 equivalent, taking 63.4% of the total CO_2 contributor in the year, and then will increase to 27,1 million metric tonnes CO_2 equivalent, contributing 95.8% of CO_2 emissions in 2050 (28.3 million metric tonnes CO_2 equivalent).

Figure 4.5 shows the CH_4 emissions trending in 2019 – 2050. Contribution of CH_4 emissions mainly came from diesel in 2019 and 2020. The technology dispatch which calculated endogenously by LEAP indicates that biomass will start operating in 2029. As the effect, the emission of CH_4 will be rapidly increased in this year, starting with 33.9 metric tonnes CO_2 equivalent in 2029 and rising up to 108 thousand metric tonnes CO_2 equivalent or 91.9% of the total CH_4 contribution in 2050 (117.5 thousand metric tonnes CO_2 equivalent).

The N_2O emissions trending in 2019 – 2050 is shown in Figure 4.6. In 2019, the total GHG emission is 1,502 metric tonnes CO_2 equivalent. Diesel takes the major portion in this year with 953.2 metric tonnes CO_2 equivalent. The N_2O emissions of coal is increased in 2020 with 12.3 thousand metric tonnes CO_2 equivalent. Biomass is then starting to take the major portion of N_2O emissions in 2029 followed by coal in the second place. Furthermore, biomass will produce 127.2 thousand metric tonnes CO_2 equivalent (53.8%) from 236.6 thousand metric tonnes CO_2 equivalent of total N_2O emissions in 2050, followed by coal with 108.7 thousand metric tonnes CO_2 equivalent (45.9%).

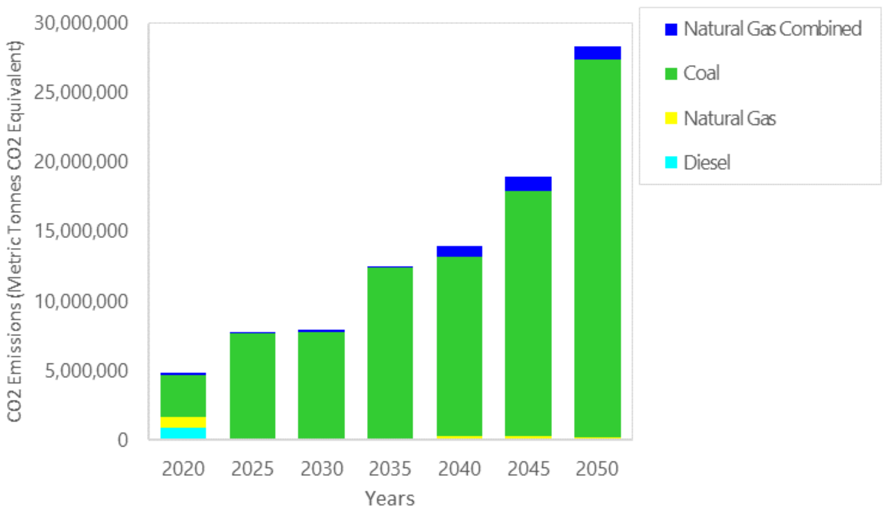


Figure 4.4 CO_2 emissions 2019 - 2050 (BAU scenario)

Figure 4.5 CH_4 emissions 2019 - 2050 (BAU scenario)

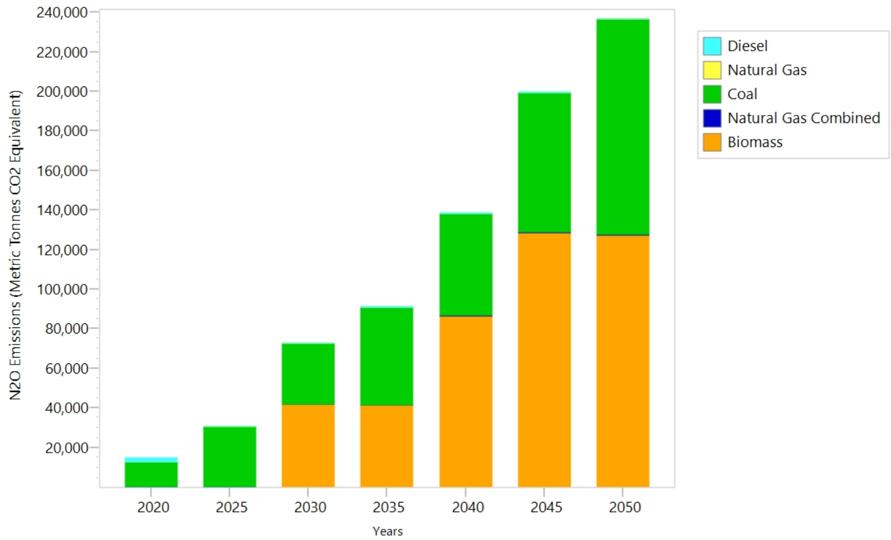


Figure 4.6 N_2O emissions 2019 - 2050 (BAU scenario)

4.1.4 Cost benefit analysis

The cost analysis in this report is conducted only for electricity generation, excluding cost from demand side (for example cost for fuel in transportation) and resources side (import and export cost). The environmental costs are also neglected as there are no externalities such as polluter pays or environmental taxes applied in Indonesia at the moment. The total cost for electricity generation is calculated based on the data of capital cost, fixed operation maintenance cost, and variable operation maintenance cost per technology shown in Table D.1 and Table D.2 (Appendix D).

The discounted cost for electricity generation in the BAU scenario from 2019 to 2050 is shown cumulatively in Figure 4.7 and Figure 4.8. The total cost is increased from 1.8 billion USD in 2019 to 27.7 billion USD in 2050. Figure 4.7 shows the trending cost per category, in which fixed operation and maintenance cost takes the biggest portion with 1.8 billion USD (100%) in 2019 and 25.2 billion USD (91%) in 2050. Capital cost placed the second biggest portion with 2.2 billion USD (7.9%) in 2050, while variable operation and maintenance cost is in the least portion with 0.3 billion USD (1.1%) in 2050.

Figure 4.8 indicates the total cost per technology of electricity generation. Cost for the power plant was produced mainly from natural gas in 2019 with 1.1 billion USD (61.1%), followed by diesel (0.4 billion USD) and coal (0.3 billion USD). In 2050, natural gas still takes the biggest portion for total cost with 12.3 billion USD (44.5%), followed by coal with 7.4 billion USD (26.8%), diesel with 3.5 USD (12.8%), solar with 2.1 billion USD (7.7%), NGCC with 1.1 billion USD (4.1%), biomass with 0.8 billion USD (3.1%), and hydro with 0.3 billion USD (1.1%). It is shown from these results that conventional non-renewable fuels still take the major part in total cost for electricity generation in 2050 considering the large portion of added capacity for non-renewable power plants in 2020 until 2050.

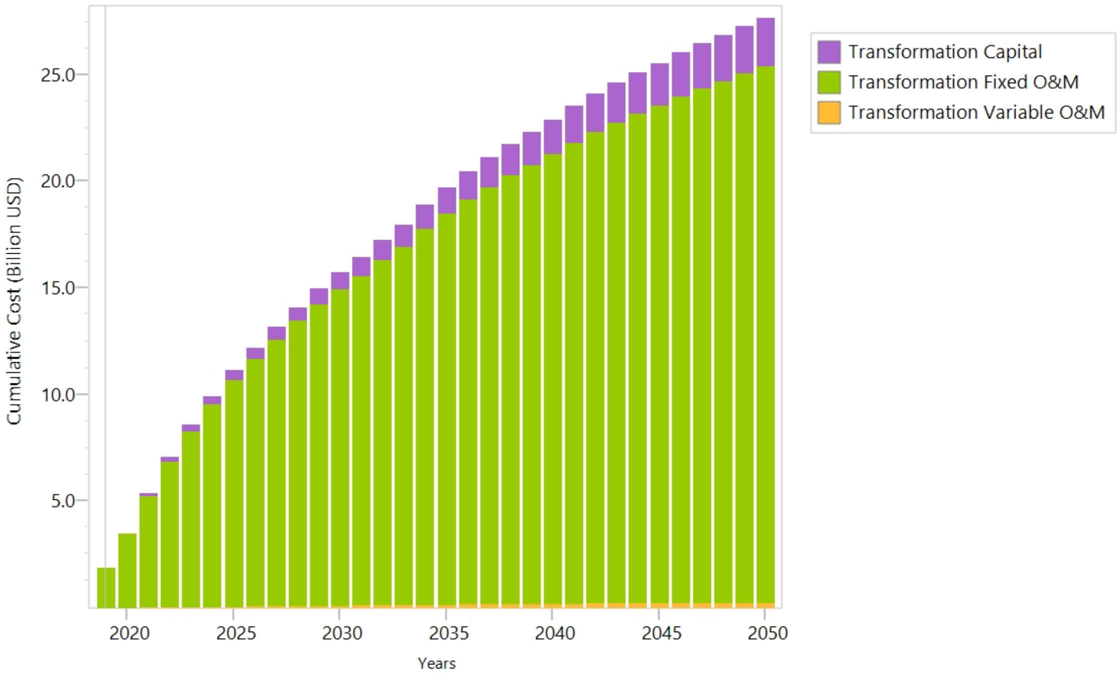


Figure 4.7 Cumulated discounted cost 2019 - 2050 (BAU scenario)

