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Powering Nusantara: Modeling the Electricity Future of Indonesia's New Capital City

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Executive Summary

Indonesia's capital city will relocate from Jakarta on Java Island to Nusantara on Borneo Island. The new city's construction began in 2022 and is set for initial relocation in August 2024. Following the government mandate stipulated in Indonesia's Law 3/2022 and the Presidential Decree 63/2022, Nusantara must be powered by 100% renewable electricity and achieve net zero by 2045.

The city itself is projected to be populated by 1.4 to 1.8 million people, which will require 4ilable in the North Kalimantan region of Borneo, while wind resource is very minimal and solar is moderate.

According to our supply demand model, the government's target to achieve 100% renewable energy penetration by 2045 is not impossible to reach. On the contrary, this will be naturally achieved without any government intervention because of the technical lifetime limitation of the existing fossil power plants and reduction in price of renewable energy.

Several policies are required to be implemented to ensure a smooth transition of electricity generation. First, the IKN's electricity business area should be established for the Authority itself to create a more streamlined permitting process and innovate more robust fiscal policies to attract private investments into the Nusantara. Secondly, the electricity supply demand projection should be integrated in the main electric utility's Electricity Supply Business Plan. In addition, several targeted policies are recommended to be implemented in the case of specific scenarios or pathways that are developed in this report.

Calibration and feedback from stakeholders are required to improve accuracy of the projection as well as disseminating the finding to all stakeholders to ensure good cooperation between stakeholders.

Background

After enduring rising sea-levels, excessive groundwater extraction, vulnerability to earthquakes, and increasing congestion, President Joko Widodo of the Republic of Indonesia announced in 2019 that the capital city will be relocating from Jakarta to Eastern Kalimantan[1]. Sitting over 2,000 kilometers away from Jakarta, the new capital city - now known as Nusantara – is located on the forested region of Borneo Island.

Figure 1 shows the capital city relocating northeast from Jakarta on Java Island to Nusantara on Borneo Island

As the President hopes to lift some burdens off Jakarta that is populated by over ten million people, aspirations for Nusantara are high. Chosen for its geographic location and tropical rainforest landscape, the new city is planned to become a smart and green hub that emphasizes sustainable development toward a more advanced economy. Led by the National Capital City Authority (Ibu Kota Negara, IKN), construction began in 2022 and is set for initial relocation on 17 August 2024, coinciding with the country's 79th anniversary of independence.

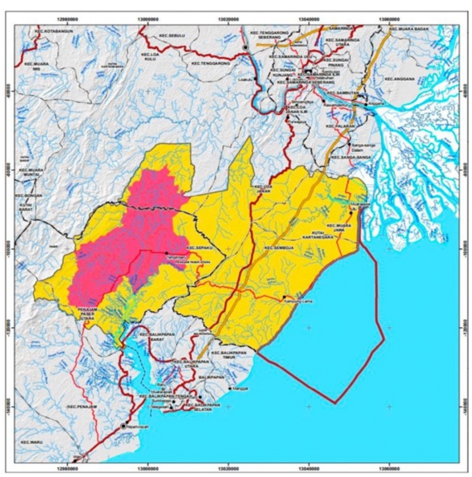

Figure 2 shows the pink area that denotes the capital region and yellow area that denotes the extended capital region.

[1]Chappell, Bill. "Jakarta Is Crowded And Sinking, So Indonesia Is Moving Its Capital To Borneo." *NPR*, 26 Aug. 2019. *NPR*, https://www.npr.org/2019/08/26/754291131/indonesia-plans-to-move-capital-to-borneo-from-jakarta.

The Nusantara metropolis will comprise of cities like Balikpapan and Samarinda in the Eastern Kalimantan province, which are now inhabited by approximately 700,000 residents. Broken down into five phases, the initial relocation stage focuses on the central government area and concludes in 2045 with a targeted population of 1.9 million. Additionally, Indonesia's Law 3/2022 and the Presidential Decree 63/2022 states that Nusantara must be powered by 100% renewable electricity and achieve net zero by 2045.[2] This highlights a huge amount of effort that IKN will undertake, as energy, specifically electricity, is essential in building a foundation for not just any new city's development, but one that runs on low to zero emissions.

Objectives

Given the mandate, this practicum's purpose is to model the projected electricity demand and supply for Nusantara to help IKN, our official partner in this project, meet their goal of reaching 100% renewable power and net zero by 2045.[3] The guiding questions that will help us meet our objectives are:

1) What does the projected demand for electricity for Nusantara look like from 2024 to 2045?
2) Which clean sources are most feasible to supply full clean power in the region by 2045?
3) What policies can IKN implement to help realize their goals?

Before diving into case studies and methodologies, it is critical to understand the current landscape of the power sector in Indonesia. We identified regulatory and utility players, the available sources of electricity and its transmission in the Kalimantan region, and barriers for renewable energy adoption.

Current Electricity Landscape Overview

Regulatory and Utility Players

The President sets the overall ambition for the country's power sector, followed by specific obligations executed by relevant ministries. This includes the Ministry of Energy and Mineral Resources (ESDM) that oversees laws on energy and acts as a market regulator. The Ministry of State-Owned Enterprises approves the electric utility's annual budget and conducts their performance reviews, while the Ministry of Finance recommends subsidy amounts and approves government guarantees for the electric utility's loans and Power Purchase Agreement (PPA) obligations. [4]

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[2] "UU No. 3 Tahun 2022 Tentang Ibu Kota Negara [JDIH BPK RI]," n.d. https://peraturan.bpk.go.id/Home/Details/198400/uu-no-3-tahun-2022.

[3] MAPC. "What Is Net Zero – MAPC," n.d. https://www.mapc.org/net-zero/what-is-net-zero/.

[4] World Economic Forum. "Policy Opportunities to Advance Clean Energy Investment in Indonesia." *WEF,* November 2022. https://www3.weforum.org/docs/WEF_Policy_Opportunities_to_Advance_Clean_Energy_Investment_2022.pdf

The main electric utility in Indonesia is *Perusahaan Listrik Negara* (PLN), which is a government-owned vertically integrated utility. PLN, the major producer of electricity in the country, also purchases electricity generated by independent power producers (IPP) through take-or-pay structured PPAs[5]. This means that PLN agrees to either take and pay for the electricity agreed in the contract or pay for the amount that is not being used. The electricity will then be resold to end customers with prices approved by ESDM. By the end of every PPA, the ownership of the project is then transferred to PLN.

Available Sources of Electricity

PLN is required to lay out a 10-year Electricity Supply Business Plan (RUPTL) every year to revise their portfolio and ensure the reliability, affordability, and now sustainability of power supply to customers. The most recent RUPTL (2021-2030) marks a milestone for a fossil fuel heavy country like Indonesia, as it is the first time that majority of new projects will be coming from renewable sources.

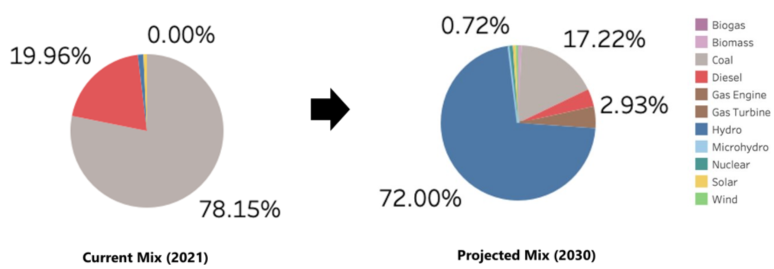

Figure 3 shows the projected change from heavy reliance on coal in 2021 to hydro in 2030 in Kalimantan.

For the whole of Kalimantan, the total capacity is projected to grow by more than fourfold from 3,417 MW to 14,804 MW between 2021 and 2030. As shown in Figure 3 above, renewable or emissions-free energy, mainly hydro, will account for 70% of that expected growth.[6] This lays out a promising future for Nusantara's sustainable energy targets, as it aligns with PLN's goals.

To understand how PLN and in turn, Nusantara can achieve these ambitions, we analyzed the potential of several types of renewable energy for the Kalimantan region. Wind exhibits low potential, while solar has a medium potential and hydro possesses a high potential (See Appendices A, B, and C).

[5] CMS Law-Now. "Indonesian Power Purchase Agreements Regulation No 10 2017 on Principles of Power Purchase Agreements," n.d. https://cms-lawnow.com/en/ealerts/2017/04/indonesian-power-purchase-agreements-regulation-no.-10-2017-on-principles-of-power-purchase-agreements.

[6] PT PLN (Persero). "Listrik untuk Kehidupan yang Lebih Baik - PT PLN (Persero)," n.d. https://web.pln.co.id/stakeholder/ruptl.

Some projects undergoing construction that are worth noting include the 70 MW *Tanah Laut* Wind Power Plant paired with a 10 MW battery energy storage system in South Kalimantan that has a Commercial Operation Date (COD) of 2025[7]. Additionally, the massive 9 GW Kayan River Hydro Project in Northern Kalimantan that has a COD of 2026 will provide electricity to the provinces of North, South, Central, and East Kalimantan, which includes Nusantara.[8] This provides some clarity of where Nusantara can get a considerable amount of renewable electricity supply from, given that transmission infrastructure gets built accordingly.

Figure 4 shows Kalimantan's current transmission lines (solid lines) and the planned transmission expansion (dotted line)

Transmission line expansion has become a key focus area for the PLN, as they are planning to invest IDR 213 trillion (USD 15 million) nationally on transmission and substation infrastructure through 2030. This can help integrate new renewable energy projects such as *Tanah Laut* and Kayan that come online in Kalimantan and create robust interconnections within and beyond the region. For instance, the utility is working with Malaysia to assess the prospects of power trade between East Kalimantan and Sabah, Malaysia.[9] In this case, it can even lay the groundwork for further transmission extension from Borneo Island to Mindanao in the Philippines.

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[7] Reve. "PLN Signs PPA with Total Eren, Adaro Power and PJBI for Wind Project in Indonesia | REVE News of the Wind Sector in Spain and in the World," May 8, 2023. https://www.evwind.es/2023/05/08/pln-signs-ppa-with-total-eren-adaro-power-and-pjbi-for-wind-project-in-indonesia/91727.

[8] Isabella, Yovanda. "Indonesia Backs Hydro to Power New Capital City." *China Dialogue*, April 18, 2023. https://chinadialogue.net/en/cities/indonesia-backs-hydro-to-power-new-capital-city-nusantara/.

[9] Admin. "Renewables Focus: Indonesia's PT PLN Unveils Plans for the next Decade." *Power Line Magazine*, January 7, 2023. https://powerline.net.in/2021/11/08/renewables-focus/#:~:text=As%20per%20the%20new%20electricity,substations%20between%202021%20and%202030.&text=The%20Indonesian%20transmission%20system%20has%20eight%20interconnected%20networks%20and%20600%20isolated%20grids.

Barriers for Renewable Energy Adoption

Although renewable energy has become more cost competitive than fossil fuels, there have been regulatory barriers in Indonesia that ultimately affects the low adoption of renewables across the country. These are important to identify, as we investigate policy alternatives that can expand the markets for low carbon energy and reduce greenhouse gas emissions for Nusantara.

1) **Take-or-Pay PPAs:**
   The Take-or-Pay obligations in long-term PPAs between IPPs and PLN are mostly fossil fuel power plants. This creates contractual inflexibility that hinders the adoption of new renewable capacity. The guaranteed payments of the PPAs by the government also discourages the utility from accelerating its renewable portfolio.

2) **Oversupply and underuse of coal:**
   The optimism of consumption growth along with the Take-or-Pay scheme of PPAs created high coal reserve margins, which leads to an oversupply and underuse of the source.

3) **Domestic market obligation (DMO):**
   DMO requires local coal producers to supply 25% of their annual production to PLN at a price cap that is much lower than international markets. This ensures low cost of electricity for end consumers but poses a challenge for renewable energy penetration in the power markets.

4) **Fossil fuel subsidies:**
   Fossil fuel and electricity subsidies amounted to over IDR 280 trillion (USD 19 billion) in 2021. The electricity price benchmark that is set by PLN and IPPs is based on fossil fuels' production costs, which are highly subsidized. The present tariff mechanism does not allow renewable energy to be as competitive even with current tax incentives for renewables.

5) **Local content requirement (LCR):**
   LCR has been restrictive for renewable technologies in Indonesia, mostly for solar photovoltaics (PV). PV's LCR has increased from 40% in 2012 to 60% in 2019. This has made it almost impossible for renewables to scale up, as locally manufactured panels are not yet as cost-competitive or efficient as ones from abroad.[10]

Although a sizable amount of the country's electricity regulatory policies poses barriers to renewable integration, this also provides an opportunity for IKN to detect and act on the right

[10] Elrika, Hamdi. "Indonesia's Solar Policies". *Institute for Energy Economics and Financial Analysis*, February 2019. https://ieefa.org/wp-content/uploads/2019/02/Indonesias-Solar-Policies_February-2019.pdf

policy signals to attract investments in low emissions technologies for Nusantara. This will be explored further after the analysis of findings from our demand and supply models.

Stakeholder Assessment

In the pursuit of our practicum, we acknowledge the importance of alignment with entities that play an influential role in the realization of this relocation plan. Therefore, we have identified key stakeholders for our project that supports IKN's targets. Appendix D lays out the different players involved along with its level of influence and stakes in the project.

Nusantara Capital City Authority (*Otorita Ibu Kota Negara* – IKN Authority**):** The Authority is a cabinet level-agency formed by the Indonesian government, working directly under the President of Indonesia. They are tasked with managing and governing the city of Nusantara, future capital of Indonesia located on Kalimantan is currently chaired by Mr. Bambang Susantono. They are our main partner in this research, particularly under the team of Prof. Ali Berawi, the Deputy of Green and Digital Transformation for the Authority.

***Perusahaan Listrik Negara* (PLN):** PLN is the state-owned electricity company in Indonesia. They are responsible for generating, transmitting, and distributing electricity to customers throughout the country. PLN Indonesia was founded in 1945 and has since played a crucial role in the development of the Indonesian economy by providing reliable electricity to businesses, homes, and industries. The company is also responsible for implementing government policies related to the electricity sector, such as promoting the use of renewable energy sources and improving energy efficiency.