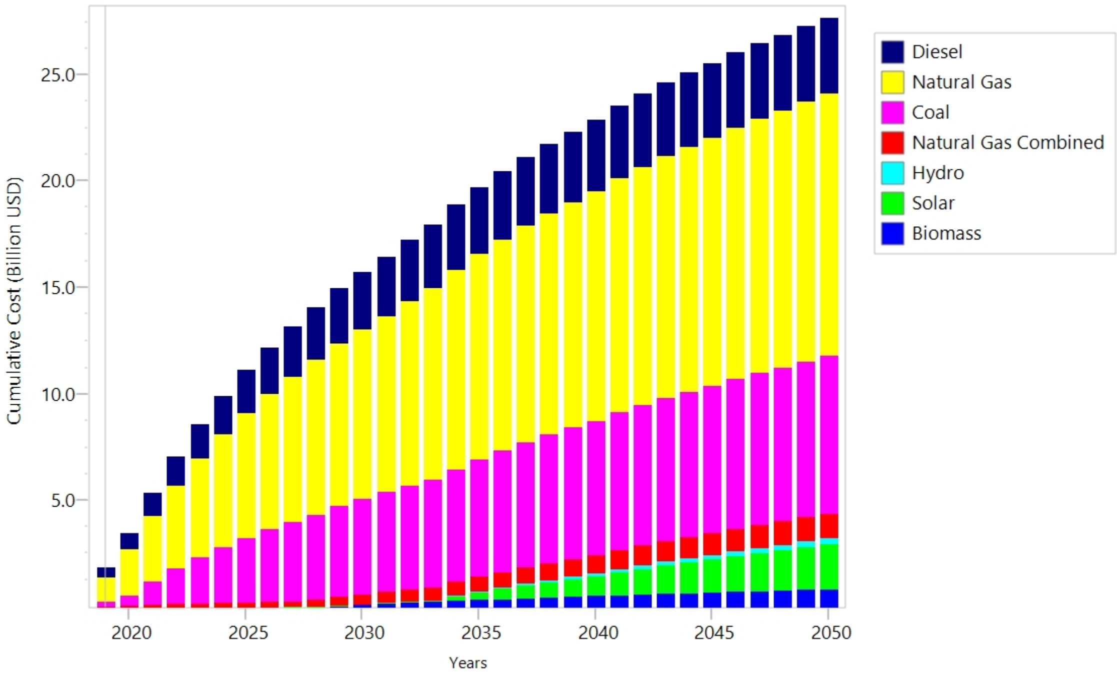


Figure 4.8 Cumulated discounted cost per technology 2019 - 2050 (BAU scenario)

4.2 THE CAPITAL CITY RELOCATION SCENARIO

4.2.1 Demand side analysis

The change in electricity demand in this scenario is mostly due to the increase in the population which comes from the civil servants in Jakarta. As it is stated before in section 2.6., around 1.5 million of people are predicted to move to the new capital after the first period of the relocation is completed in 2024 (BAPPENAS, 2019). With an assumption that the average growth rate per year is 1.54% (DEN, 2019a), the trending of population before and after the relocation can be seen in Figure 4.9.

Figure 4.10 shows the electricity demand in this scenario. The additional population directly affects the increasing demand in household and transportation sectors. In other hand, business, industrial, and general sectors are assumed to remain the same with BAU scenario as there is no information yet about how much capacity added for these sectors even though the development of these sectors is stated in the preliminary plan. There will be 60,820 GWh of total electricity demand in 2050, or 12,896 GWh of additional demand compared to the BAU scenario. Household sector will remain having the largest demand with 38,652 GWh in 2050, or 10,717 GWh of additional demand compared to the BAU scenario. Transportation sector will have 2,179 GWH of additional demand compared to the BAU scenario, giving 7,860 GWH of electricity demand in 2050. The composition of electricity demand in 2050 will be: household 63.6%, transportation 12.9%, general 12.4%, business 7.2%, and industrial 3.9% (see Figure 4.11).

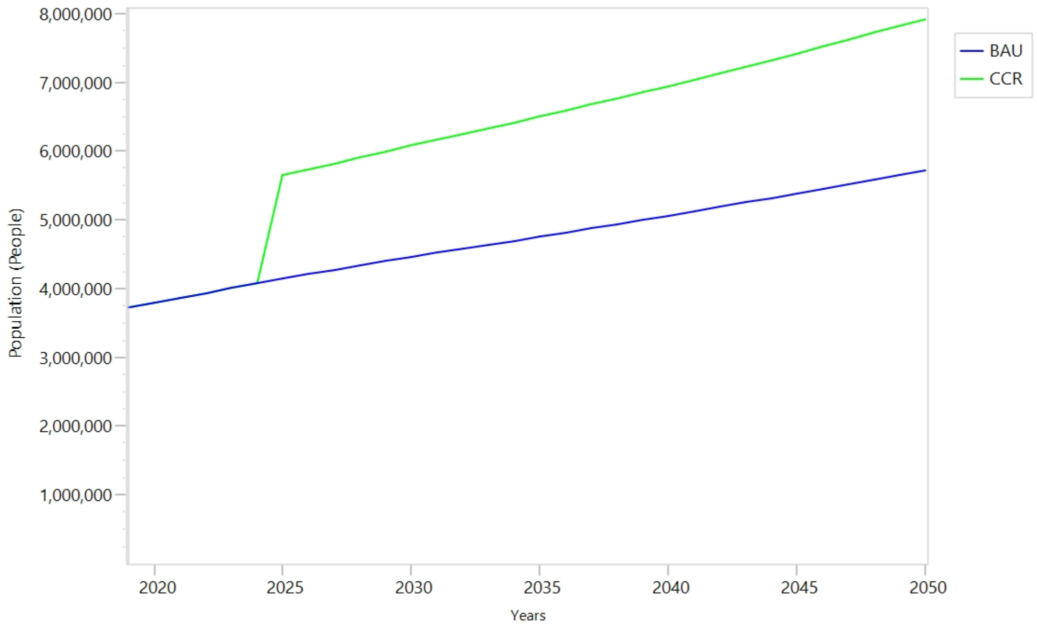


Figure 4.9 Population of East Borneo 2019 - 2050

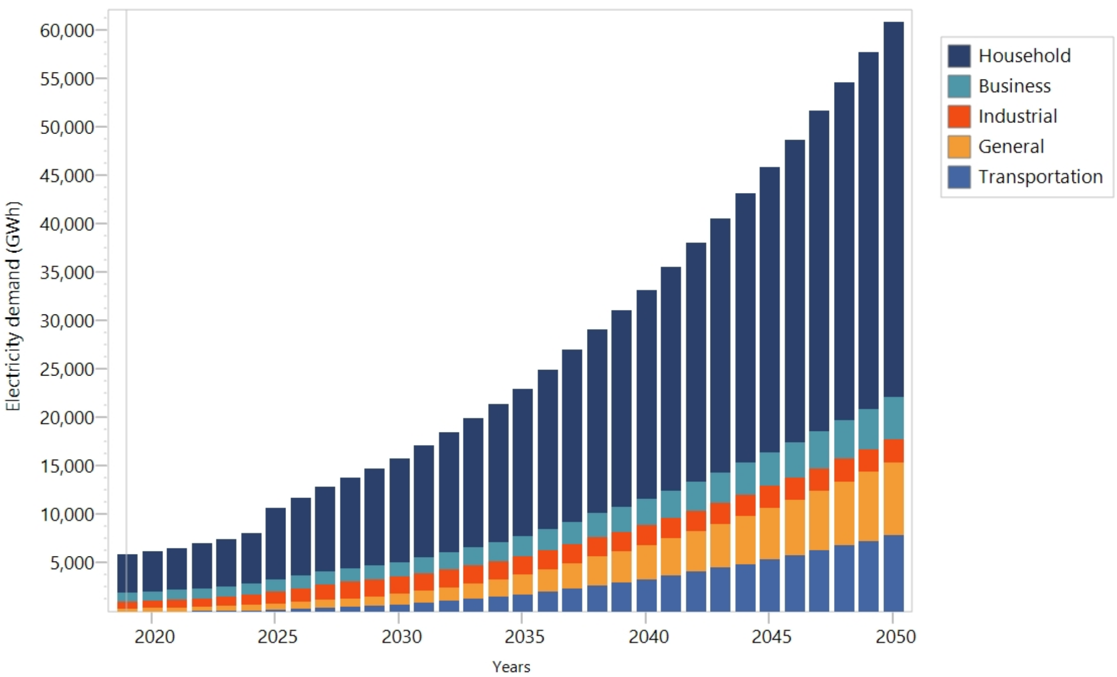


Figure 4.10 Electricity demand 2019 - 2050 (CCR scenario)

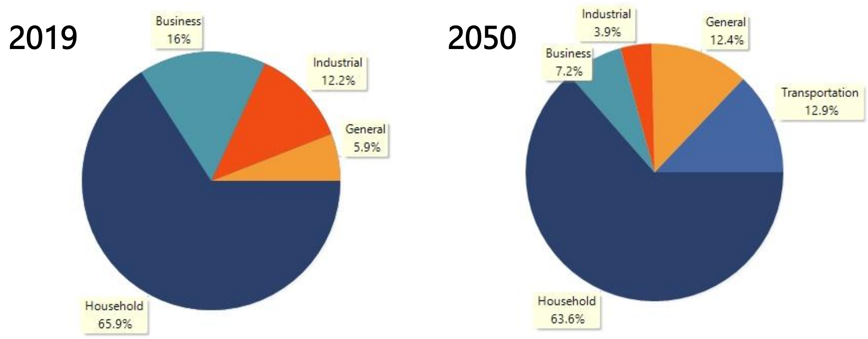


Figure 4.11 Electricity demand composition 2019 - 2050 (CCR scenario)

4.2.2 Electricity mix analysis

The electricity mix for the CCR scenario is simulated based on the planning concept of the new capital city of Indonesia in East Borneo. As the enhancement of renewable energy development is promoted in this concept, the additional electricity generation capacity of 500 MW is addressed for the renewable energy resources which are potentially utilized in the province. Solar and hydropower are chosen as they have the biggest potential of renewable energy capacity in East Borneo (see Table 2.1). On the other hand, bioenergy (biomass or biogas) is not chosen because it still produces a carbon footprint, while geothermal and wind energy have a little potential capacity reserved in East Borneo. Henceforth, 250 MW of solar power and 250 MW of hydropower are added endogenously in the LEAP software to maintain the planned reserve margin above the planned value (35%).

The result of the electricity mix for this scenario from the calculation of the LEAP software is shown in Figure 4.12. The capacity rises along with the increasing electricity demand as it is discussed in section 4.2.1. Total electricity generation capacity in 2050 is 205.2 GW, or 52.6 GW higher than the BAU scenario. Coal still gives the highest portion in 2050 with 80.8 GW of capacity, but it has a lower portion (39.4%) compared to BAU scenario (46.7%). The second highest portion comes to biomass with 31.1 GW or 15.2% of the total capacity in 2050. Hydropower and solar placed in third and fourth place with 25.7 GW (12.5%) and 22.1 GW (10.8%) of capacity in 2050 respectively. The portion of total renewable energy in 2050 is 38.5%. It means that the electricity mix will exceed the target of 31% if compared to the national energy target in 2050.

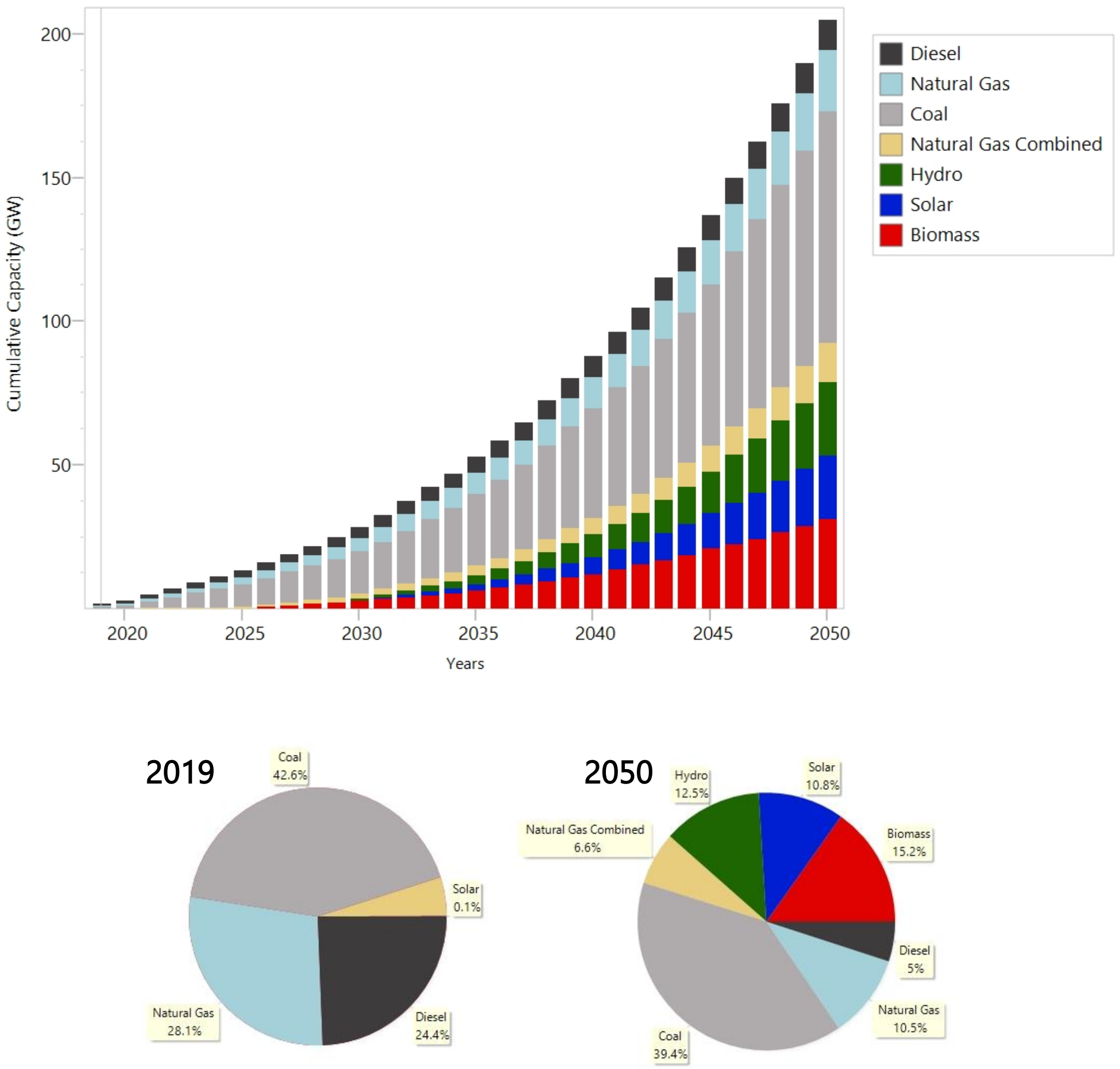


Figure 4.12 Electricity mix 2019 - 2050 (CCR scenario)

4.2.3 GHG emissions analysis

The GHG emissions for the electricity generation in the CCR scenario is also calculated based on IPCC Tier 1 emissions factors. As it can be seen in Figure 4.13, the total GHG emissions for electricity in 2050 will reach 33.5 million metric Tonnes of CO_2 equivalent, or 4.8 million metric Tonnes of CO_2 equivalent higher than what BAU scenario produces. The biggest contributor of total GHG emissions will be the coal power plant with 96% of total emissions in 2050, followed by natural gas (2.9%), biomass (0.9%), and diesel (0.1%). Most of the GHG emissions will come from CO_2 with 98.6%, followed by N_2O (0.9%) and CH4 (0.5%).

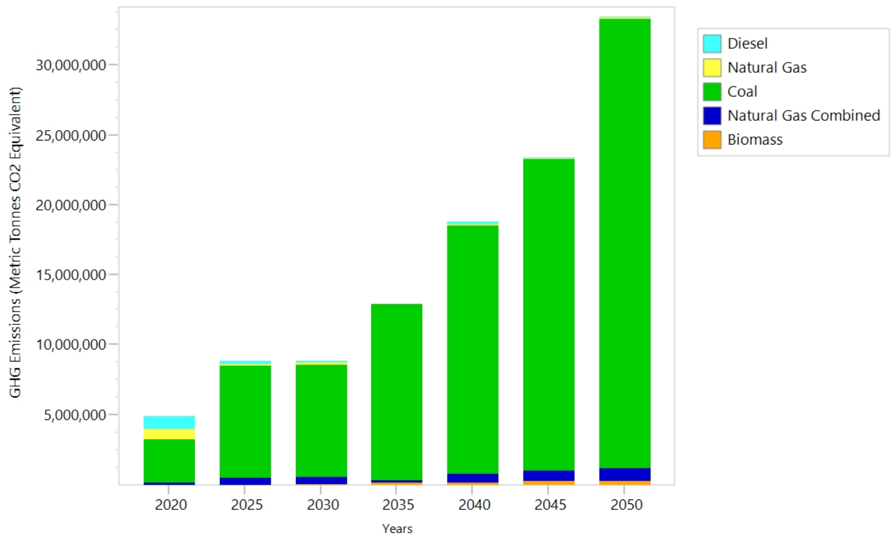


Figure 4.13 GHG emissions 2019 - 2050 (CCR scenario)

The CO_2 emissions trending in 2019 – 2050 is shown in Figure 4.14. Coal gives the biggest GHG emissions in 2050 with 32 million metric Tonnes of CO_2 equivalent, or 4.9 million metric Tonnes of CO_2 equivalent higher than the BAU scenario. Meanwhile, the other technologies only give a small amount of emissions, with NGCC 0.9 million metric Tonnes of CO_2 equivalent and natural gas 0.19 million metric Tonnes of CO_2 equivalent. Figure 4.15 indicates the trends of CH_4 emissions in 2019 to 2050. Biomass gives the biggest contributor for CH_4 emissions in 2050 with 144 thousand metric Tonnes of CO_2 equivalent, or 36 thousand metric Tonnes of CO_2 equivalent higher than the BAU scenario. Lastly, Figure 4.16 shows the trends for N_2O emissions in 2019 – 2050. The N_2O emissions in 2050 is 299 thousand metric Tonnes of CO_2 equivalent, or 62 thousand metric Tonnes of CO_2 equivalent higher than the BAU scenario. Most of the N_2O emissions comes from biomass and coal, with biomass produces 170 thousand metric Tonnes of CO_2 equivalent and coal produces 128 thousand metric Tonnes of CO_2 equivalent in 2050. Meanwhile, the other technologies only produce a small amount of N_2O in 2050 compared to biomass and coal (NGCC = 410 diesel = 87, natural gas = 51.5 metric Tonnes of CO_2 equivalent).

Reflecting to NDC target for Indonesia in compliance with Paris Agreement, energy sector will produce around 58.17% of the total GHG emissions in 2030 (Masripatin et al., 2017). By applying this percentage to East Borneo with the same value in 2050, the total GHG emissions for all sectors will be around 49 million metric Tonnes of CO_2 equivalent. Based on the NDC target (Masripatin et al., 2017), the GHG emissions in energy sector need to be reduced 11% from this total emissions. Nevertheless, the CCR scenario gives a higher GHG result instead of reduction, i.e. 9.75% from total GHG emissions. In other words, there are 20.75% deviation from NDC target for this scenario. The main reason is because of the added capacity from coal that produce a significant amount of GHG emissions.