Ministry of Energy and Mineral Resources (ESDM): The ministry is responsible for formulating and implementing policies related to the management of energy and mineral resources in Indonesia. Its key areas of focus include ensuring a reliable and affordable supply of energy to meet the country's growing demand, promoting the use of renewable energy sources, developing the country's mineral resources, and ensuring the sustainable management of these resources. ESDM Indonesia also plays an important role in regulating and supervising the activities of companies operating in the energy and mineral sectors in Indonesia.

Ministry of National Development Planning (BAPPENAS): The ministry is responsible for formulating and implementing Indonesia's national development policies and plans, as well as monitoring and evaluating their implementation. BAPPENAS Indonesia is also responsible for coordinating and harmonizing development programs and projects across various ministries and government agencies, as well as with international development partners. The agency plays a critical role in guiding Indonesia's economic and social development by identifying priority areas for investment and ensuring that development efforts are aligned with the government's long-term goals and objectives.

Development banks: Development banks like the Asian Development Bank (ADB) or World Bank assist the Indonesian government in realizing the IKN project through assistance, partnership, and financial support. ADB, in particular, also has interest in retiring coal power plant in Indonesia which may align with IKN’s target of 100% renewable energy penetration.

Ministry of Investment (BKPM): BKPM is a Government Agency which oversees implementing policy and service coordination in investment. As the primary interface between business and government, the Ministry is mandated to boost domestic and foreign direct investment through creating a conducive investment climate. Restored to Ministerial status in 2009 and reporting directly to the President of the Republic of Indonesia, this investment promotion agency’s goal is not only to seek more domestic and foreign investment, but also seek quality investments that improve social inequality and reduce unemployment.

Ministry of Public Works and Public Housing of Republic of Indonesia (PUPR): This ministry is responsible for planning, implementing, and evaluating public works and housing programs and policies across the country. The ministry's responsibilities include the development and maintenance of infrastructure such as roads, bridges, ports, airports, and irrigation systems, as well as the provision of housing for low-income families. PUPR is also responsible for promoting sustainable development and environmental protection in its infrastructure projects. The ministry works closely with other government agencies, private sector partners, and international development partners to achieve its goals and objectives, which include improving access to basic services and infrastructure, reducing poverty and inequality, and promoting inclusive economic growth.

International and Local Developers: These developers are enterprises that build and generate renewable power plants in Indonesia. They are the key private entities which can help PLN accelerate the construction of renewable energy power plants in Indonesia. Developers are also the one who will look for foreign investment, raising debt, etc to build power plant infrastructure.

Non-governmental Organizations: NGOs are independent, non-profit organizations that are not part of the government and operate independently of the state. In Indonesia, NGOs play an important role in promoting social and environmental causes, providing humanitarian assistance, and advocating for human rights and democracy. They are involved in a wide range of activities, including community development, environmental protection, health and education initiatives, and the promotion of good governance and democracy. Some of the well-known NGOs relevant to our studies include Walhi and Greenpeace Indonesia. These and other NGOs are often involved in partnerships with government agencies, international organizations, and other stakeholders to achieve their goals and objectives.

Case Studies

The experiences of other nations pursuing similar city development goals can provide lessons for IKN. Nusantara is unique in its joint endeavor as a greenfield capital city targeting 100% renewable electricity. Given the lack of precedents in this field, this project explores case studies in the following two categories instead:

- Greenfield capital cities, and
- Cities powered by 100% renewable electricity.

Figure 5: Case study locations

A total of eight cities were studied across six countries for their technical system planning, socio-economic integration, environmental impact, financial feasibility and political strategies.

Greenfield Capital Cities

Brasilia, Brazil

Population: 5.3 million[11]

Founded in 1960, Brasilia is similar to Nusantara with its forest location and role as a symbol of modernity for the country. It was designed to house only government actors; but experienced unexpectedly high internal migration. Critical issues include water stress[12] due to disorganized urban growth, grid overreliance on hydropower[13], low water availability in recent years, high city construction costs leading to increased inflation and political instability, and high levels of deforestation and social inequality. At the country level, strategies used to mitigate the energy crisis include increasing thermal power generation, accelerating completion of wind power projects, reducing demand through electricity price increase and allowing back-up generators to operate as base load.

[11] "Brasilia Population 2023." Accessed May 9, 2023. https://worldpopulationreview.com/world-cities/brasilia-population.

[12] "Brasilia | GPSC." Accessed May 9, 2023. https://www.thegpsc.org/city/brasilia.

[13] Statista. "Brazil: Electricity Generation Share by Source 2021." Accessed May 9, 2023. https://www.statista.com/statistics/985665/brazil-electricity-generation-source/.

Putrajaya, Malaysia

Population: 120,000[14]

Overcrowding, high congestion and land values in Kuala Lumpur drove the Malaysian government to relocate its capital city, a megaproject by the incumbent Prime Minister. Putrajaya was designed as a showpiece for the country on 'garden city' and 'intelligent city' themes. However, it has been criticized for its heavy reliance on air-conditioning and its failure to avoid the urban heat island effect[15]. The city's high construction costs ($8.1 billion) at a time of extreme recession[16] also put a strain on the country's resources.

Cities Powered by 100% Renewable Electricity

Reykjavik, Iceland

Population: 137,618[17]

The city of Reykjavik in Iceland sources 100% of its electricity from renewable sources, one of the first city's in the world to do so[18]: 73% from hydro and 27% from geothermal (used for heating purposes). Iceland's abundant geothermal resources and high hydropower potential enabled the city's clean energy mix, in line with national energy security goals, despite being classified as a 'developing country' by the UNDP in the 1970s[19]. Favorable legal and regulatory frameworks, government incentives, and a collaborative approach between municipalities, government and the public supported the transition. Additionally, the cascading use of geothermal energy fostered the development of many new companies in the field, promoting circular economy[20].

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[14] "Department of Statistics Malaysia." Accessed May 9, 2023. https://www.dosm.gov.my/portal-main/landingv2.

[15] Tran, Vincent. "In The Name Of Utopia, The Case Study Of Putrajaya, Malaysia's Planned Administrative Capital." University of Florida, 2010.

[16] The Malaysian Reserve. "The Journey of Putrajaya — Malaysia's Jewel Capital City," January 31, 2019. https://themalaysianreserve.com/2019/01/31/the-journey-of-putrajaya-malaysias-jewel-capital-city/.

[17] "Reykjavik Population 2023." Accessed May 9, 2023. https://worldpopulationreview.com/world-cities/reykjavik-population.

[18] https://www.facebook.com/GCityTimes. "Green City: Reykjavik, Iceland | Green City Times," October 26, 2010. https://www.greencitytimes.com/reykjavik/.

[19] Nations, United. "Iceland's Sustainable Energy Story: A Model for the World?" United Nations. United Nations. Accessed May 9, 2023. https://www.un.org/en/chronicle/article/icelands-sustainable-energy-story-model-world.

[20] POWER. "Iceland Offers Case Study of Geothermal's Powerful Potential." POWER Magazine (blog), April 1, 2022. https://www.powermag.com/iceland-offers-case-study-of-geothermals-powerful-potential/.

Burlington, Vermont, USA

Population: 44,781[21]

The small town of Burlington, Vermont in the United States adopted a holistic community-led approach to cleaning its electricity grid and became the first city in the U.S. to do so. Its diversified energy mix prevents reliance on any one specific source: biomass, hydro and wind power provides a third of the electricity generated each, with solar accounting for 1%[22]. The city's strong leadership, with support from the local community[23], facilitated the transition from coal to hydro in the late 1970s, without increasing electricity rates for residents. This positively impacted the utility's credit rating and has been used a hedge against future carbon regulations[24]. However, a key challenge the city faces today is the frequent flooding of the river Winooski, on which its 7.4MW hydro plant is located.

Boa Vista, Brazil

Population: 350,000[25]

Boa Vista, was the first city in Brazil to achieve 100% clean municipal energy. Not connected to the Brazilian grid due to its geographical remoteness, the city was driven to explore other alternatives. Given the high solar incidence, Boa Vista turned to solar projects. It adopted a unique community-first approach by starting its transition with a solar project for an indigenous rural community. The success of this project led to its expansion to public lighting, schools and other municipal buildings (bus terminal, market and city hall). This approach has had multiple co-benefits including the creation of green jobs for locals, and increased financial savings from avoiding costly fossil fuel plants which have been directed towards other development areas like education and health[26].

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21 "U.S. Census Bureau QuickFacts: Burlington City, Vermont." Accessed May 9, 2023. https://www.census.gov/quickfacts/burlingtoncityvermont.

22 "Burlington: 100% Renewable Electricity City - CDP." Accessed May 9, 2023. https://www.cdp.net/en/articles/cities/burlington-100-renewable-electricity-city.

23 Woodard, Colin. "America's First All-Renewable-Energy City." POLITICO Magazine, November 17, 2016. https://www.politico.com/magazine/story/2016/11/burlington-what-works-green-energy-214463.

24 "For Burlington, Vermont, Going 100% Renewable Was Just the Start." Accessed May 9, 2023. https://nextcity.org/urbanist-news/for-burlington-vermont-going-100-renewable-energy-was-just-the-start.

25 "Boa Vista, Brazil Metro Area Population 1950-2023." Accessed May 9, 2023. https://www.macrotrends.net/cities/20185/boa-vista/population.

26 C40 Cities. "Boa Vista's Four Year Journey to 100% Clean Municipal Energy," 2020. https://c40.my.salesforce.com/sfc/p/#36000001Enhz/a/1Q000000gRaM/IvY3iErwFNn2.133gOaH.uJP01Ksoz.wvgzZtonfjvk.

Basel, Switzerland

Population: 563,000[27]

Basel's utility company, Industrielle Werke Basel (IWB), which supplies electricity to the city runs 100% on renewables[28] – hydropower (90%) and wind, biomass and solar (10%). This was enabled by the clear vision and strong political will of the city's leaders which in turn, helped facilitate citizen buy-in for the transition. The city used financial tools such as promotional taxes, incentive taxes and savings bonus to boost clean energy production and impact behavior. The city's success has made it a model example for the rest of the country to follow in light of Switzerland's 'Energy Strategy 2050'[29].

Samso Island, Denmark

Population: 3,724[30]

The Danish Island of Samso is the world's first renewable energy island. 100% of its electricity comes from offshore and onshore wind power and biomass. The island is energy-positive, exporting renewable electricity to the mainland. The city's financing model had participation of citizens and stakeholders and local ownership of the renewable energy investments at its core. For instance, wind turbines are owned by a combination of private owners, investor groups, the municipal government and local cooperatives. The enthusiasm to be a self-sufficient thriving community has also resulted in Samso having Denmark's highest number of electric cars per capita. This model has led to significant benefits for the island community and economy, new jobs and local growth[31].

Georgetown, Malaysia

Population: 300,000[32]

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[27] "Basel, Switzerland Metro Area Population 1950-2023." Accessed May 9, 2023. https://www.macrotrends.net/cities/22600/basel/population.

[28] Climate-KIC. "Municipality-Led Circular Economy Case Studies," 2018.

[29] EM Magazine. "How the World's Cities Are Transitioning to Renewable Energy." Accessed May 9, 2023. https://www.energymanagermagazine.co.uk/how-the-worlds-cities-are-transitioning-to-renewable-energy/.

[30] "Samsø, Denmark | SMILE." Accessed May 9, 2023. https://h2020smile.eu/the-islands/samso-denmark/.

[31] "Samsø: An Island Community Pointing to the Future | Denmark | UNFCCC." Accessed May 9, 2023. https://unfccc.int/climate-action/un-global-climate-action-awards/climate-leaders/samso.

[32] "Population of Cities in Malaysia 2023." Accessed May 9, 2023. https://worldpopulationreview.com/countries/cities/malaysia.

Georgetown, located in the state of Penang in Malaysia, achieved its goal of 100% renewable electricity in 2016, becoming the first city in Southeast Asia to do so[33]. This was made possible through the development of renewable energy infrastructure, energy efficiency measures, and a commitment to sustainable development. The city's government worked with private sector partners to build solar panels and wind turbines to generate renewable energy, which was then fed into the local grid. In addition, the city implemented energy efficiency measures, such as retrofitting buildings with energy-efficient lighting and appliances. One of the key factors that enabled Georgetown to achieve 100% renewable electricity was the city's small size and relatively low energy demand compared to other cities.

Summary

1. **Technical:**
   Nusantara must strive to establish a diverse energy mix to ensure reliability and energy security. To counter pressures from high population growth and resource unavailability, forward planning of infrastructure is essential.
2. **Socio-economic:**
   Nusantara may see positive impacts in the generation of green jobs for locals and potentially larger funds available for investments in health and education due to financial savings. However, negative impacts to be aware of include social inequalities that top-down urban planning may perpetuate, along with the displacement of local communities.
3. **Environmental:**
   As it is located in an ecologically sensitive area, high deforestation risks exist. Renewable sources such as biomass and geothermal will negatively impact local vegetation and wildlife, which must factor into the energy mix planning.
4. **Financial:**
   High financial costs during city development can result in inflation and high debt in the future. Nusantara must consider comprehensive legal & regulatory frameworks and government incentives to reduce risk where possible. Financial tools to impact user behavior can be explored as well.
5. **Political:**
   Given the uncertainty in global markets, energy security and self-sufficiency are key aspects of the transition that can help gather broader political support in Nusantara. To promote stakeholder, buy-in, IKN can consider adopting a more consultative and collaborative approach.

[33] "The Georgetown Goes Green: Malaysia's Penang Island is Leading the Charge to Renewable Energy." The Guardian. June 21, 2016. https://www.theguardian.com/cities/2016/jun/21/georgetown-green-malaysia-penang-renewable-energy.