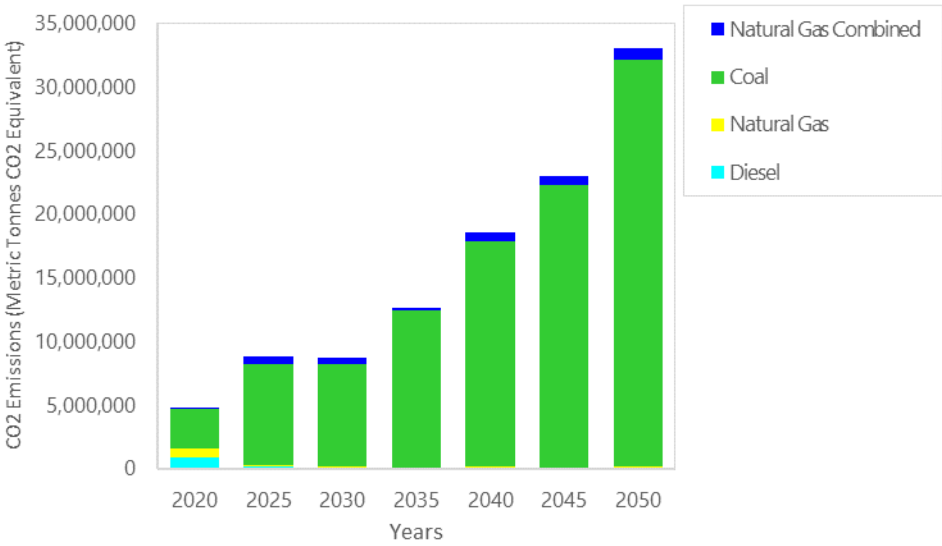


Figure 4.14 CO_2 emissions 2019 - 2050 (CCR scenario)

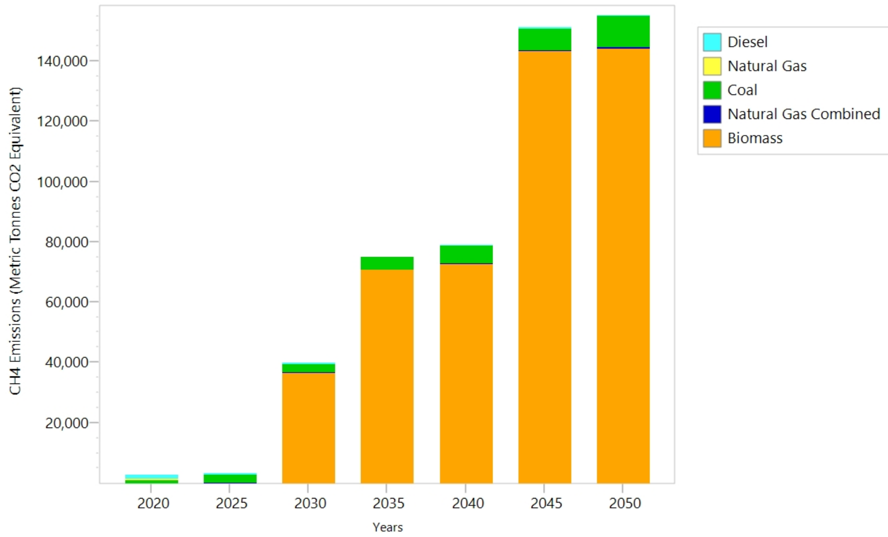


Figure 4.15 CH_4 emissions 2019 - 2050 (CCR scenario)

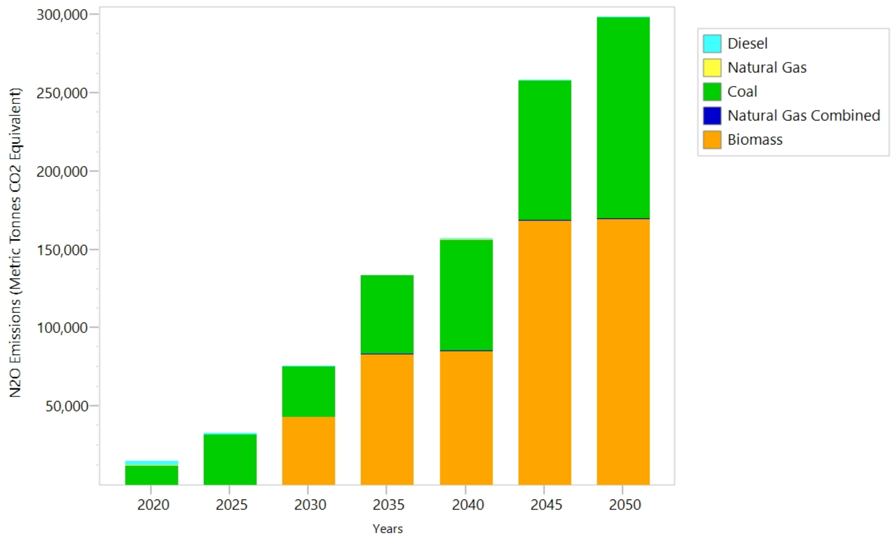


Figure 4.16 N_2O emissions 2019 - 2050 (CCR scenario)

4.2.4 Cost benefit analysis

The cost for electricity generation in the CCR scenario from 2019 to 2050 is shown cumulatively in Figure 4.17 and Figure 4.18. The total cost in 2050 is 35.7 billion USD, or 8.1 billion USD (29.2%) higher than the BAU scenario. The additional cost comes from the capacity added of the electricity generation for the new capital. It can be seen in Figure 4.17 that the majority cost comes from the fixed operation and maintenance cost with 32.1 billion USD, or 6.9 billion USD higher than the BAU scenario.

The cumulated discounted cost per technology for this scenario can be seen in Figure 4.18. Natural gas still gives the biggest portion for total cost with 13.4 billion USD (37.5%), following by coal with 8 billion USD (22.4%), solar with 7.2 billion USD (20%), diesel with 3.6 billion USD (10%), NGCC with 13.4 billion USD (4.1%), biomass with 1.3 billion USD (3.6%), and hydro with 0.9 billion USD (2.4%). The increasing number of populations by this scenario affects significantly in solar power generation cost. The CCR scenario gives 5 billion USD additional cost for solar compared to BAU scenario. In other hand, hydropower only contributes to 0.6 billion USD additional cost compared to BAU scenario. The trending of additional cost for CCR scenario compared to BAU scenario can be seen in Figure 4.19.

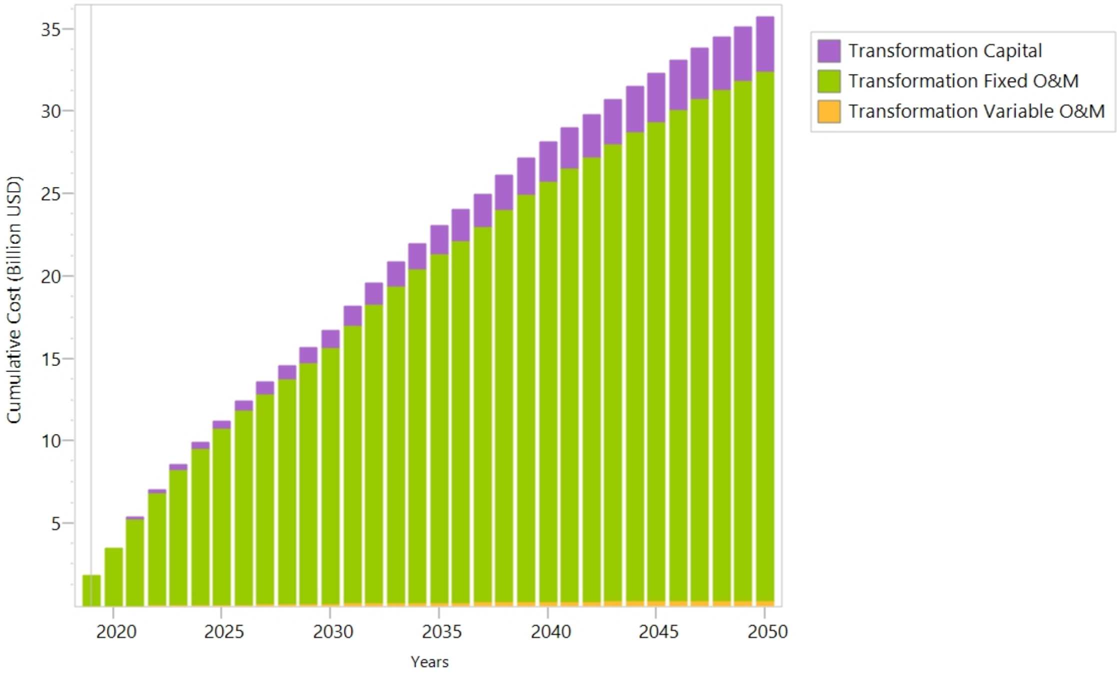


Figure 4.17 Cumulated discounted cost 2019 - 2050 (CCR scenario)

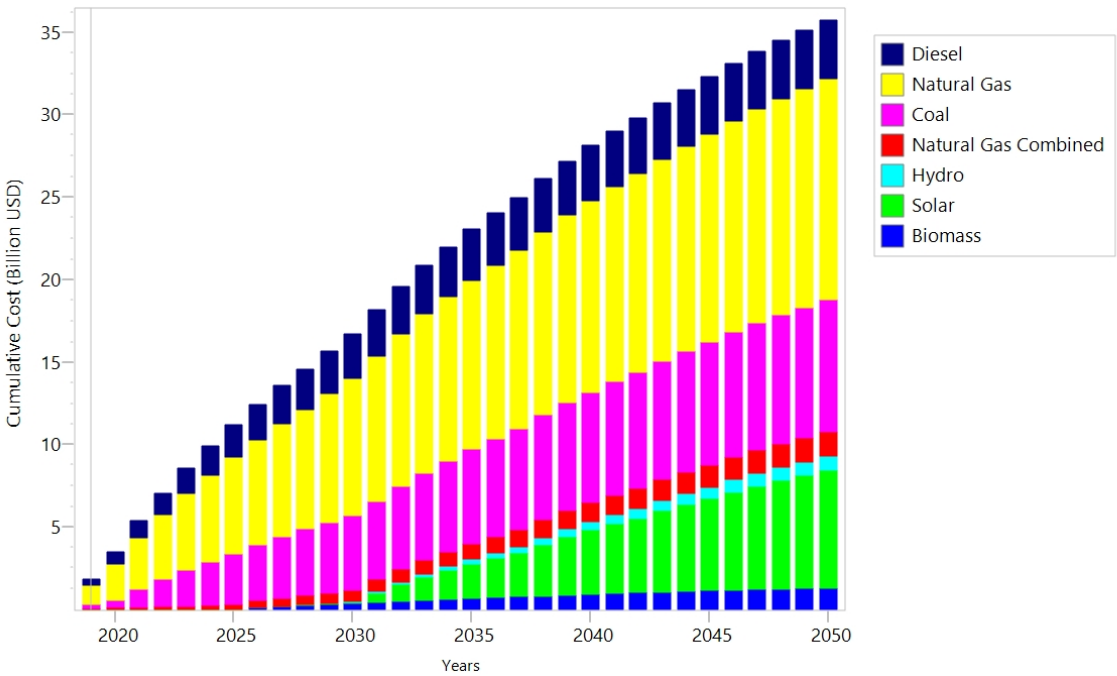


Figure 4.18 Cumulated discounted cost per technology 2019 - 2050 (CCR scenario)