Methodology

To identify the demand and supply of electricity in new capital city of Indonesia, Nusantara, this study adopts the methodology outlined in the figure below:

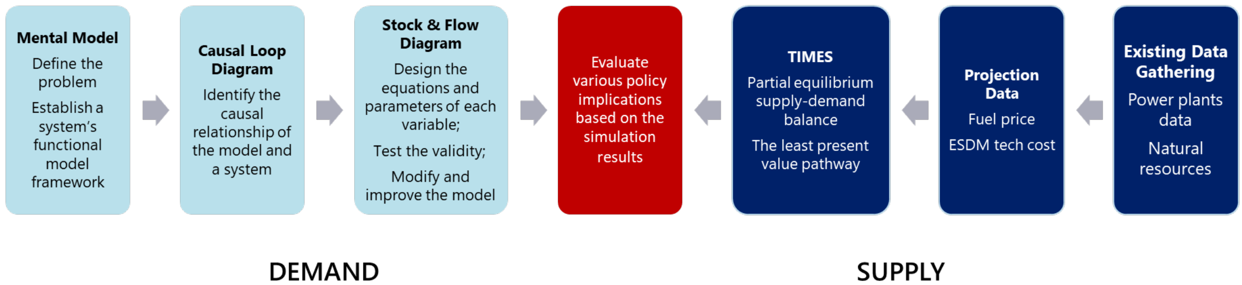

Figure 6 Flow diagram of methodology

The methodology adopts two different frameworks for each side of the modeling:

For Demand Modeling: System dynamics
System dynamics is a framework for modelling complex systems that can capture correlations and feedback across variables and deal with nonlinearities. It comprises of the following steps[34][35]:

- Formulate the problem
- Define functional model framework
- Identify the causal relationship between variables using feedback loops
- Incorporate the model with quantitative equations and parameters
- Test the validity of the model
- Optimize and modify the model to get best performance
- Simulate policy scenarios based on the model

For Supply Modeling: TIMES-ETSAP
TIMES (an acronym for The Integrated MARKAL-EFOM System) is a technology-based economic model framework ideal for representing energy dynamics over a multi-period time horizon[36]. TIMES uses linear-programming to produce a least-cost energy system considering a range of user constraints. It chooses energy services at minimum cost and considers optimum operating factors such as availability and efficiency. It also assumes the model has perfectly competitive markets and perfect foresight.

By assuming a perfectly competitive market, TIMES assumes many firms produce identical products which in this study is electricity. Also, buyers and sellers are available and rational, and

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[34] Chaolin Gu et al., "System Dynamics Modelling of Urbanization under Energy Constraints in China," Scientific Reports 10, no. 1 (June 19, 2020): 9956, https://doi.org/10.1038/s41598-020-66125-3.
[35] Jay Forrester, "World Dynamics" (Wright-Allen Press, Inc, 1973).
[36] Gargiulo, M. Introduction to the TIMES Model Generator. ETSAP (2022)

make rational decisions about the products. Furthermore, TIMES assumes the market has no barriers to entry for firms.

Perfect foresight means that TIMES finds the optimal solution over the whole-time horizon. The decision of choosing the optimum conditions consider the entire future model horizon. In other words, TIMES will not be myopic, and will consider the entire conditions, constraints, and assumptions that users consider for the future.

Demand Modeling

Model Overview
Relocation of Indonesia's capital city is a phenomenon that affects multiple sectors. Due to the complexity of the correlation between variables and nonlinearities while correlating variables of interest across sectors, this study chooses system dynamics as the method to obtain projected electricity demand.

The model involves correlation between investment, households' consumption and government spending[37] to constitute *City Gross Domestic Product* (CGDP) using expenditure approach. The CGDP represents the growth of economic activities in the city over time.

$$Y = C + (I_G + I_{PVT}) + G \qquad \dots (1)$$

This study assumes that Cobb-Douglas model in production approach and expenditure-CGDP is equal. By holding total factor production and capital constant, the number of labor force in the city can be projected.

$$N_t^{LF} = (1 - \frac{g_Y}{\beta}) * N_{t-1}^{LF} \qquad \dots (2)$$

The investment[38] for the city also indicates how progressive government facilities are being built. By using the approach of number of government officials' residential units, how many governments is being relocated can be also projected.

$$N_t^G = Govt.\ facility * Ratio\ of\ Officials\ per\ Facility \qquad \dots (3)$$

$$Govt.\ facility = (I_G + I_{PVT}) * \text{Ratio Facility per Rp.} * \text{Proportion for Officials'Residence} \qquad \dots (4)$$

This study assumes that the population is only the aggregate of the initial population, labor force and government officials subtracted by birth and date over time.

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[37] This study assumes there is no net export that affects the CGDP.
[38] This study combines the investment from government and private sector that can be seen in formula (1) and (4).

$$POP_t = POP_{t0} + \int_{t0}^{t} (N_t^G + N_t^{LF} + Birth_t - Death_t)dt \qquad \ldots (5)$$

After obtaining the projected CGDP, the energy demand of this city (ELCC) can be projected using the multiplication of energy intensity and the CGDP.

$$ELCC = Y * EI \qquad \ldots (6)$$

All correlations of these variables are depicted using causal loop diagram below:

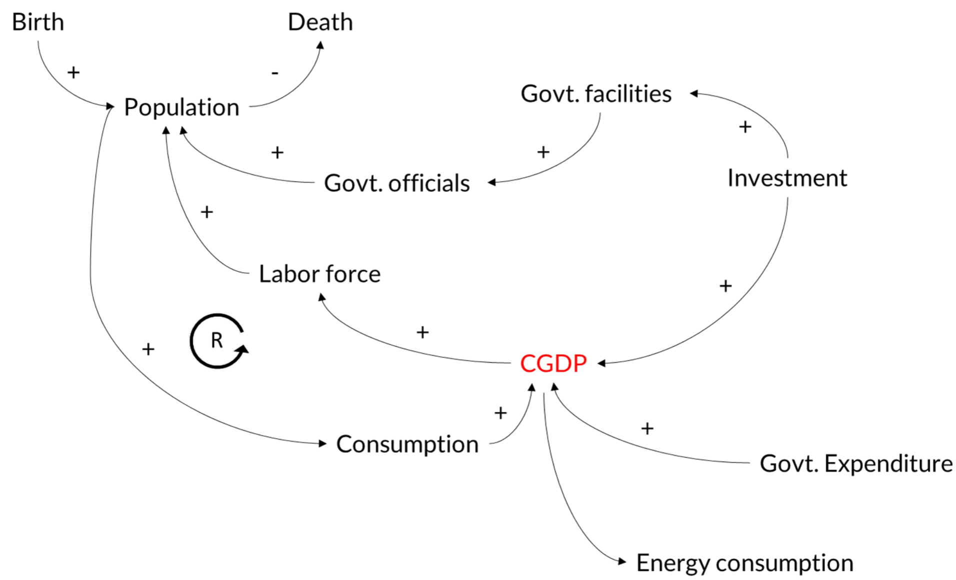


Figure 7 Causal Loop diagram of Demand Model

Data and Assumptions

This model is built upon several assumptions and data sets completed with sources as shown in Table 1.

Table 1 Assumption, data sets and sources used for the model

Variables	Parameter	Unit	Year	Scale	Source
Fertility	1.64	%	2021	Indonesia	United Nation
Death rate	0.96	%	2022	Indonesia	BPS
Net migration rate	9.93	%	2021	IKN	Shimamura (2020)[39]
GDP to mortality exponent	0.02		2023	Indonesia	LCDI
Household consumption per capita	27,000,000	Rupiah	2019	Jakarta	BPS
Share of household	0.024	%	2019	Jakarta	BPS

[39] Takuya Shimamura and Takeshi Mizunoya, "Sustainability Prediction Model for Capital City Relocation in Indonesia Based on Inclusive Wealth and System Dynamics," Sustainability 12, no. 10 (May 25, 2020): 4336, https://doi.org/10.3390/su12104336.

Electricity intensity	0.00001096	kWh/Rupiah	2021	Jakarta	Author's calculation
Share of local government expenditure	4.1	%	2019	PPU	BPS
Labor elasticity	0.382		2019	Indonesia	Darma (2023)[40]
Total Investment	1.73x10^15	Rupiah	2023	IKN	Otorita IKN
Ratio facility per rupiah	1.83x10^-0	%	2023	IKN	Otorita IKN
Proportion investment to residence	3	%	2023	IKN	Otorita IKN
Existing electricity demand	95	GWh/year	2021	PPU	BPS

Stock and Flow Diagram

This study draws all the assumptions, data sets, equations and causal loop diagram on stock and flow diagram using Powersim. The result of the diagram from this software is illustrated in Figure 8.

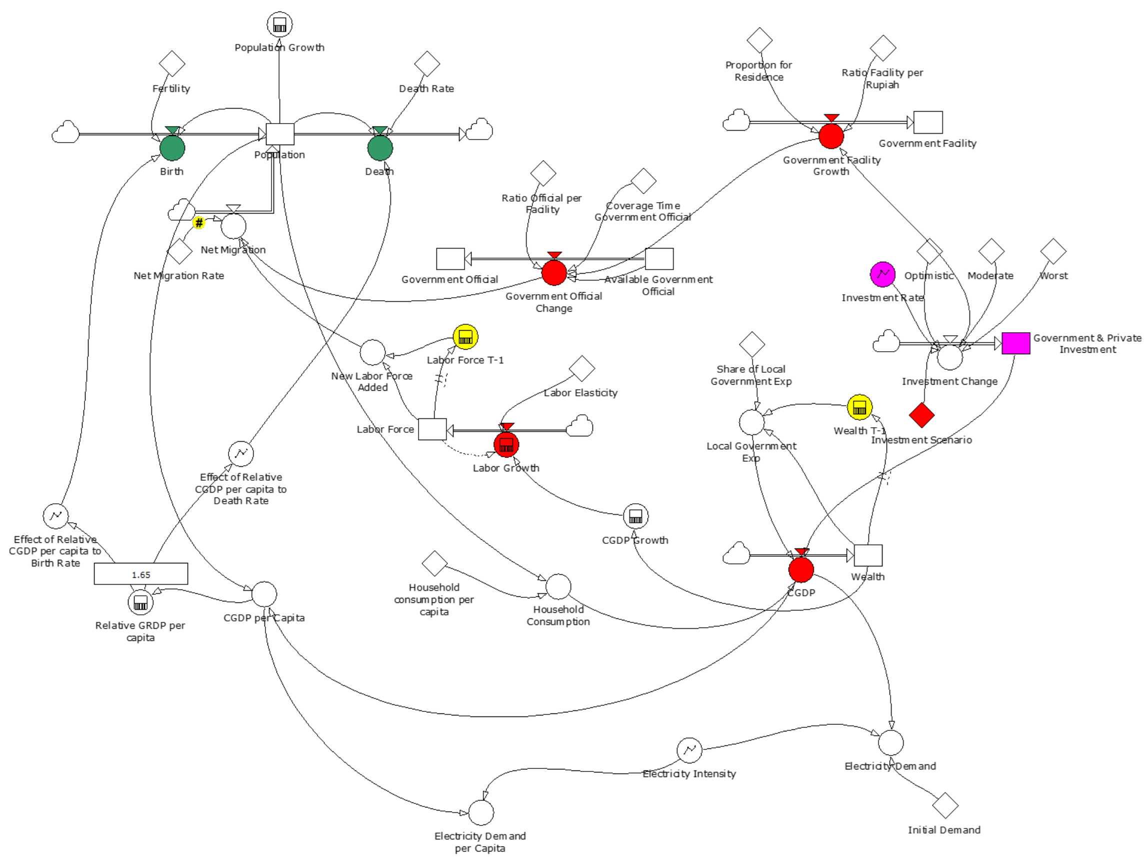


Figure 8 Stock and Flow Diagram of Demand Model

[40] Sekolah Tinggi Ilmu Ekonomi Samarinda, Department of Management, Indonesia et al., "Employment Absorption: Elasticity in the Industry and Services Sector in Indonesia," MANAGEMENT AND ECONOMICS REVIEW 5, no. 1 (June 15, 2020): 125–35, https://doi.org/10.24818/mer/2020.06-10.

Supply Modeling

Data and Assumptions

The model is built based on existing power plant data from PLN RUPTL[41] 2021-2030, the power plant list can be seen in Appendix A, while the summary can be seen in the figure below. This data is cross referenced with an Indonesian power plant database to get the specific commercial operation date of each power plant, so that the technical lifetime and decommissioning details of each power plant can be more accurately estimated.

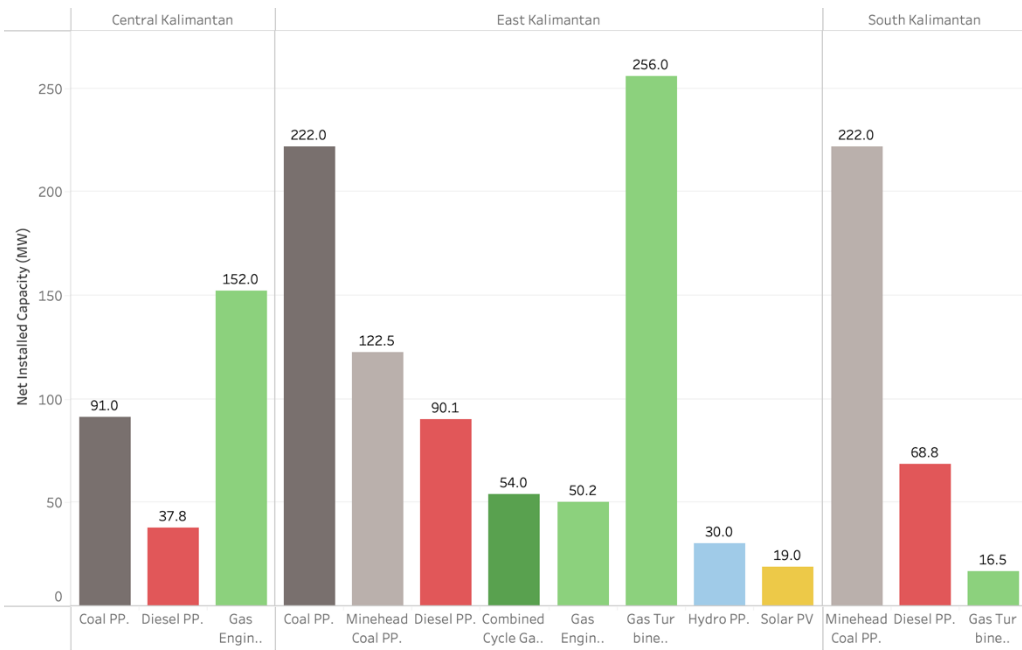


Figure 9 Power plants capacity in the Mahakam-Barito grid by province and technology

In addition to the existing power plants, information about possible new power plants are also considered as seen in the table below.