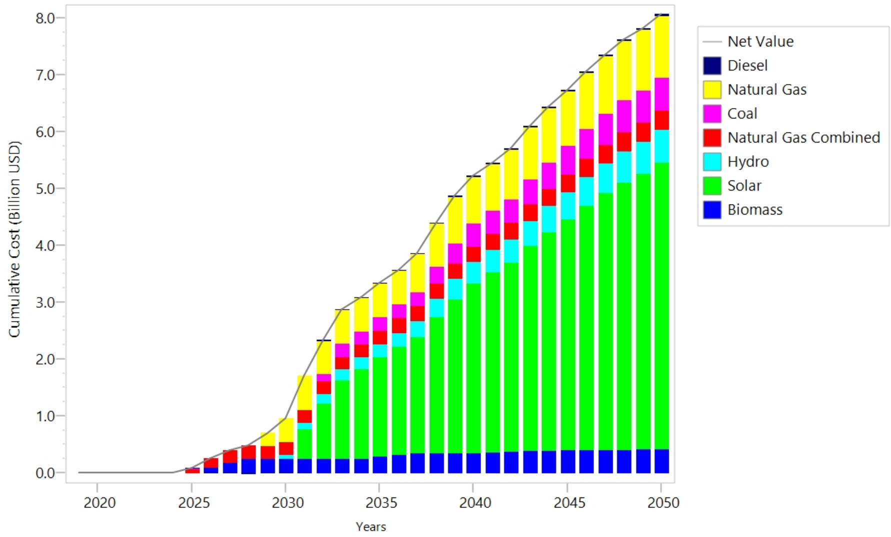


Figure 4.19 Cumulated discounted additional cost per technology 2019 - 2050 (CCR scenario)

4.3 FINDING AND DISCUSSION

The LEAP simulation indicates the effect of the relocation of the new capital of Indonesia in CCR scenario in comparison with BAU scenario. The demand analysis shows that the increasing number of populations in East Borneo due to the relocation affects directly to the increasing electricity demand in household and transportation sectors. As the demand is increasing, the capacity needed for the power generation is also increasing. The summary for LEAP analysis result in electricity mix, GHG emissions, and investment cost is presented in Table 4.2. It is shown that electricity generation in 2050 will be 34.5% higher than BAU scenario due to capital city relocation. The simulation shows that the capacity for renewable power generation in existing scenario will take 27.3% of the total electricity mix in 2050. Meanwhile, the new capital city scenario prioritizes the development of renewable energy resources for their electricity generation. Thus, hydropower and solar will significantly increase and the portion of renewable energy for this scenario is increased to 38.5% in 2050 which exceeds the national energy target of 31% renewable energy in 2050.

Even so, the rising emissions cannot be avoided as the non-renewable, especially coal-fired power plants are still needed to meet the increasing electricity demand for the new capital. It is shown from Table 4.2 that 17.8% of total GHG emissions will increase as the effect of the new capital city, with coal giving the highest emission contribution. In other words, the NDC target from Paris Agreement will not be achieved without any mitigation scenario such as fuel switching from coal to cleaner fuel or expansion of renewable energy with bigger capacity. Moreover, the cost for power generation for the new capital city scenario will be expanded 29.2% from the total cost in BAU scenario. The generation of renewable power plant capacity in the new capital city promotes the increasing number of investment cost with solar power as the major contributor.

Table 4.2 LEAP analysis results summary

Parameter	BAU scenario	CCR scenario	% deviation
Electricity capacity (GW)	**152.6**	**205.2**	**34.5%**
Diesel	10.1	10.3	2.0%
Natural gas	18.7	21.5	15.0%
Coal	70.7	80.8	14.3%
NGCC	11.3	13.6	20.4%
Hydro	9.9	25.7	159.6%
Solar	7.5	22.1	194.7%
Biomass	24.3	31.1	28.0%
GHG emissions (million T $CO_{2,\,eq}$)	**28.7**	**33.5**	**17.8%**
Diesel	0.1	0.1	0.0%
Natural gas	0.2	0.2	0.0%
Coal	27.3	32.0	17.2%
NGCC	1.0	1.0	0.0%
Hydro	-	-	-
Solar	-	-	-
Biomass	0.2	0.3	50.0%
Investment cost (billion USD)	**27.7**	**35.7**	**29.2%**
Diesel	3.5	3.6	2.9%
Natural gas	12.3	13.4	8.9%
Coal	7.4	8.0	8.1%
NGCC	1.1	1.5	36.4%
Hydro	0.3	0.9	200.0%
Solar	2.1	7.2	242.9%
Biomass	0.8	1.3	62.5%

CHAPTER 5 CONCLUSIONS

This chapter structurally concludes the thesis by answering the main question and sub research questions. Moreover, the restrictions and recommendations for further research are explained.

5.1 CONCLUSIONS

The objective of this research is to analyse the energy model for the planned new capital city of Indonesia located in East Borneo until 2050. Relying on the target for the National Energy General Plan and Paris Agreement, this research tries to examine the scenario of capital city relocation in comparison with the existing electricity scenario.

Below is the explanation of the answers for the sub research questions.

1. *How will the newly planned capital of Indonesia look like in terms of location, size, functions and activities?*

The new capital city of Indonesia is planned to be located in the district of Penajam Paser Utara and Kutai Kartanegara, East Borneo. The total area of the new capital city is 56,180.87 hectares, with 5,644 hectares allocated for the centre area of the government. Around 1.5 million people consisting of civil servants and their relatives are expected to move from Jakarta to the new capital. The relocation planning will be divided into two stages, the first stage (2021-2024) which prioritizes the construction for the government function and core infrastructures, and the second stage (2025-2029) which points out the construction of support functions such as business, industries, and public facilities. As the new capital city will uphold the concept of smart, green, and sustainable city, the development of renewable energy such as hydropower and solar is planned to meet the increasing demand of electricity. An evaluation has been made and it is concluded that the plan is still considered weak because legal framework has not been enacted yet and there is lack of rationality and conformity regarding to the current condition of Indonesia in general and East Borneo in particular.

2. *How would the energy system for the power sector of the new capital of Indonesia look like?*

The implication of electricity generation of the new capital city is analysed by developing the scenarios of Business as Usual (BAU) and Capital City Relocation (CCR) in LEAP energy modelling tool. The result of the model shows that the new capital requires higher electricity capacity as the population is increasing which leads to additional electricity demand. Total electricity generation capacity in 2050 will be 205.2 GW, or 52.6 GW higher than the BAU scenario. Coal still gives the highest portion in 2050 with 80.8 GW of capacity, but it has a lower portion (39.4%) compared to BAU scenario (46.7%) as larger portion of renewable fuel such as biomass, solar, and hydropower is expected in the development of the new capital city. Furthermore, the electricity mix in 2050 is expected to achieve national energy general plan target for renewable energy with estimated renewable energy portion 38.5%.

3. *What are the estimated CO_2 equivalent emissions impacts for East Borneo of the relocation of the capital of Indonesia?*

Using the same LEAP model in electricity mix analysis, the GHG emissions show an increasing figure in the new capital as a result of an increase in electricity capacity. The total GHG emissions for electricity in 2050 will reach 33.5 million metric Tonnes of CO_2 equivalent, or 4.8 million metric Tonnes of CO_2 equivalent higher than what BAU scenario produces. As the consequence of high coal capacity added to the new capital city, the province cannot achieve NDC target of Paris Agreement for GHG emissions reduction.

4. *What are the implications of the relocation of the capital to East Borneo for the costs of power production in East Borneo?*

Further LEAP analysis in cost-benefit of the electricity generation after the capital relocation shows that the relocation also affects to the increasing cost of electricity generation. Total cost for power production in 2050 will be 35.7 billion USD, or 29.2% higher than the BAU scenario. High investment will be needed for the cost of fixed operation and maintenance transformation, especially in solar power generation.

These lead to answering the main question below:

How will the power system of East Borneo develop until 2050 with the relocation of the capital of Indonesia to the region if the system will be designed in accordance with the Paris Agreement on Climate Change?

The relocation of Indonesia’s new capital city will actually increase the power generation capacity in the province as a result of the increasing demand of electricity. This will affect to a growing number of GHG emissions and investment cost. Even though it already embraces the concept of a green and sustainable city in its development plan, the new capital is predicted to fail to meet the NDC target of Paris Agreement in 2050 because non-renewable energy technology, especially coal, is still largely included in the energy plan.

5.2 RECOMMENDATIONS

Such mitigation scenarios need to be promoted in order to reduce GHG emissions and subsequently achieve the NDC target. A drastic transition would be difficult for the province since coal has already contributed to one third of the economy in East Borneo (Agus Praditya Tampubolon, Arinaldo, & Adiatma, 2018). Thus, partially fuel switching from coal to cleaner technologies can be an alternative solution for this scenario. For example, the development of biomass or natural gas co-firing into coal-fired power plants can reduce GHG emissions significantly (Basu, Butler, & Leon, 2011; Cheng et al., 2016; Choi et al., 2020; Roni et al., 2017; Thanapal, Annamalai, Ansley, & Ranjan, 2016; Truong, Patrizio, Leduc, Kraxner, & Ha-Duong, 2019). The extensive number of additional costs is the effect of high fixed cost of solar. Nevertheless, as the price of solar and other renewable energy resources will be much lower in the future (BloombergNEF, 2019; IRENA, 2016), renewable energy will further develop electricity generation. In the end, the electricity target for East Borneo could be achieved without neglecting the Paris Agreement by combining the development of renewable energy and cleaner technology for non-renewable energy. Moreover, coal transition to cleaner renewable energy provides more benefits for Indonesia to overcome the environmental burden of coal. This measure also anticipates economic risks of coal export in the future as major coal export destination countries are also adapting more clean energy policies (Deon Arinaldo; Julius Christian Adiatma, 2019).

The energy model of the new planned capital has been correlated with the Paris Agreement’s target. However, this research is limited in regards of finding the detail information of the planning for the capital city relocation. With no legal framework and detail planning in business and industrial sectors, the energy model is restricted to only a few sectors. This model would benefit greatly once the provision of law for the new capital has been enacted and more detail information such as the demand planning for business and industrial sector could be gathered. More factual scenarios related to climate change adaptation could be carried out then in future work. As a result, this analysis is expected to be more in-depth and comprehensive so that it can provide more accurate and impactful results for decision makers. Ultimately, this study contributes to providing an initial analysis of the environmental impact of the planned new capital city development. Despite the limited availability of data, this study has shown major consequences of planned relocation to the environment. Ignoring the results of this study will only pose bigger problems for sustainability in the future. Thus, this research is expected to provide an initial signal for the government to continue to promote renewable energy development in the plan for the new capital to prevent these problems and maintain the sustainability of the city.

REFERENCE

Abidin, H., Andreas, H., Gamal, M., Gumilar, I., Napitupulu, M., Fukuda, Y., … Riawan, E. (2010). *Land subsidence characteristics of the Jakarta basin (Indonesia) and its relation with groundwater extraction and sea level rise*. (January 2018), 113–130. https://doi.org/10.1201/b10530-11

Agus Praditya Tampubolon, Arinaldo, D., & Adiatma, J. C. (2018). *The Future of Coal in Indonesia study: Coal Dynamics and Energy Transition in Indonesia*.

Akhmad, & Amir. (2018). Study of fuel oil supply and consumption in indonesia. *International Journal of Energy Economics and Policy*, *8*(4).

Ancrenaz, M., Marshall, A., Goossens, B., van Schaik, C., Sugardjito, J., Gumal, M., & Wich, S. (2008). Pongo pygmaeus ssp. morio. *IUCN Red List of Threatened Species. Version 2010.1*, *8235*.

BAPPENAS. (2019). *Buku Saku Pemindahan Ibukota Negara*. Jakarta: Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional Republik Indonesia.

Basu, P., Butler, J., & Leon, M. A. (2011). Biomass co-firing options on the emission reduction and electricity generation costs in coal-fired power plants. *Renewable Energy*, *36*(1), 282–288. https://doi.org/10.1016/j.renene.2010.06.039

BloombergNEF. (2019). *New Energy Outlook 2019*. New York, USA.

Böhringer, C., & Rutherford, T. F. (2011). Combining Top-Down and Bottom-Up in Energy Policy Analysis: A Decomposition Approach. *SSRN Electronic Journal*, (06). https://doi.org/10.2139/ssrn.878433

Borneo, T. G. of E. (2016). Potensi Kehutanan Kalimantan Timur. Retrieved June 8, 2020, from https://kaltimprov.go.id/halaman/potensi-kehutanan

Cheng, L., Ye, X. P., English, B. C., Boylan, D., Johnson, T., & Zemo, B. (2016). Co-firing switchgrass in a 60-megawatt pulverized coal-fired boiler: Effects on combustion behavior and pollutant emissions. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, *38*(3), 322–329. https://doi.org/10.1080/15567036.2012.756563

Chin, H. S. (2006). Putrajaya – Administrative Centre of Malaysia -Planning Concept and Implementation-. *Sus. Urban Devt & Governance Conference, Seoul*, (May), 1–20.

Choi, M., Kim, K., Li, X., Deng, K., Park, Y., Seo, M., … Choi, G. (2020). Strategic combustion technology with exhaust tube vortex flame: Combined effect of biomass co-firing and air-staged combustion on combustion characteristics and ash deposition. *Energy*, *203*(x), 117839. https://doi.org/10.1016/j.energy.2020.117839

Debnath, K. B., & Mourshed, M. (2018). Challenges and gaps for energy planning models in the developing-world context. *Nature Energy*, *3*(3), 172–184. https://doi.org/10.1038/s41560-018-0095-2

DEN. (2017). *Peraturan Presiden Republik Indonesia Nomor 22 Tahun 2017 Tentang Rencana Umum Energi Nasional*. Retrieved from https://www.esdm.go.id/assets/media/content/content-rencana-umum-energi-nasional-ruen.pdf

DEN. (2019a). *Lampiran I Perda Provinsi Kalimantan Timur Nomor 8 Tahun 2019 tentang Rencana Umum Energi Daerah*.

DEN. (2019b). *Lampiran II Perda Provinsi Kalimantan Timur Nomor 8 Tahun 2019 tentang Rencana Umum Energi Daerah*.

Deon Arinaldo; Julius Christian Adiatma. (2019). *Indonesia's Coal Dynamics: Toward A Just Energy Transition*. Retrieved from http://iesr.or.id/wp-content/uploads/2019/08/Indonesias-Coal-Dynamics_Toward-a-Just-Energy-Transition.pdf

ESDM. (2015). *Rencana Umum Ketenagalistrikan Nasional 2015 - 2034*.

ESDM. (2017). *Kajian Penggunaan Faktor Emisi Lokal (Tier 2) dalam Kajian Inventarisasi GRK Sektor Energi*.

ESDM. (2019). *Rencana Umum Ketenagalistrikan Nasional 2019 - 2038*. Retrieved from http://repositorio.unan.edu.ni/2986/1/5624.pdf

FAO. (2011). *Indonesia: Country report for the state of the world's forest genetic resources*.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., …

Dorland, R. van. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.20892/j.issn.2095-3941.2017.0150

Hamdani, R. S. (2020). Proyek Lintas Batas Administrasi : Analisis Partisipasi Publik dalam Proses Perencanaan Ibu Kota Negara Republik Indonesia. *Journal of Regional and Rural Development Planning*, *4*(1), 43–62.

Handayani, K. (2019). *Electricity & climate change: seeking for the triple nexus of electrification, climate change mitigation, and climate change adaptation*. University of Twente, Enschede.

Handayani, K., Filatova, T., Krozer, Y., & Anugrah, P. (2020). Seeking for a climate change mitigation and adaptation nexus: Analysis of a long-term power system expansion. *Applied Energy*, *262*(December 2019), 114485. https://doi.org/10.1016/j.apenergy.2019.114485

Handayani, K., Krozer, Y., & Filatova, T. (2017). Trade-offs between electrification and climate change mitigation: An analysis of the Java-Bali power system in Indonesia. *Applied Energy*, *208*(August), 1020–1037. https://doi.org/10.1016/j.apenergy.2017.09.048

Handayani, K., Krozer, Y., & Filatova, T. (2019). From fossil fuels to renewables: An analysis of long-term scenarios considering technological learning. *Energy Policy*, *127*(December 2018), 134–146. https://doi.org/10.1016/j.enpol.2018.11.045

Heaps, C. G. (2020). *LEAP: The Low Emissions Analysis Platform.* Retrieved from https://leap.sei.org

Hur, J. Y., Cho, W., Lee, G., & Bickerton, S. H. (2019). The “Smart Work” Myth: How Bureaucratic Inertia and Workplace Culture Stymied Digital Transformation in the Relocation of South Korea’s Capital. *Asian Studies Review*, *43*(4), 691–709. https://doi.org/10.1080/10357823.2019.1663786

IESR. (2019). *A Roadmap for Indonesia’s Power Sector: How Renewable Energy Can Power Java-Bali and Sumatera*. Jakarta.

Indonesia Climate Change Sectoral Roadmap (ICCSR). (2010). *Scientific basis: analysis and projection of sea level rise and extreme weather event*. Retrieved from https://www.bappenas.go.id/files/2013/5229/9917/analysis-and-projection-of-sea-level-rise-and-extreme-weathe__20110217130224__1.pdf

Indonesia, R. (2007). *UU Republik Indonesia nomor 26 tahun 2007 tentang penataan ruang*.

Indonesian Government. (2014). *Indonesian Government Law No 79 In 2014 About National Energy Policy* (p. 8). p. 8.

IRENA. (2016). The Power to Change: Solar and Wind Cost Reduction Potential to 2025. In *Inernational Renewable Energy Agency*.

Irsyad, M. I. Al, Halog, A. B., Nepal, R., & Koesrindartoto, D. P. (2017). Selecting tools for renewable energy analysis in developing countries: An expanded review. *Frontiers in Energy Research*, *5*(DEC). https://doi.org/10.3389/fenrg.2017.00034

Isburhan, R. W. P., Nuraeni, G., Verdhora Ry, R., Yudistira, T., Cipta, A., & Cummins, P. (2019). Horizontal-to-Vertical Spectral Ratio (HVSR) Method for Earthquake Risk Determination of Jakarta City with Microtremor Data. *IOP Conference Series: Earth and Environmental Science*, *318*(1). https://doi.org/10.1088/1755-1315/318/1/012033

IUCN. (2020). IUCN Red List of Threatened Species. Retrieved July 22, 2020, from https://www.iucnredlist.org/

Julita, L. (2019). Bank Dunia: Macet Bikin Rugi Indonesia Rp 56 T Per Tahun. Retrieved March 18, 2020, from CNBC Indonesia website: https://www.cnbcindonesia.com/news/20191003141047-4-104180/bank-dunia-macet-bikin-rugi-indonesia-rp-56-t-per-tahun

Kieft, J., & Liu, L. (2019). Deforestation in Borneo is slowing, but regulation remains key. Retrieved June 6, 2020, from UN environment programme website: https://www.unenvironment.org/news-and-stories/story/deforestation-borneo-slowing-regulation-remains-key

KNAW, Centres, N. F. of U. M., Research, N. O. for S., Federatie, T., Sciences, N. A. of U. of A., & Vsnu. (2018). Netherlands Code of Conduct for Research Integrity. *World Development*. https://doi.org/https://doi.org/10.17026/dans-2cj-nvwu

Kydes, A. S., Shaw, S. H., & McDonald, D. F. (1995). Beyond the horizon: Recent directions in long-term energy modeling. *Energy*, *20*(2), 131–149.

https://doi.org/10.1016/0360-5442(94)00060-G

Margono, B. A., Potapov, P. V., Turubanova, S., Stolle, F., & Hansen, M. C. (2014). Primary forest cover loss in indonesia over 2000-2012. *Nature Climate Change*, *4*(8), 730–735. https://doi.org/10.1038/nclimate2277

Masripatin, N., Rachmawaty, E., Suryanti, Y., Styawan, H., Farid, M., & Iskandar, N. (2017). *Strategi implementasi NDC (Nationally Determined Contribution)*. Jakarta.