Table 2 Possible new power plant technology properties

Technology	Construction Time	Thermal Efficiency	Max Capacity Factor	Lifetime
Solar PV Class 10	2 Years		15%	25 years
Wind Class 10	3 Years		20%	25 years
Hydro Dam Class 8	4 Years	95%	76%	50 years
Run of the river Minihydro	3 Years	80%	76%	50 years
Combine cycle gas	4 Years	56%	85%	25 Years
Gas Turbine	3 Years	33%	85%	25 Years
Diesel Engine	1 Years	45%	80%	15 Years

[41] PT Perusahaan Listrik Negara (PLN) Persero is a electricity state-owned company which operates the vertically integrated electricity system in Indonesia. Rencana Umum Usaha Penyediaan (Business Plan) PT PLN 2021-2030 is a master plan that includes development power plant and some assumptions that are used in this study.

These existing and new power plants are chosen by TIMES individually to power IKN when needed under various applied constraints. When TIMES chooses a specific power plant, the power plant will produce certain amount of electricity at a certain cost, including fixed and variable operation and maintenance costs, and fuel costs for a fossil powered power plant. Capital investment costs is also applied if TIMES choses to build a new power plant. The model chooses the most cost-efficient power plant to power IKN discounted by 6% to the base year of 2023.

Power plants that are not cost-efficient are not selected in this model. However, it is important to note that this does not mean that these power plants is not operating. Since only the demand under IKN is modeled, it is very likely (because the electricity demand growth is high in this region) that these power plants will still produce electricity to another region which are currently free from renewable energy constraints. This is one of the limitations of the model arising from the defined scope of the practicum and limited information available regarding the surrounding region demand growth projections.

Fixed and variable operation and maintenance costs and investment cost (only for the newly built power plants) are based on Ministry of Energy and Mineral Resources (MoEMR) price catalog[42]. These costs are not constant but tend to decrease in the future, following specific technology experience curves. Fuel cost assumption is based on empirical price[43] of specific fuel which then will be extrapolated by TIMES.

In addition to cost, each fossil-based production activity also produces emissions. The emission factor used can be seen in the table below.

Table 3 Emission factor for each fuel

Fuel	Coal	Gas	Diesel	Solar	Wind	Hydro	Biomass
*Units	kt/PJ	kt/PJ	kt/PJ	kt/PJ	kt/PJ	kt/PJ	kt/PJ
CO2	91.23	50.33	70.33	NA	NA	NA	NA

Model Constraints

There are several constraints we use in this model to best represent the planned policies.

1. **Renewable energy penetration**
   Based on the mandate of the President Joko Widodo, IKN should be powered 100% by renewable energy in 2045. Thus the renewable power plant options include solar PV, wind, hydro and minihydro power plants. Each technology cost and technical properties are

[42] Technology Data for the Indonesian Power Sector Catalogue for Generation and Storage of Electricity February 2021, can be accessed through https://ens.dk/sites/ens.dk/files/Globalcooperation/technology_data_for_the_indonesian_power_sector_-_final.pdf

[43] The fuel price is obtained from data set that is used by EIA. It can be accessed through https://www.eia.gov/electricity/state/unitedstates/state_tables.php

based on the same MoEMR price catalog mentioned before, adjusted to local renewable resources[44].

2. **Solar production fluctuation**
   Solar PV production is modeled to supply the demand in the day following the figure below.

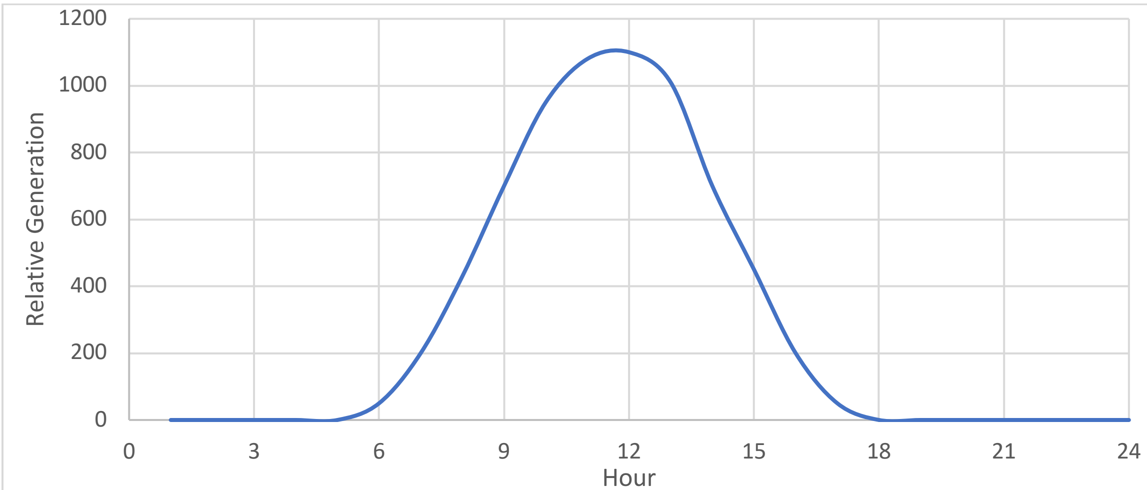


Figure 10 Solar PV daily production

3. **Technology capacity growth**
   Each technology has its own growth limit constraint to limit massive sudden growth in one technology. This constraint also models the preference of the market to develop all possible technologies, not only one, which means the project pipeline should be heterogenous in terms of technology. The constraint is set by based on PLN's project pipeline in 2030, and extrapolated annually by 20% for solar PV, 5% for hydro, 15% for biomass and wind.

[44] Adjusted means the maximum capacity factor is adjusted to East Kalimantan resources, since the catalog is based on Indonesia national average, which might overestimate the generation of solar and wind power plant and underestimate the generation of hydro power plant.

Scenarios and Pathways Development

Three scenarios are used in the demand model, determined by the percentage of investment that will be obtained by IKN until 2045. For each scenario, the CGDP, population and electricity demand are obtained using system dynamics and vary. The scenarios and results are written below:

- **Scenario 1**
  Scenario 1 is the ideal scenario where IKN achieves 100% of its investment targets. In this scenario, in 2045, the CGDP is projected to reach Rp651.8 trillion with a population of 1.83 million, which includes the existing population and new residents consisting of migrated labor force and relocated government officials. Based on this population, the electricity demand is assumed to be 7.2 TWh in 2045.
- **Scenario 2**
  Scenario 2 describes a condition where IKN reaches 80% of its targeted total investment. The projected CGDP is Rp533.3 trillion with a population of 1.68 million and total demand of electricity of 5.9 TWh in 2045.
- **Scenario 3**
  Scenario 3 describes a less-than-ideal situation where investment falls short of IKN's plan. In this scenario, IKN only meets 57% of its investment targets. The projected CGDP is Rp400.1 trillion with a total population of 1.48 million and an electricity demand of 4.5 TWh in 2045.

These demand model results by scenario can be seen in the figures below.

Figure 11 City GDP growth over time by scenario

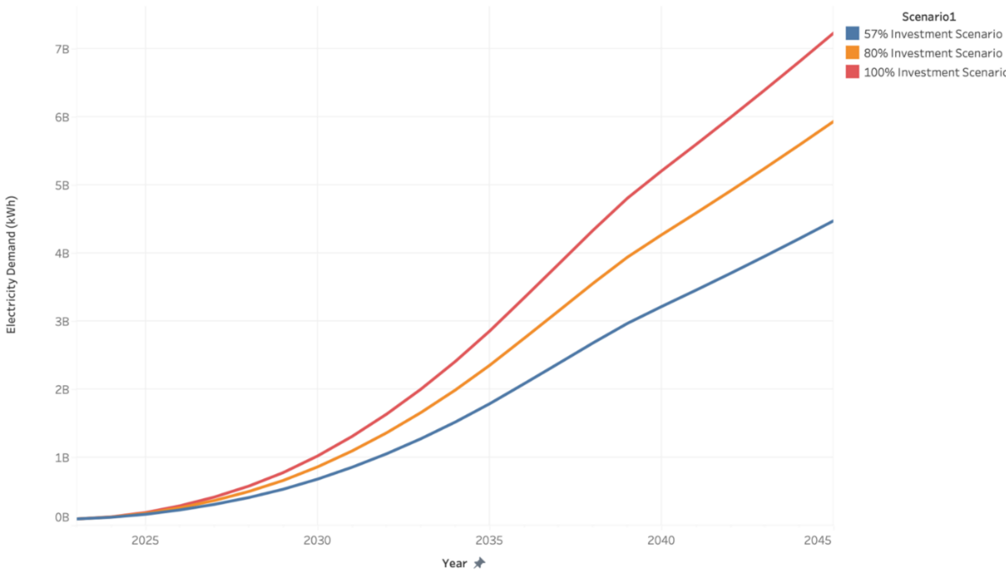


Figure 12 Electricity demand growth over time by scenario

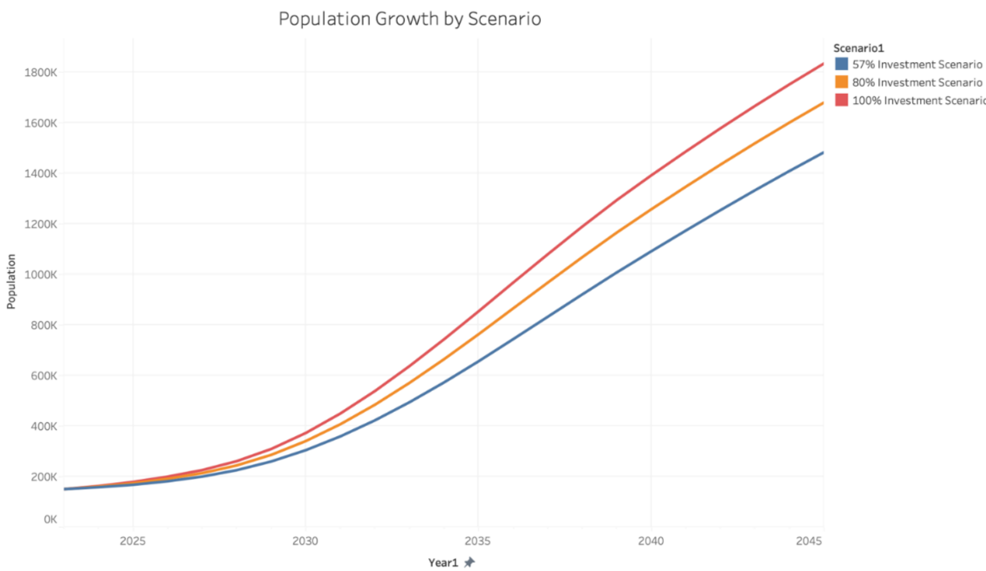


Figure 13 Population growth over time by scenario

While the scenarios describe the investment outlook, this practicum also outlines two pathways that IKN could use in terms of providing electricity for the city (see figure below). **Pathway 1** represents IKN's stated goal in Perpres No. 63/2022[45] - to provide electricity using 100% new renewable energy by 2045. **Pathway 2** represents an accelerated transition, where IKN can provide electricity using 100% new renewable energy ten years earlier than what was determined in the Presidential Decree, that is, by 2035.

[45] Peraturan Presiden No. 63 Tahun 2022 tentang Perincian Rencana Induk Ibu Kota Nusantara (Presidential Decree No. 63/2022 about Detailed Grand Plan for Capital City Nusantara)

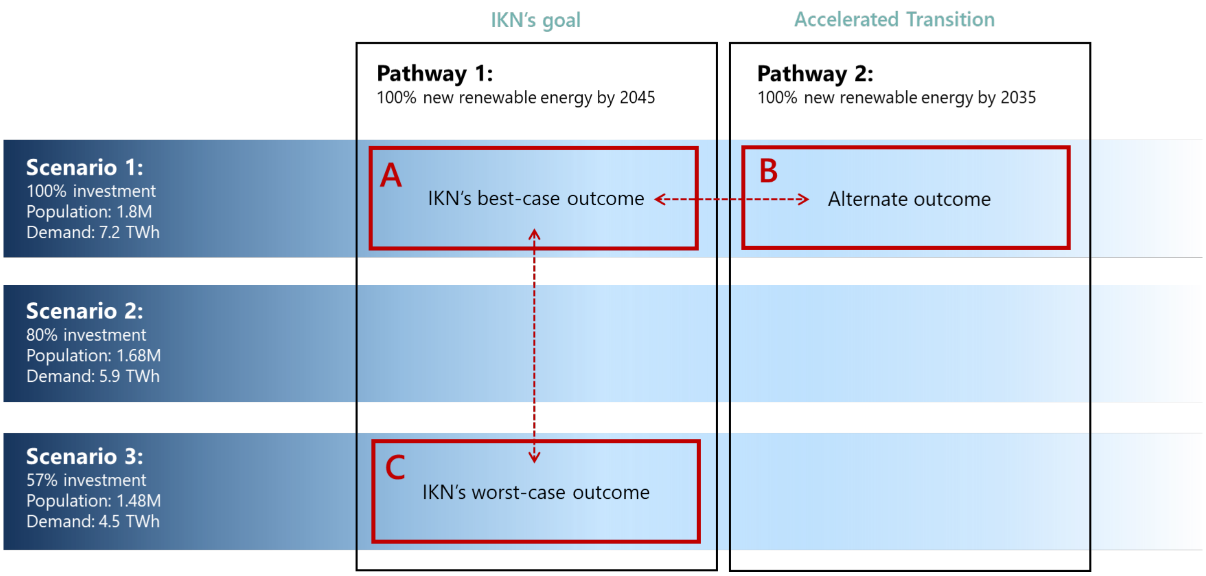


Figure 14 Scenario and pathways development

Based on the 3 Scenarios and 2 Pathways, this practicum focuses on 3 outcomes which are described below:

- **Case A**
  Case A is a combination of Scenario 1 and Pathway 1 which is IKN's best-case outcome. In this case, 100% of the investment is met and 100% renewable energy is achieved by 2045.
- **Case B**
  Case B is the alternate outcome for IKN, where IKN has met 100% of its investment target and has achieved 100% new renewable energy by 2035. It is the combination of Scenario 1 and Pathway 2.
- **Case C**
  Case C is the worst-case scenario for IKN, as it assumes that IKN will only meet 57% of its investment target and achieve 100% renewable energy by 2045. It is the combination of Scenario 3 and Pathway 1.