Moser, S. (2010). Putrajaya: Malaysia's new federal administrative capital. *Cities*, *27*(4), 285–297. https://doi.org/10.1016/j.cities.2009.11.002

Nur Azhar, H., Putri Fatima, H. H., & Tamas, I. N. (2020). Preliminary study of Indonesia capital city relocation based on disaster mitigation principle with mental model approach. *E3S Web of Conferences*, *148*, 1–7. https://doi.org/10.1051/e3sconf/202014806002

Oliveira, V., & Pinho, P. (2015). Evaluation in urban planning : from theory to practice. *Journal of Planning Literature*, *24*(October), 31–49. https://doi.org/10.1177/0885412210364589

Ouedraogo, N. S. (2017). Africa energy future: Alternative scenarios and their implications for sustainable development strategies. *Energy Policy*, *106*, 457–471. https://doi.org/10.1016/j.enpol.2017.03.021

Pandey, R. (2002). Energy policy modelling: Agenda for developing countries. *Energy Policy*, *30*(2), 97–106. https://doi.org/10.1016/S0301-4215(01)00062-3

PLN. (2011). *PLN Statistics 2010*. Retrieved from http://www.pln.co.id/dataweb/STAT/STAT2012ENG.pdf

PLN. (2019a). *RUPTL Rencana usaha penyediaan tenaga listrik PT PLN (Persero) 2019 - 2028*.

PLN. (2019b). *Statistik PLN 2018*. https://doi.org/10.1017/CBO9781107415324.004

Pokharel, S., Ahmade, A. A., Al-Ansari, F. A., Allaf, H. Al, Daneshvar, M. S., & AbdelQadir, A. M. (2012). Energy modeling for policy analysis. *Proceedings of the 3rd Gas Processing Symposium*, 199–208. https://doi.org/10.1016/b978-0-444-59496-9.50029-1

Post, T. J. (2019). 'Nagara Rimba Nusa' announced as winner of new capital city design contest. Retrieved April 17, 2020, from https://www.thejakartapost.com/news/2019/12/23/nagara-rimba-nusa-announced-as-winner-of-new-capital-city-design-contest.html

Putra, R. A. (2019). Pengamat: Waspada Potensi Konflik Sosial Akibat Pemindahan Ibu Kota Negara. Retrieved June 8, 2020, from dw.com website: https://www.dw.com/id/pengamat-waspada-potensi-konflik-sosial-akibat-pemindahan-ibu-kota-negara/a-49840002

Quistorff, B. (2015). Capitalitis? Effects of the 1960 Brazilian Capital Relocation. *SSRN Electronic Journal*, 1–30. https://doi.org/10.2139/ssrn.2588620

Rebelatto, B. G., & Frandoloso, M. A. L. (2020). *Energy Modelling: Methods and Applications*. (January), 0–12. https://doi.org/10.1007/978-3-319-71057-0

Reva, D. (2016). *Capital city relocation and national security: the cases of Nigeria and Kazakhstan* (University of Pretoria Faculty of Humanitites). https://doi.org/10.2307/20630710

Rivers, N., & Jaccard, M. (2005). Combining top-down and bottom-up approaches to energy-economy modeling using discrete choice methods. *Energy Journal*, *26*(1), 83–106. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol26-No1-4

Römer, B., Julliard, Y., Fauzianto, R., Poddey, M. J., & Rendroyoko, I. (2017). Pioneering smart grids for Indonesia - the case of a smart grid roadmap development. *CIRED - Open Access Proceedings Journal*, *2017*(1), 2484–2487. https://doi.org/10.1049/oap-cired.2017.0318

Roni, M. S., Chowdhury, S., Mamun, S., Marufuzzaman, M., Lein, W., & Johnson, S. (2017). Biomass co-firing technology with policies, challenges, and opportunities: A global review. *Renewable and Sustainable Energy Reviews*, *78*(May 2016), 1089–1101. https://doi.org/10.1016/j.rser.2017.05.023

Rossman, V. (2017). Capital cities: Varieties and patterns of development and relocation. In *Routledge*. https://doi.org/10.1080/07352166.2018.1522906

Rypdal, K., Flugsrud, K., & Irving, W. (2000). *IPCC good practice guidance and uncertainty management in national greenhouse gas inventories, Chapter 7: Methodological choice and recalculation*. https://doi.org/10.4324/9781315691688-2

Rypdal, K., Paciornik, N., Eggleston, S., Goodwin, J., Irving, W., Penman, J., & Woodfield, M. (2006). *IPCC guidelines for national greenhouse gas inventories, Chapter 1: Introduction*.

Samouilidis, J. (1980). Energy modelling: A new challenge for management science. *Omega*, *8*(6), 609–621. https://doi.org/10.1016/0305-0483(80)90002-X

Shimamura, T., & Mizunoya, T. (2020). Sustainability prediction model for capital city relocation in Indonesia based on inclusive wealth and system dynamics. *Sustainability (Switzerland)*, *12*(10). https://doi.org/10.3390/su12104336

Thanapal, S. S., Annamalai, K., Ansley, R. J., & Ranjan, D. (2016). Co-firing carbon dioxide-torrefied woody biomass with coal on emission characteristics. *Biomass Conversion and Biorefinery*, *6*(1), 91–104. https://doi.org/10.1007/s13399-015-0166-6

Truong, A. H., Patrizio, P., Leduc, S., Kraxner, F., & Ha-Duong, M. (2019). Reducing emissions of the fast growing Vietnamese coal sector: The chances offered by biomass co-firing. *Journal of Cleaner Production*, *215*, 1301–1311. https://doi.org/10.1016/j.jclepro.2019.01.065

Urban, F., Benders, R. M. J., & Moll, H. C. (2007). Modelling energy systems for developing countries. *Energy Policy*, *35*(6), 3473–3482. https://doi.org/10.1016/j.enpol.2006.12.025

US EPA. (2017). Understanding Global Warming Potentials | Greenhouse Gas (GHG) Emissions | US EPA. Retrieved June 20, 2020, from https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

van Beeck, N. (2003). *A New Decision Support Method for Local Energy Planning*. Tilburg University.

Van de Vuurst, P., & Escobar, L. E. (2020). Perspective: Climate Change and the Relocation of Indonesia's Capital to Borneo. *Frontiers in Earth Science*, *8*(January), 1–6. https://doi.org/10.3389/feart.2020.00005

van Ruijven, B., Urban, F., Benders, R. M. J., Moll, H. C., van der Sluijs, J. P., de Vries, B., & van Vuuren, D. P. (2008). Modeling Energy and Development: An Evaluation of Models and Concepts. *World Development*, *36*(12), 2801–2821. https://doi.org/10.1016/j.worlddev.2008.01.011

Vezzoli, C., Ceschin, F., Osanjo, L., M'Rithaa, M. K., Moalosi, R., Nakazibwe, V., & Diehl, J. C. (2018). *Designing Sustainable Energy for All*. https://doi.org/10.1007/978-3-319-70223-0

Wartiharjono, S. (2017). Potensi konflik dan pembentukan modal sosial : belajar dari sebuah desa transmigran di Kalimantan Timur. Conflict potential and social capital construction : a case study of a transmigrant village in East Kalimantan. *Masyarakat, Kebudayaan Dan Politik*, *30*, 84–93.

APPENDIX A CAPITAL CITY RELOCATIONS

Table A.1 Capital city relocations list

No	Year	Old	New	Country	Notes
1	1950	Tel Aviv-Jaffo	Jerusalem	Israel	
2	1959	Karachi	Rawalpindi	Pakistan	
3	1960	(none)	Nouakchott	Mauritania	
4	*1961*	*Rio de Janeiro*	*Brasilia*	*Brazil*	*Purpose-built*
5	1962	Butare	Kigali	Rwanda	
6	1962	Ta'izz	Sana'a	North Yemen	
7	1965	Mafeking	Gaborone	Botswana	
8	*1969*	*Rawalpindi*	*Islamabad*	*Pakistan*	*Purpose-built*
9	*1970*	*Belize City*	*Belmopan*	*Belize*	*Purpose-built, partial*
10	1970	Salalah	Muscat	Oman	Partial
11	1974	Zomba	Lilongwe	Malawi	Partial (parliament moved in 1994)
12	1974	Madina do Boe	Bissau	Guinea Bissau	
13	1975	Luang Prabang	Vientiane	Laos	
14	1976	Quezon City	Manila	Philippines	
15	1976	Saigon	Hanoi	Vietnam	
16	1982	Colombo	Kotte	Sri Lanka	
17	1983	Abidjan	Yamoussoukro	Cote d'Ivore	Partial (many admin functions and embassies stayed in Abidjan)
18	1989	Kolonia	Palikir	F.S. of Micronesia	
19	1990	Santiago	Valparafso	Chile	Partial (legislative only)
20	1990	Aden	Sana'a	(South) Yemen	
21	*1991*	*Lagos*	*Abuja*	*Nigeria*	*Purpose-built*
22	1996	Dar es Salaam	Dodoma	Tanzania	Partial (legislative only)
23	1997	Almaty	Astana	Kazakhstan	
24	1999	Bonn	Berlin	Germany	Partial (certain functions transferred in 1990)
25	1999	Kuala Lumpur	Putrajaya	Malaysia	*Purpose-built, partial (executive only)*
26	*2005*	*Yangon*	*Naypyidaw*	*Myanmar*	*Purpose-built*
27	*2006*	*Koror*	*Ngerulmud*	*Palau*	*Purpose-built*
*28**	*2012*	*Seoul*	*Sejong*	*South Korea*	*Purpose-built, partial (several ministries only)*

Source: Quistorff (2015)

*updated, not from the source

APPENDIX B THE ALGORITHM OF LEAP

The algorithm of LEAP model is divided into the sections below:

a) *Total demand calculation*

The energy demand is calculated as the result of the total activity level (e.g. number of households) and energy intensity at each sector (Heaps, 2020), as follows below formula:

$$D_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t}$$

Where *D* is energy demand, *TA* is total activity, *EI* is energy intensity, *b* is the sector branch, *s* is scenario, and *t* is year.

b) *Capacity expansion calculation*

The additional capacity of the electricity generation is calculated endogenously, which means LEAP internally calculates the capacity expansion in order to maintain a minimum planning reserve margin (Heaps, 2020). The capacity expansion is calculated as follows:

- Existing capacity before the addition of endogenously calculated additions is calculated as follows for each technology in each year:

$$Cap_x = (Exogenous\ cap + Endogenous\ cap_{x-1}) \times CC,$$

where Cap_x is the capacity before additions, $Exogenous\ cap$ is the capacity that is added exogenously (reflecting existing capacity as well as planned/committed capacity additions), $Endogenous\ cap_{x-1}$ is the endogenous capacity that is added in the previous year, and *CC* is capacity credit that is used to adjust actual capacity value that could have less value due to intermittent process (e.g. solar).