Results

Power Plant Capacity Mix

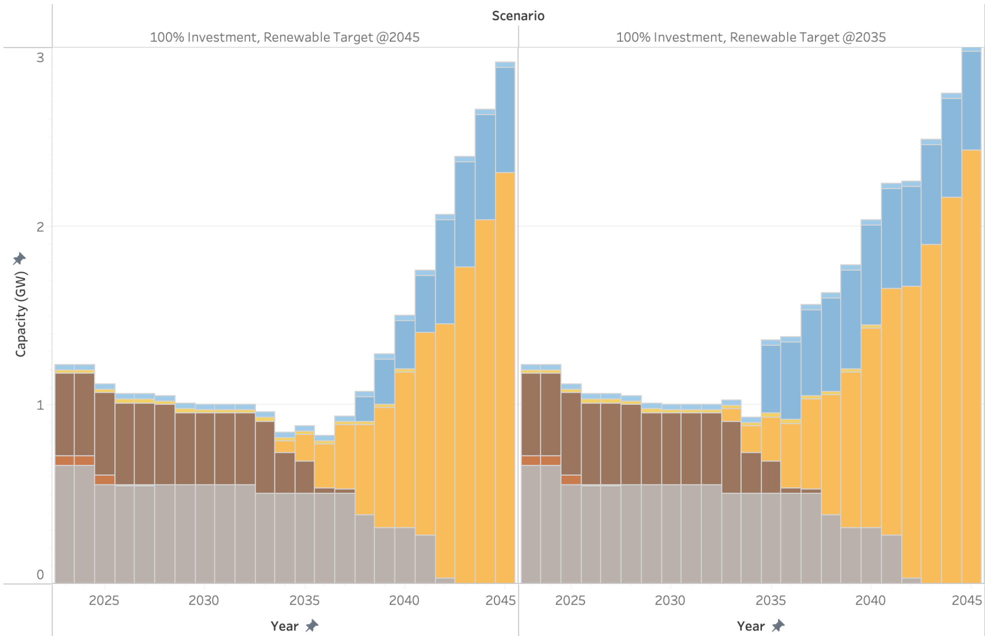


Figure 15 Capacity Mix for Scenario 1

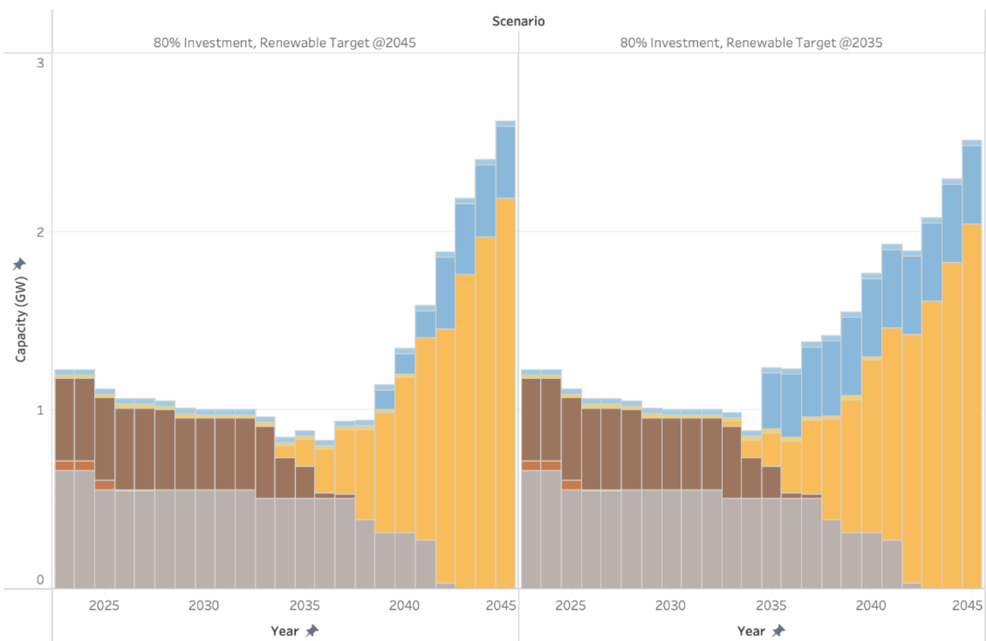


Figure 16 Capacity mix for Scenario 2

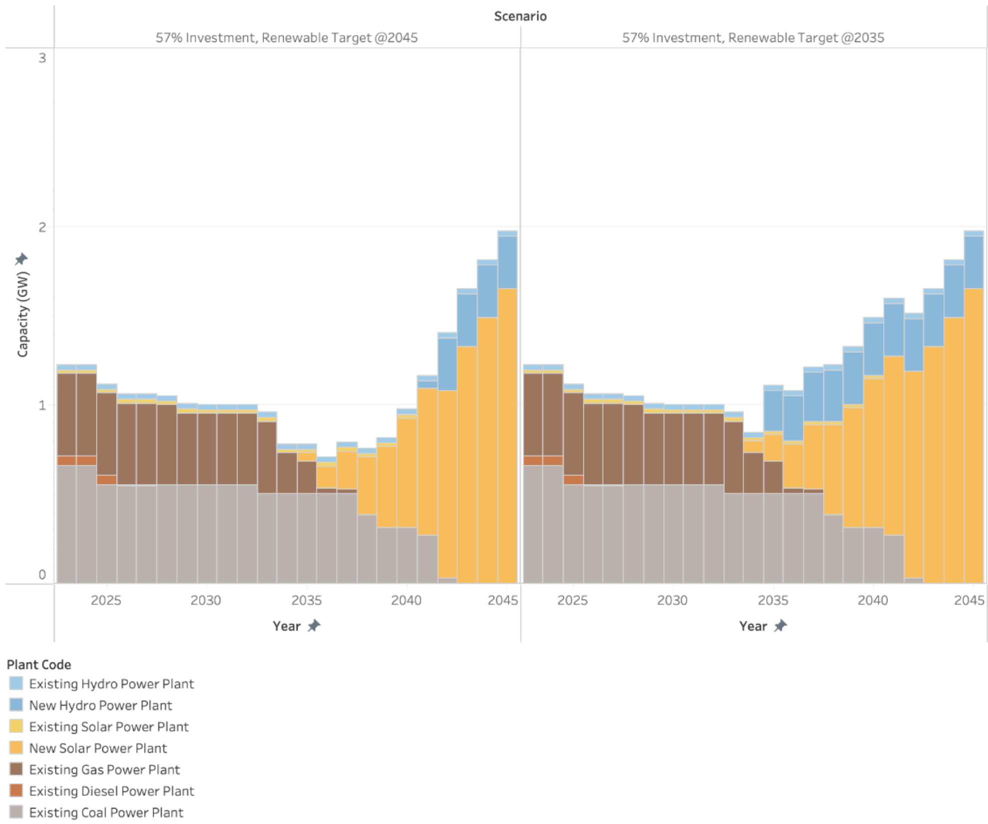


Figure 17 Capacity mix for Scenario 3

The results demonstrate that fossil-based power plants will naturally be decommissioned by 2042 without any government intervention. The first technology to be retired is diesel, followed by natural gas, and then coal power plants. As we can see, there is no future installation of fossil power plants. This might be explained by the relatively higher cost of electricity of fossil-based power plants compared to solar and hydro. However, being fully dependent on renewable production is not ideal due to uncertainty and reliability of natural resources. Hence, minimal capacity of fast ramping fossil-based power plant is still required for energy security reasons, which cannot be modelled in this projection.

Renewable energy power plant starts to ramp up from 2033 in Case A (100% investment) and on later years in the lower investment scenarios, as illustrated in the graphs below. We can also conclude that from all the scenarios, the first renewable technology to be installed is solar. Despite solar resource in East Kalimantan region being not very high, this happens due to the cost of installing new solar PV that is relatively cheaper than hydro power plants. Another possible explanation is the long construction duration of hydro power plants relative to solar PV.

Faster capacity of hydro installation is seen in 100% renewable energy target pathway by 2035. This is consistent in all scenarios. This happens because a sudden demand of massive renewable energy capacity required supply 100% the demand, and the only technology with high enough capacity factor to provide this whilst under growth scenario is hydro. We can still conclude that hydro is more expensive, because in the pathway without 2035 100% renewable energy constraint, similar hydro capacity will only be required starting at 2042.

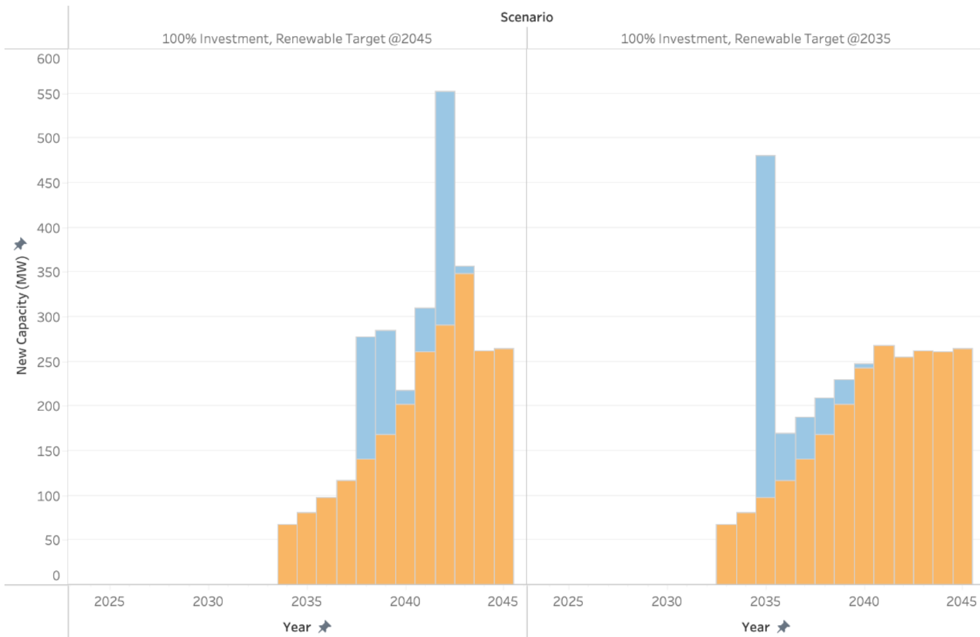


Figure 18 New capacity installation for Scenario 1

Figure 19 New capacity installation for Scenario 2

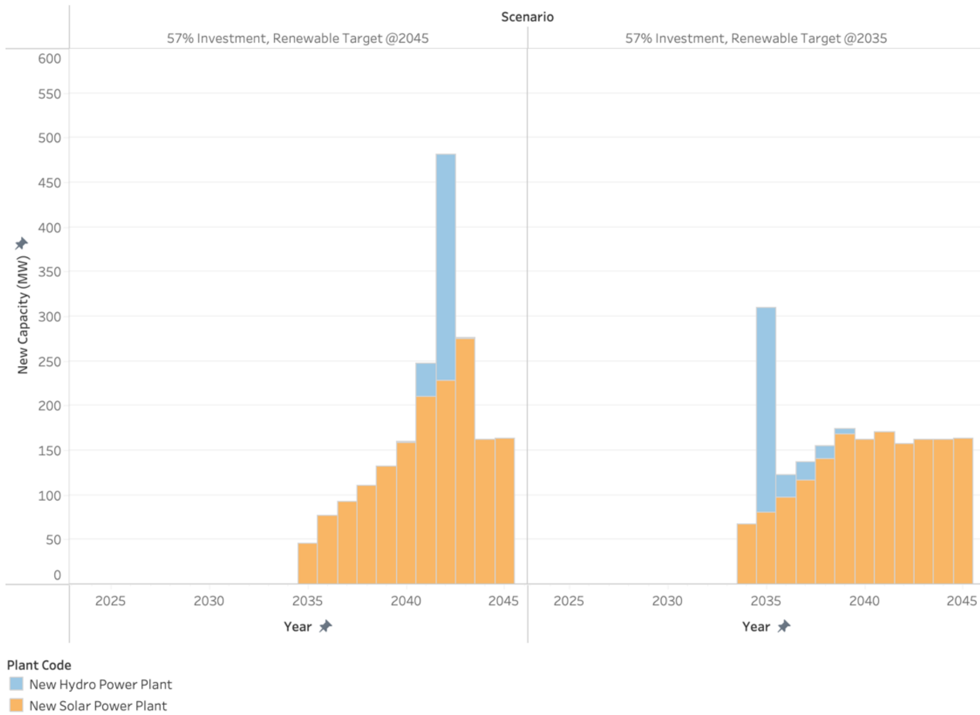


Figure 20 New capacity installation for Scenario 3

Rapid hydro power plant installation is projected for all scenarios and pathways. However, this rapid installation is rather feasible if viewed in nominal terms. The biggest installation in one year happen in Scenario 1, and 2035 renewable energy pathway. In this scenario, around ~350 MW of hydro power plant is projected to be online by 2035. This capacity can actually be fulfilled by 1 hydro power plant in Kayan, North Kalimantan with total feasible capacity of 9000 MW.

A more reasonable growth is seen for the solar PV power plant, aligned with the growth constraint set in the model. The biggest solar PV installation in one year is 350 MWp installation in 2043 in Scenario 1 and 2045 renewable energy pathway. This capacity can be supplied by 3 to 7 solar farm if we assume the standard utility size solar PV of 50-100 MWp per farm. This number is not impossible based on recent experience from other country like China, the US, and the Europe.

Electricity Production Mix

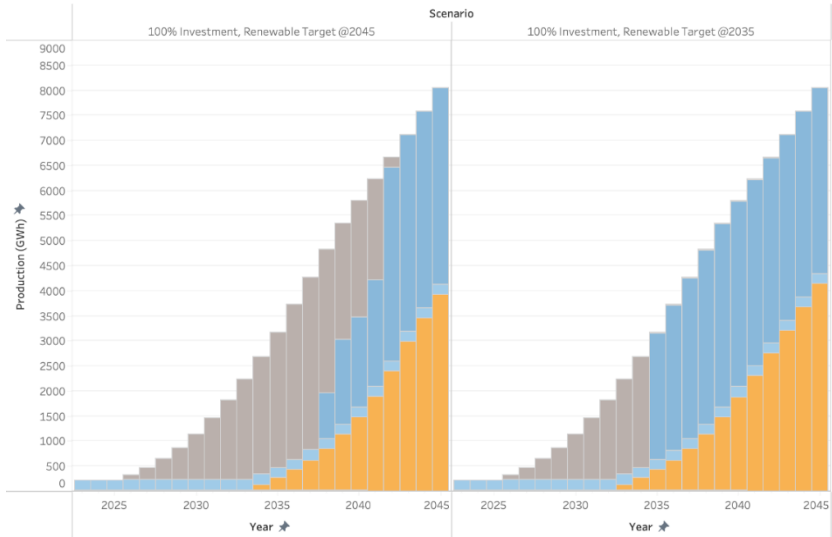


Figure 21 Electricity production for Scenario 1

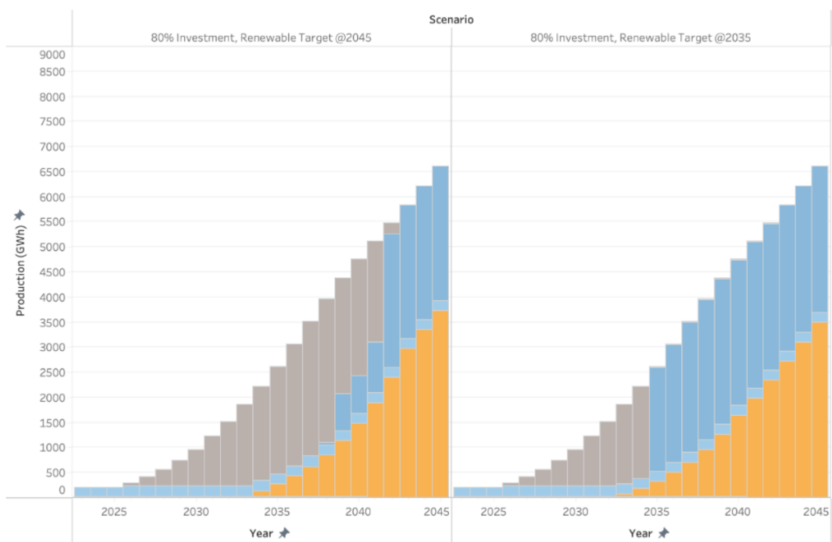


Figure 22 Electricity production for Scenario 2

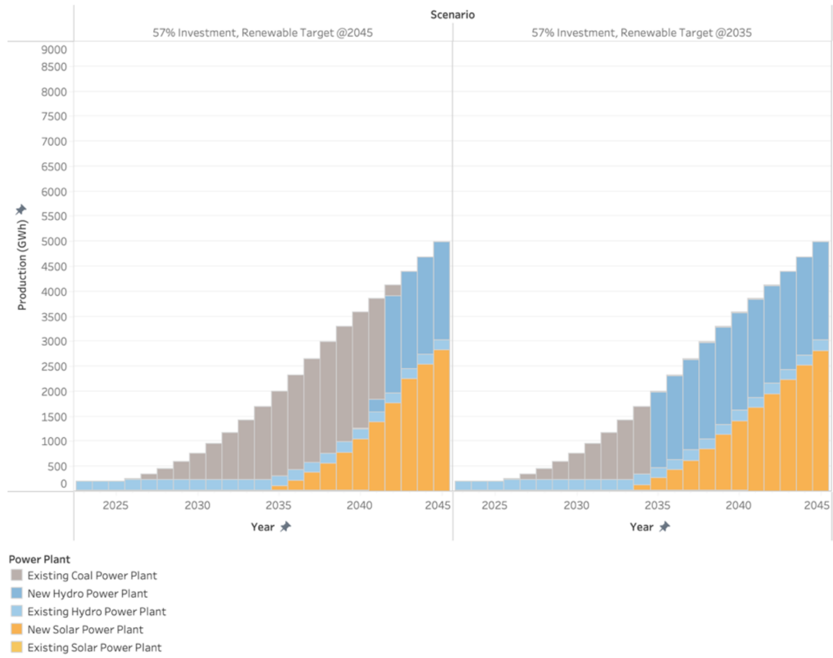


Figure 23 Electricity production for 57% investment scenario

Electricity produced and supplied to the demand follows the set renewable energy penetration targets. From the earlier section we know that the fossil power plant will be fully retire by 2042, however since the production has stop before the retirement year, we can conclude that there is possible loss by PLN that cannot sell the dirty electricity to PLN. However, this does not necessarily mean this fossil power plant is not operating at all. Since we only model the demand from IKN region, there is a very huge possibility (because the electricity demand growth is high in this region) that these power plants will still produce electricity to supply another demand in another region, which does not need any renewable energy constraint like IKN. This is obviously one of this model limitation, since we do not have any information regarding surrounding region demand growth projection and this is not in our research goal to model it.

Electricity produced in the early years will only come from existing hydro, solar, and coal power plants. No electricity is produced from gas or diesel. It is because electricity from gas and coal is relatively expensive. This is also aligned with current electricity production practice in Indonesia where coal is used to produce majority of the electricity.

Massive renewable energy penetration might put a risk to the stability of the grid. But, since that this is not only a 2 GW grid, but a much bigger grid serving east-central-north Kalimantan, with projection to be interconnected to the whole Kalimantan and surrounding island, the renewable energy penetration should not actually be this high. In addition, hydro, which considered to be not as fluctuate as solar, produces majority of the electricity. Nevertheless, hydro does not have fast ramp up capability to counter solar PV intermittent production.

Further study is required to assess grid stability and overall renewable energy penetration because of the limitation of our research. If this issue persists, renewable baseload generation like nuclear power plant needs to be considered. In addition, fast ramp up solutions are required by installing battery energy or gas power plant to counter the solar PV sub hourly fluctuation. Finally, massive pump hydro storage system potential should also be explored in the region to solve daily fluctuation. Further study is required to model this with a smoother time slice to hourly (or even sub-hourly level).

Total Cost

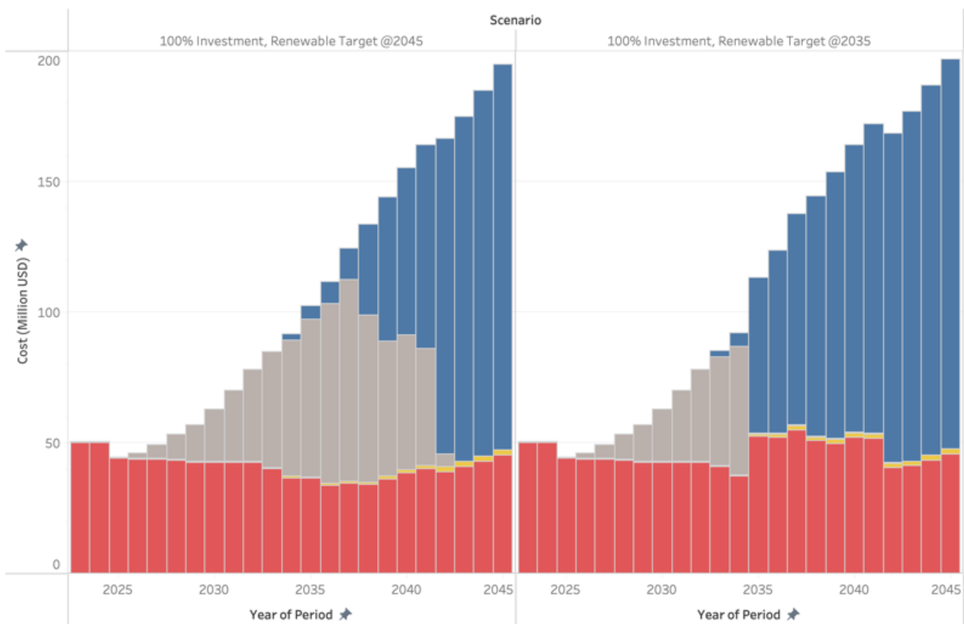


Figure 24 Total annual cost for Scenario 1

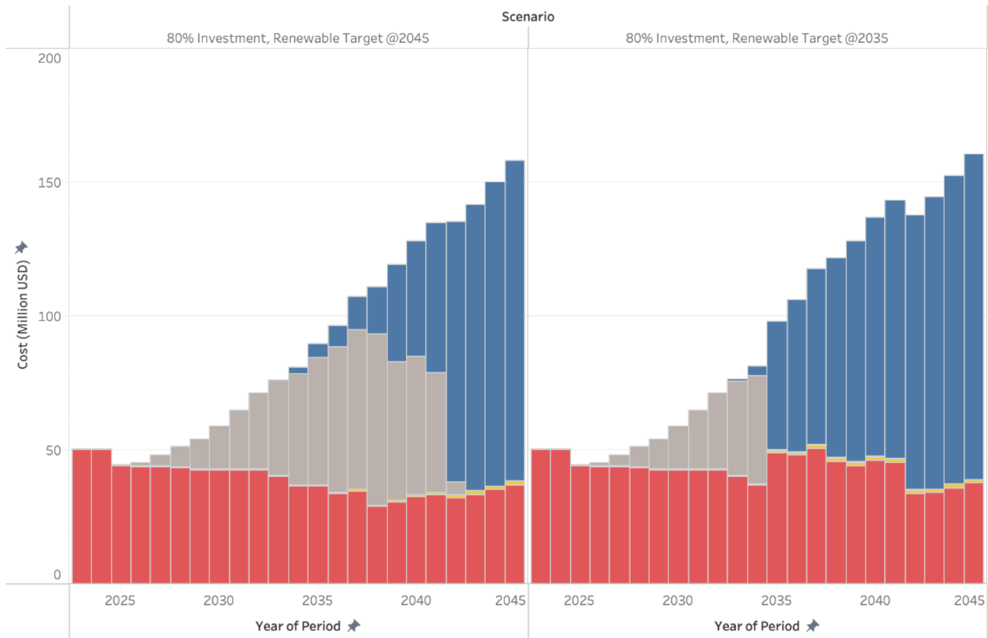


Figure 25 Total annual cost for Scenario 2

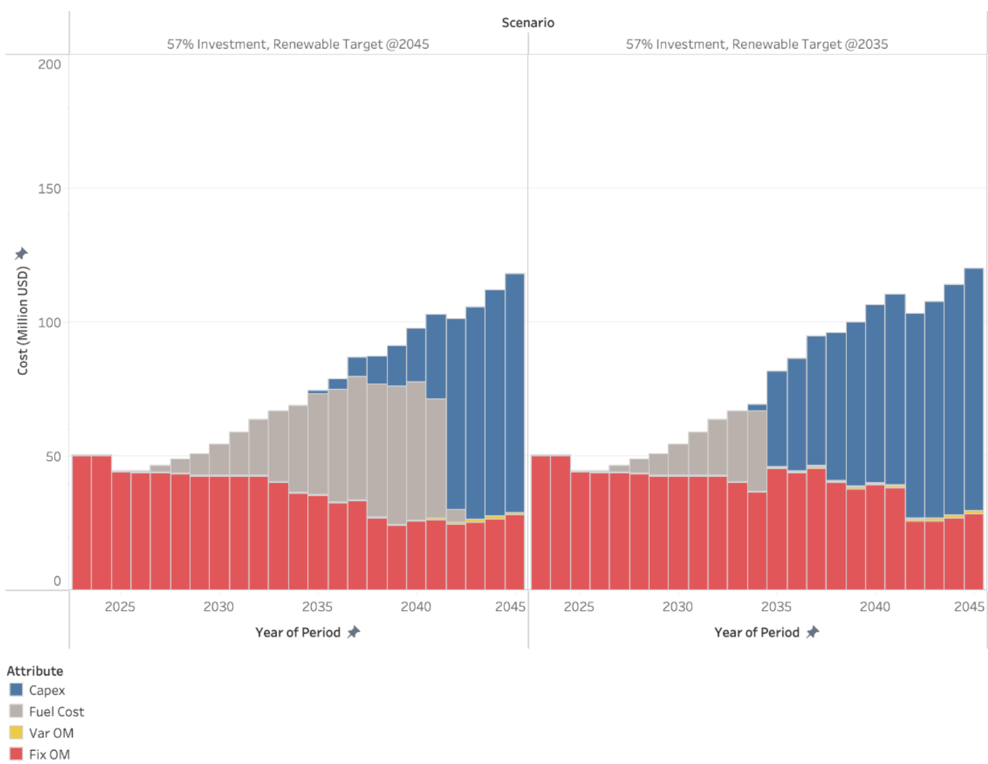


Figure 26 Total annual cost for Scenario 3

Renewable penetration target makes the cost distribution shift from largely fuel costs to upfront capital costs. Thus, securing sufficient investments via a robust investment strategy is critical to enable this energy transition.