- Peak requirements for the power system are calculated as a function of the total energy requirements and the load factor. The load factor is calculated as the average height of a load shape.

$$Peak\ requirement\ [MW] = \frac{Energy\ requirement\ [MWh]}{load\ factor\ x\ 8760\ [\frac{h}{year}]}$$

- The reserve margin before the additions of endogenous capacity (RM_x) is calculated as follows:

$$RM_x = \frac{Cap_x - Peak\ requirement}{Peak\ requirement}$$

- The endogenous capacity additions required is calculated as a function of the difference between planning reserve margin ($RM_{planning}$) with the reserve margin before additions (RM_x) and the peak requirement:

$$Endogenous\ cap_{req} = \left(RM_{planning} - RM_x\right) \times Peak\ requirement$$

- The endogenous capacity additions required are then calculated for each technology for the next year and so it goes repetitively until the final year.

c) *GHG emission calculation*

The GHG emissions are calculated based on IPCC Tier 1 with defined emissions factors. Ouedraogo (2017) defines the calculation as follows:

$$GHG_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \times EF_{b,s,t},$$

where *GHG* is the GHG emissions, *EF* is the emissions factor from sector *b*, scenario *s*, and year *t,* while *TA* and *EI* are as specified above.

d) *Cost benefit analysis*

Total cost benefit calculation is defined by Handayani, Krozer, & Filatova (2019) as the total net present value of the system over the entire period as follows:

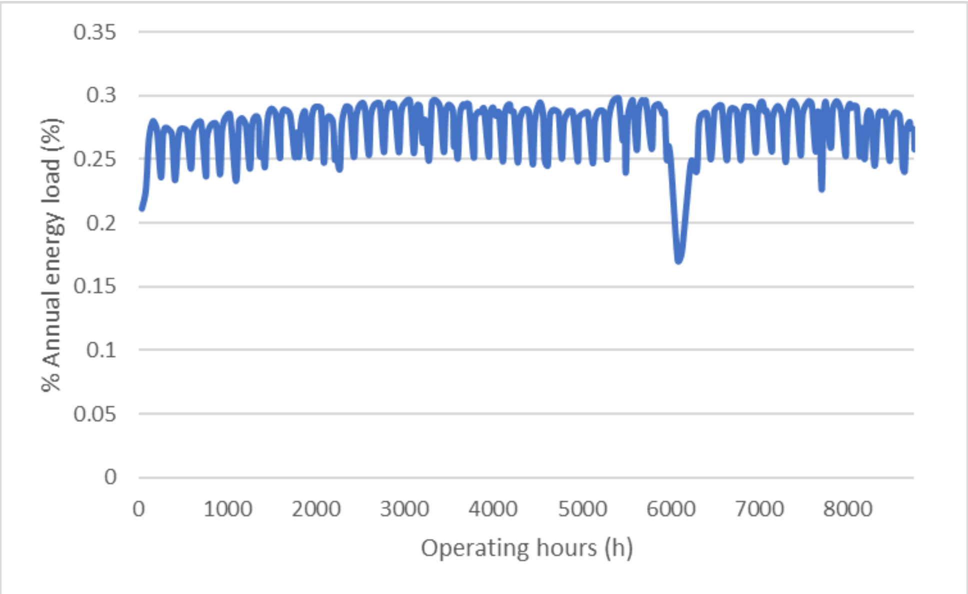
$$TC = \sum_t^{N_t} \sum_p \frac{1}{(1+d)^t} (C_c \times Ca_t + foC_c \times Ca_t + VoC_c \times P_t + Fc_t),$$

Where *TC* is the total cost, N_t indicates the number of years within the period, *p* is the technology, *d* is the discount rate, C_c is the initial capital cost, Ca_t is the capacity in year *t*, foC_t is the fixed operation and maintenance costs in year *t*, VoC_t is the variable operation and maintenance costs in year *t*, P_t is the output power in year *t*, and Fc_t is the fuel costs in year *t*.

APPENDIX C DATA FOR VALIDATION OF THE LEAP MODEL

Table C.1 Parameter list for LEAP validation

Input parameters	Value	Source
Electricity demand (2010 – 2018)	2.2 – 3.1 thousand GWh	RUPTL 2019-2028 (PLN, 2019a) PLN Statistics 2010 (PLN, 2011)
Transmission and distribution losses	10.08%	PLN Statistics 2010 (PLN, 2011)
Energy load shape	See Figure 8	(Handayani et al., 2017)
Planning reserve margin	35%	RUKN 2015 – 2034 Draft (ESDM, 2015)
Characteristics of technology mix for the electricity generation	See Table 9	
Interest rate	12%	RUPTL 2019-2028 (PLN, 2019a)



*The declining on 6000th hours happened during public holiday (Ied-Fitr)

Figure C.1 Energy load shape

Source: (Handayani et al., 2017)

Table C.2 Characteristic of power generation technology for LEAP validation

Technology	Lifetime (years)[a]	Process Efficiency (%)[a]	Maximum availability (%)[a]	Capacity credit (%)[a]	Capital cost (2015 USD/kW) [a]	Fixed OM cost (2010 USD/kW)[b]	Variable OM cost (2015 USD/MWh)[a]	Fuel cost (2010 USD/MWh) [b]
Diesel	25[c]	35 [c]	80 [c]	100 [c]	1,300 [c]	4,200	4 [c]	60.9
Natural Gas	25	36	80	100	700	1,552	1	10.2
Coal	30	40	80	100	1,400	544	2	3.3
NGCC	25	55	80	100	800	767	1	10.2

[a](Handayani, Filatova, Krozer, & Anugrah, 2020)

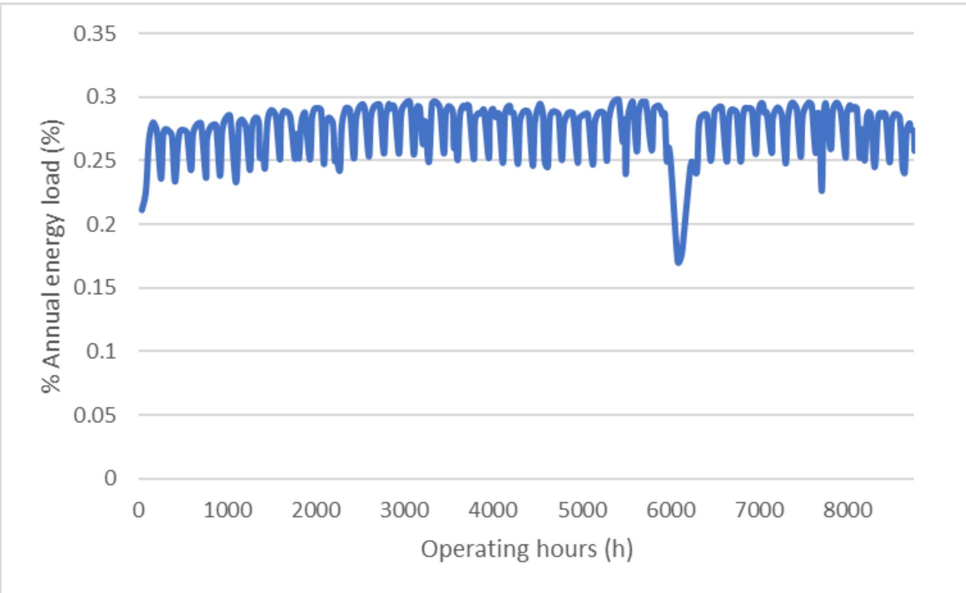
[b](PLN, 2011)

[c](IESR, 2019)

APPENDIX D DATA FOR LEAP MODEL – BAU AND CCR SCENARIOS

Table D.1 Parameter list for LEAP analysis

Input parameters	Value	Source
Added capacity (2019 – 2038)	1 – 842 MW per technology	RUED 2019 (DEN, 2019b)
Transmission and distribution losses	7.33%	PLN Statistics 2018 (PLN, 2019b)
Energy load shape	See Figure 9	(Handayani et al., 2017)
Planning reserve margin	35%	RUKN 2015 – 2034 Draft (ESDM, 2015)
Characteristics of technology mix for the electricity generation	See Table 10	
Interest rate	12%	RUPTL 2019-2028 (PLN, 2019a)



*The declining on 6000th hours happened during public holiday (Ied-Fitr)

Figure D.1 Energy load shape

Source: (Handayani et al., 2017)

Table D.2 Characteristic of power generation technology for LEAP validation

Technology	Lifetime (years)[a]	Process Efficiency (%)[a]	Maximum availability (%)[a]	Capacity credit (%)[a]	Capital cost (2015 USD/kW) [a]	Fixed OM cost (2018 USD/kW)[b]	Variable OM cost (2015 USD/MWh)[a]	Fuel cost (2018 USD/MWh) [b]
Diesel	25[c]	35 [c]	80 [c]	100 [c]	1,300 [c]	1,346	4 [c]	60.9
Natural Gas	25	36	80	100	700	3,493	1	10.2
Coal	30	40	80	100	1,400	502	2	3.3
NGCC	25	55	80	100	800	785	1	10.2
Hydro	50	100	41	51	2,000	213	1	-
Solar	20	100	17	22	2,069	4,226	0.4	-
Biomass	20	35	80	100	2,228	78[a]	6.5	2.7[a]

[a](Handayani et al., 2020)

[b](PLN, 2019b)

[c](IESR, 2019)