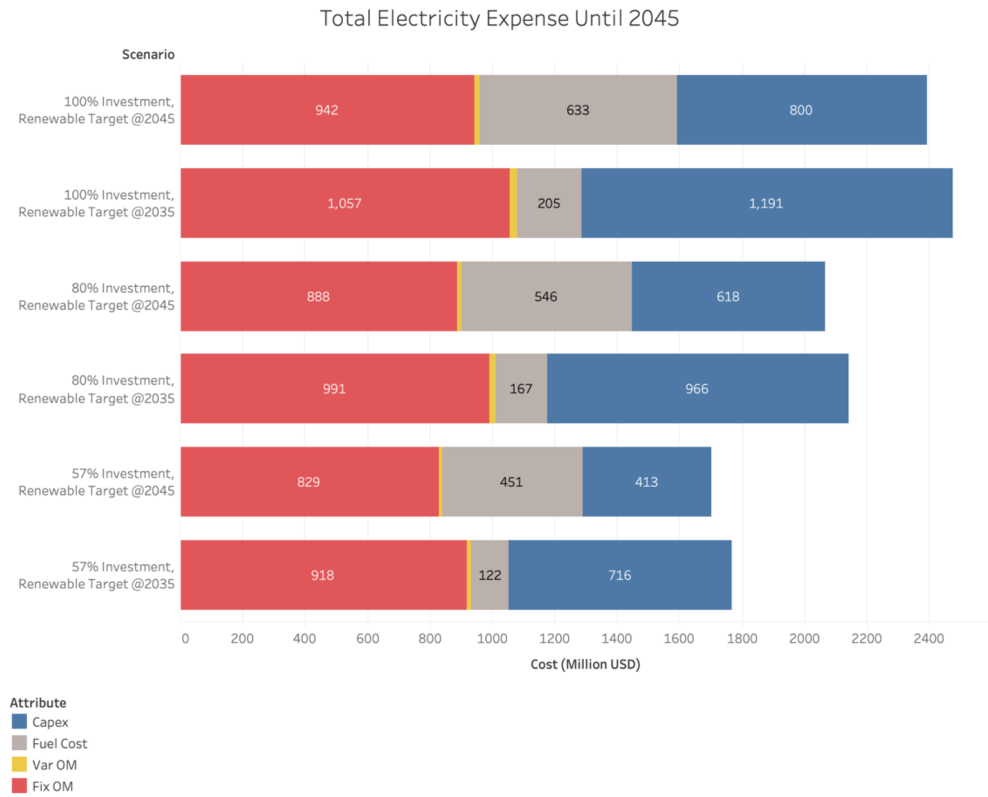


Figure 27 Total expense on electricity until 2045 for all scenarios

The annual electricity expense-to-annual city GDP of IKN is around 2.2% in 2023, and falls to around 0.2 and 0.4% in 2045 depending on the scenario. The total electricity expenses until 2045 are around 2-2.5% of the total cumulative investment required to build IKN. This indicates that IKN will be a very service-oriented city with very efficient energy-to-economy growth ratio. It also indicates that the city is still in a very rapid growth phase fueled by investment and construction which make the GDP growth much faster than the electricity demand. Electricity demand will follow economic growth after the rapid growth phase end.

The accelerated timeline in Pathway 2 results in a slightly higher total cost compared to Pathway 1 - around 4%. The difference between these two pathways comprises fuel expenses which is reduced by around 65% and substituted by the expenses on capital investment. This accelerated pathway put more pressure for the government to attract investor.

Marginal Electricity Cost

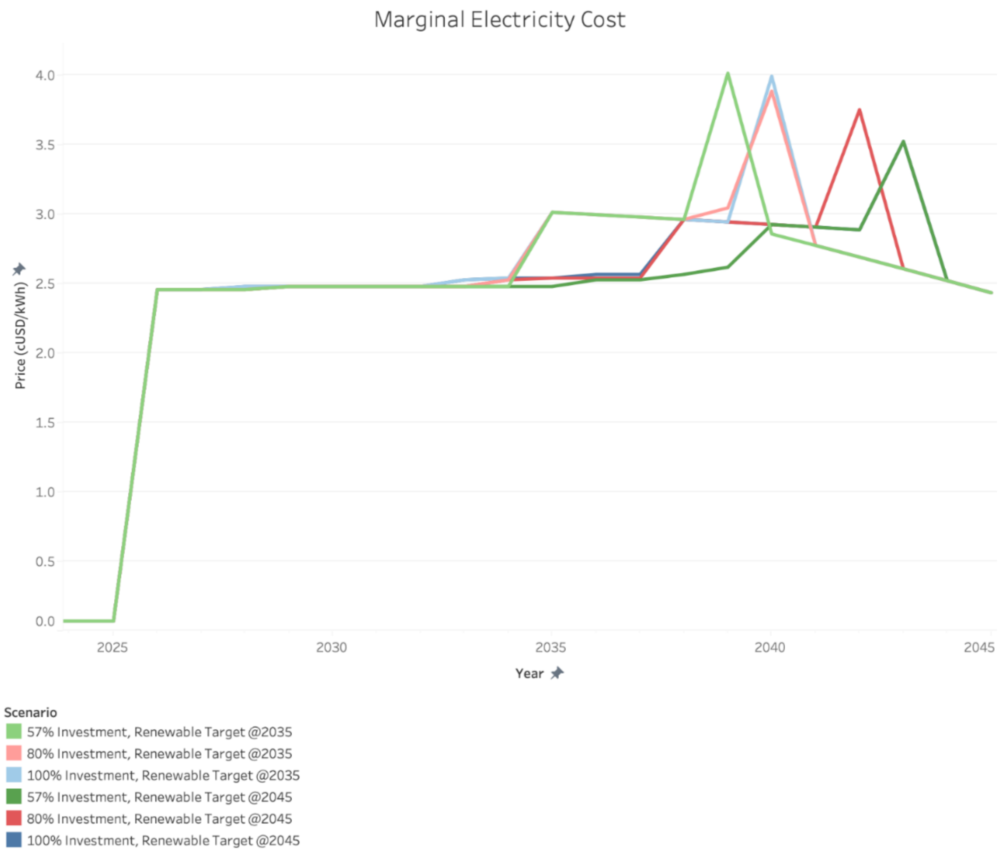


Figure 28 Marginal electricity cost for all scenarios

Before 2025, the electricity demand is fully supplied by hydro and solar which have zero marginal costs; this explains the steep curve increase in the early years.

Marginal electricity costs for Pathway 2 (the accelerated pathway) peak earlier and are greater than Pathway 1. This is aligned with the relatively larger electricity expenses associated with Pathway 1 as explained earlier. Highest costs in Pathway 2 are observed in 2039 and 2040, ahead of the peaks in Pathway 1 which occur in 2042 and 2043 across all the scenarios.

Higher marginal costs normally result in higher electricity prices either for the consumer or the government (in the case of government subsidy). However, this is only temporary. In the long run, when the renewable mix is similar to the baseline projection, the price will be the same.

Emissions

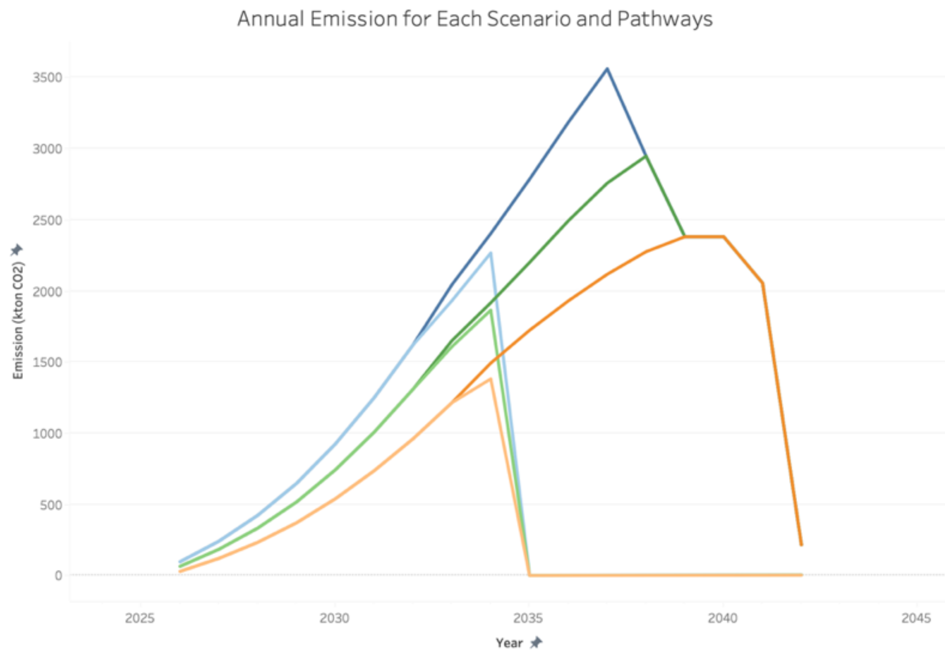


Figure 29 Annual emission for all scenarios

The model indicates that emissions from the electricity grid reach zero before the target year, 2035 and 2045 respectively, across all cases and scenarios. Peaks and drops in the graph above can be correlated with the retirement of fossil fuel-powered plants. Overall, higher investments result in higher emissions. Hence, case B i.e. the accelerated pathway results in 70% lower total emissions. These reduced emissions can be monetized via carbon abatement measures in the international carbon market. The revenue generated can be used to fund the higher capital investment required, especially in this case.

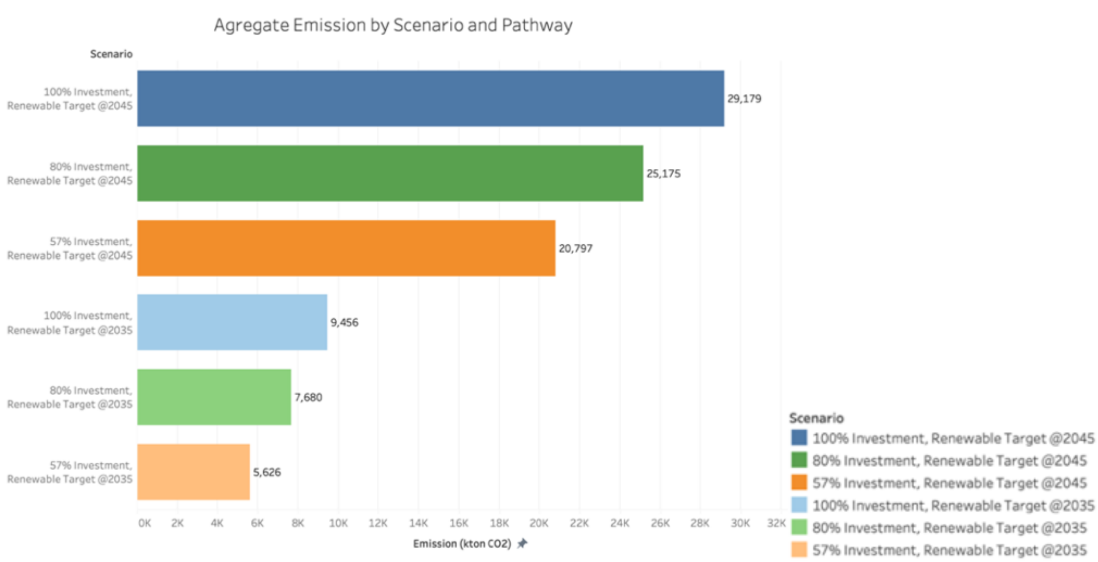


Figure 30 Aggregate emission for all scenarios

Analysis of Findings

This report intends to analyze deeper on Cases A, B, and C, which are the three scenario-pathway combination which can show the effect of extreme condition as explained before in the scenario and pathway development. Each scenario will be analyzed from five parameters (technical, socio-economic, financial, environmental, and political) to show the sensitivity analysis or the effect of changing one variable in the scenario of pathways to each of the parameter.

Case A is the 100% investment scenario with 2045 as the year of 100% renewable energy penetration target. Case B is also 100% investment scenario with 2035 as the year of 100% renewable energy penetration target. Case C is the 57% investment realization scenario with 2045 as the year of 100% renewable energy penetration target.

Overall tabulation of the comparison between the three chosen cases are illustrated in Appendix F of this report.

Technical

All cases managed to achieve 100% renewable energy, which consist of only solar and hydro. Wind and biomass are not chosen because of the low wind capacity factor and expensive biomass fuel supply. This lack of diversity mix may create an energy security issue since renewable energy resource cannot be predicted with pinpoint accuracy. Therefore, an emergency power plant with capability to ramp up quickly is required. The most suitable technology for this is typically either natural gas turbines or diesel power plants. Considering the proximity of Nusantara to Bontang liquid natural gas facility, gas turbine might be the better option.

All cases also have high solar capacity penetration, which might create instability in the grid due to solar's intermittent nature. Fast response energy storage system is required to create a buffer, which is usually done by installing battery energy storage system. Another thing to consider is to use baseload renewable power like nuclear. Small modular reactors (SMR) are one of the most plausible technologies to be implemented. Relatively disaster free area like Kalimantan is suitable for nuclear power plants.

Case A results in the biggest hydro capacity, which may lead to larger area used to be developed. Some environmental and social aspects will be discussed below under the environmental parameter. Most of the hydro resources, like the Kayan Hydro 9GW project located in North Kalimantan, will require enough transmission system to dispatch the electricity. Government needs to ensure this backbone transmission is ready by the time the project commenced.

Socio Economic

All cases result in high efficiency for Nusantara, where the electricity portion of the CGDP is around 0.44%, compared to the US which is predicted to be around 5%. The electricity demand is relatively low for a city with this GDP. This might be because the city is still in the early phase, where the GDP growth is rapidly fueled by investment. Electricity demand will grow as the city matures.

Marginal cost for the accelerated renewable energy penetration scenario peak earlier and higher than the 2045 renewable pathway. This is expected since accelerated renewable energy target will require higher electricity cost in overall. Higher marginal cost of electricity usually results in higher final price, therefore the one who bear the higher price is the consumer and/or the government in the presence of subsidy to promote accelerated target. Since the price of electricity should be approved by the parliament, this change might create political pressure to the executive government or the IKN.

The above curve shows a sudden increase in the early period, because before 2025, the demand can be fully supplied by the zero marginal cost of hydro and solar.

Financial

Case B result in the most expensive total cost until 2045. This is expected since accelerated renewable energy penetration will put additional constraint for the model. In this case, the model is constrained to use a more expensive hydro power plant which can produce more renewable electricity instead of solar PV which has limited resources in the region. However, the additional cost is only 4% of the total cost for 100% investment scenario and 2045 renewable energy pathway. It is also plausible to monetize the carbon abatement activity by choosing the accelerated target and gain higher revenue for the system to operate.

Case C result is the cheapest projection. This is expected since the electricity demand is lower, thus the total cost required to supply those demand will be lower as well.

Interestingly, the fuel expense will be zero align with zero production from fossil power plant but will be substituted by increasing capital investment for solar and hydro.

Environmental

Case A which projected to have the highest capacity of hydro power plant, will result in the biggest land impacted because of the hydro power plant construction. In addition, since hydro power plant is constructed surrounding a river or water way, this area is usually a productive land. In contrast, since solar resource does not generally change much in an area, solar PV can be constructed anywhere as long as it fulfils general flatness and does not being covered by some landscape or building. In total, 51,054 Ha of land is required. The government need to plan the zoning better to reach this target.

Case C use the least land of all, and also the least reliance on hydro power plant, which make it requires less productive land.

Total emission generated from Scenario A since 2023 to 2045 is 29.2 million ton of CO2. This emission is produced mainly from burning coal. Emission calculation only account for fuel burning reason. Further study is required to account for another carbon related activities, such as the carbon emitted from producing steel in solar PV structure and carbon absorbed from hardening of concrete in a hydro power plant construction process.

From the two analyses on carbon emission and land requirement above, Case C is the most ideal solution that produce the least carbon emission and the least land requirement.

Political

Government target to create 100% renewable electricity will create resistance from local NGOs and activists since it will require bigger size of land, especially for the hydro power plant, since mostly located in the jungle, may occupy existing animal habitat. Every construction requires good planning and impact assessment, including the environmental assessment. Transparent collaboration with the NGOs and activist may be the key to also ensuring good assessment and control and evaluation.

Another resistance will come from PLN, particularly for the accelerated renewable energy penetration target since this plan result in lowering demand for fossil-based electricity after 2035. PLN need to find another demand to replace existing demand from IKN. Additional pressure will come from coal producing company which also located mostly in Kalimantan. However, these company may also benefit from these initiatives because local demand may reduce, thus DMO threshold will also go down, which may increase profit.

Finally, all scenarios and pathways depend on good transition soon president election. Smooth transition, and stable IKN leadership, is the best outcome. However, since IKN leadership is political position, changing person in command is what usually happen when there is a new president in the office. This will also impact to investor attractiveness toward investing in Indonesia, and IKN in specific.

Policy Alternatives

To enable a smooth transition to 100% renewable electricity, Nusantara must consider to actively mitigate existing barriers for the transition as discussed in previous sections. These include regulatory barriers such as local content requirement and domestic market obligation and socio-enviro-economic impacts, among others. Policy action is recommended across two levels:

A. Establish an Enabling Framework

1. **Leverage Indonesia's Wilayah Usaha (WILUS) or Electricity Business Area Permit from PLN:**
   This permit bestows utility authority-powers upon IKN, which will enable streamlined permitting process and more innovative fiscal policies to attract investors and developers. This is supported by the fact that IKN has *lex-specialis* clause which allows them to create specific policies to favor the development in IKN.
2. **Integrate IKN's supply-demand projections into PLN RUPTL (long-term plan):** This will allow for more integrated electricity planning in the region. This projection will enable better planning in transmission and substation construction, which allow stronger interconnections with the hydro power plant in the north and improve grid stability in general.

B. Targeted Frameworks

1. Improve Technical Uncertainties:

- Install a Demand Response Program to regulate the demand in the case of high demand growth but not enough supply
- Invest in nuclear power plant for the baseload renewable generation
- Promote the use of energy storage system in the grid, and create good market mechanism to let the private developer or investor to build it

2. Manage Socio- Economic Impacts:

- Create a revenue sharing mechanism to increase community ownership
- Gradual and phased implementation to reach local content target without hindering the growth of domestic renewable energy ecosystem
- Ensure quota for local or impacted communities in the employee roster of the power plant to ensure better social impact

3. Control High Financial Costs:

- Establish a mechanism for participating in the global market for carbon credit to fund the additional cost to achieve Pathway 2, and to reduce exchange rate risk for foreign debt

- Leverage multinational partnership such as Just Energy Transition Partnership (JETP) with the US and Energy Transition Mechanism (ETM) to mobilize funds

4. Avoid Environmental Degradation:

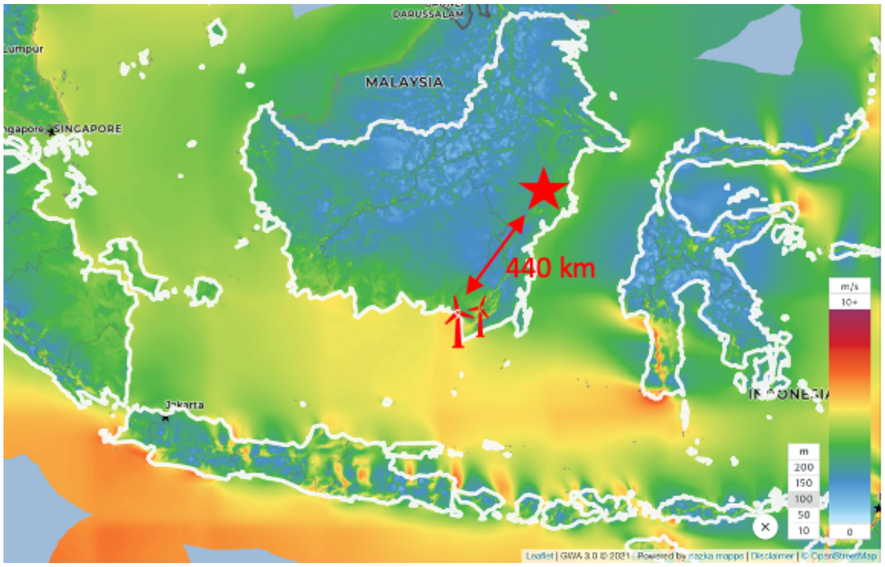
- Comprehensive mapping of potential hydro resources, create a robust framework to measure the risk quantitatively, and create better zoning policy for hydro power plant
- Encourage distributed energy resources, for example in the case of rooftop Solar PV, by promoting direct PPA between IPP and building/roof owner
- Better and periodical environmental and social impact monitoring and evaluation

5. Mitigate Political Risks:

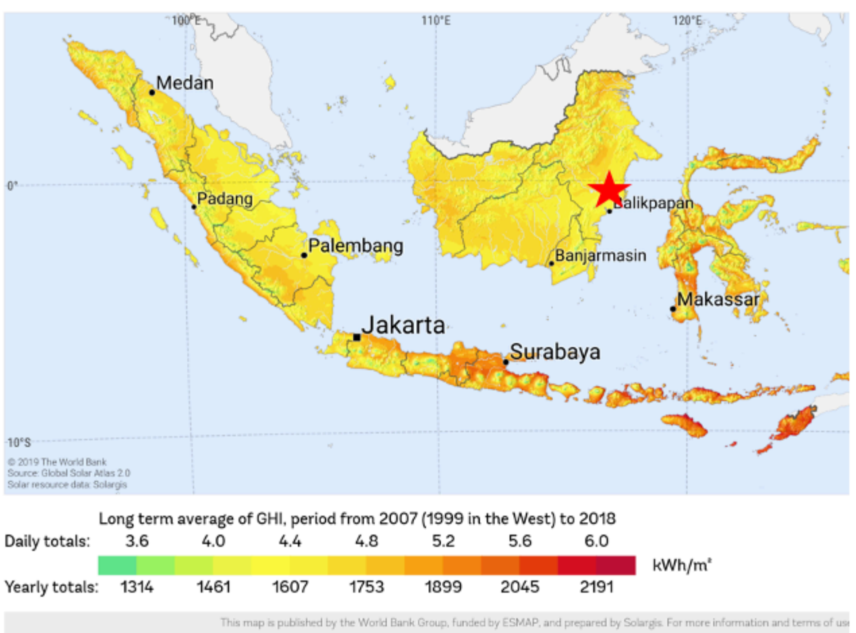
- Adopt a collaborative and consultative approach with local communities and the industry to improve transparency and buy-in and identify mutually beneficial solutions such as green job training program.
- Abolish Domestic Market Obligation (DMO) for coal producers who invest in renewable technologies.

Appendix

Appendix A – Low wind potential in Kalimantan (Source: Global Wind Atlas[46])

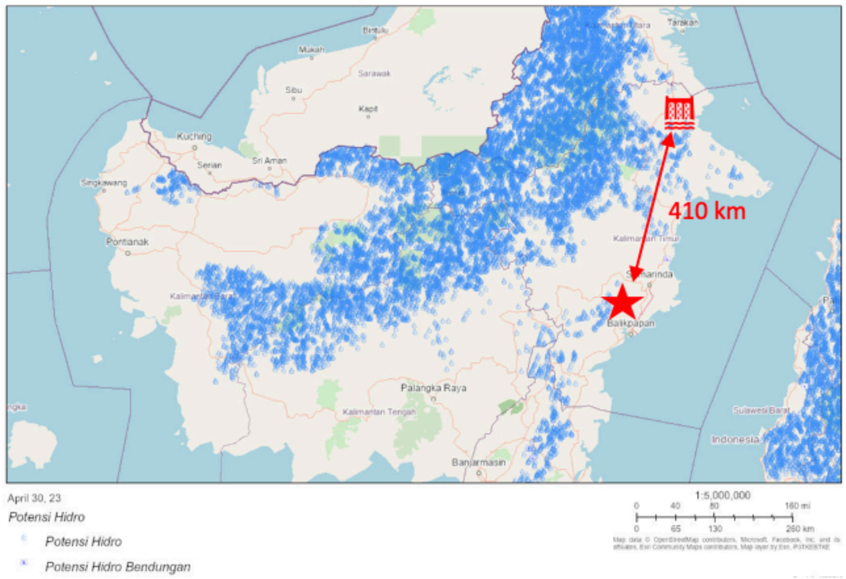


Appendix B – Medium solar potential in Kalimantan (Source: SolarGIS[47])

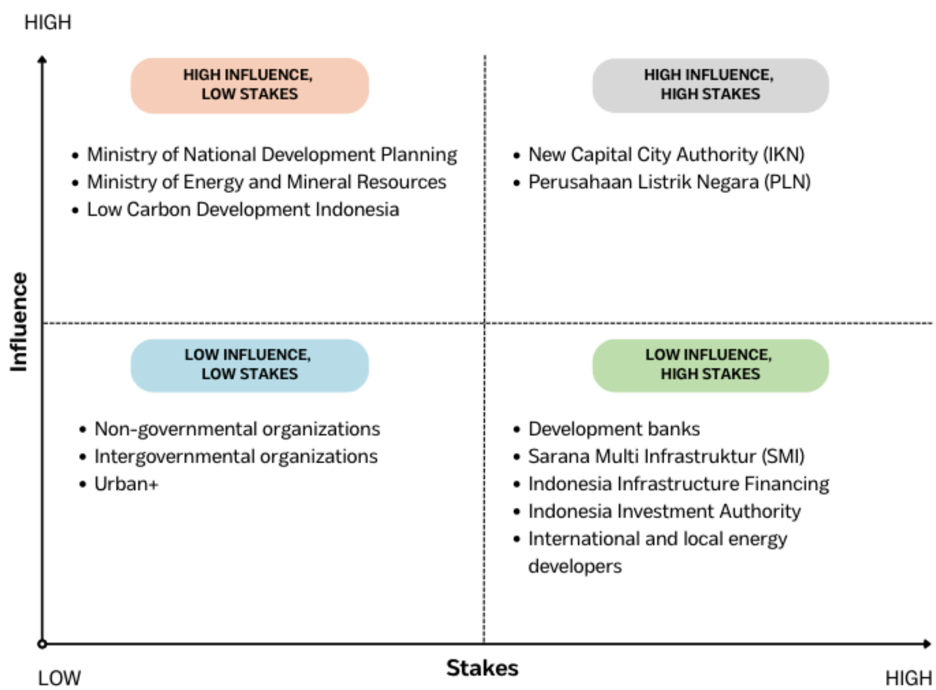


46 World Bank Group. "Global Wind Atlas," 2023. https://globalwindatlas.info.
47 Solargis. "Solar Irradiance Data," 2023. https://solargis.com/.

Appendix C – High hydro potential in Kalimantan (Source: Indonesia ESDM OneMap[48])



Appendix D – Stakeholder Analysis



48 Spatial Informatics Group. "The One Map Initiative - A Single Land Database for Indonesia." *SIG* (blog), March 20, 2023. https://sig-gis.com/projects/one-map-indonesia/.

Appendix E- Power Plant in Mahakam-Barito Grid Kalimantan

Technology Name	Thermal Efficiency	Utilization Factor	Fixed O&M Cost	Variable O&M Cost	Lifetime	Capacity	COD Year
Units	%	%	M$2020/GW	M$2020/PJ	Years	GW	Year
Exist_KS_8MW_OIL_UID2311	0.31	0.50	8.00	1.78	10.00	0.0080	1993
Exist_KS_8MW_OIL_UID2312	0.31	0.50	8.00	1.78	10.00	0.0080	1993
Exist_KS_16.5MW_GAS_UID2313	0.25	0.85	23.20	0.00	20.00	0.0165	1985
Exist_KS_2.2MW_OIL_UID2320	0.31	0.50	8.00	1.78	10.00	0.0022	1996
Exist_KS_2.2MW_OIL_UID2321	0.31	0.50	8.00	1.78	10.00	0.0022	1996
Exist_KS_0.8MW_OIL_UID2322	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KS_0.8MW_OIL_UID2323	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KT_38MW_GAS_UID2327	0.30	0.85	23.20	0.00	20.00	0.0380	2016
Exist_KT_38MW_GAS_UID2328	0.30	0.85	23.20	0.00	20.00	0.0380	2016
Exist_KT_38MW_GAS_UID2329	0.30	0.85	23.20	0.00	20.00	0.0380	2016
Exist_KT_38MW_GAS_UID2330	0.30	0.85	23.20	0.00	20.00	0.0380	2016
Exist_KS_54MW_COA_UID2331	0.39	0.85	56.00	0.04	25.00	0.0540	2000
Exist_KS_54MW_COA_UID2332	0.39	0.85	56.00	0.04	25.00	0.0540	2000
Exist_KS_57MW_COA_UID2333	0.31	0.85	56.00	0.04	25.00	0.0570	2013
Exist_KS_57MW_COA_UID2334	0.31	0.85	56.00	0.04	25.00	0.0570	2013
Exist_KT_42MW_COA_UID2335	0.32	0.85	56.00	0.04	25.00	0.0420	2016
Exist_KT_42MW_COA_UID2336	0.32	0.85	56.00	0.04	25.00	0.0420	2017
Exist_KT_1.8MW_OIL_UID2340	0.31	0.50	8.00	1.78	10.00	0.0018	1995
Exist_KT_1.9MW_OIL_UID2345	0.31	0.50	8.00	1.78	10.00	0.0019	1997
Exist_KT_1.9MW_OIL_UID2346	0.31	0.50	8.00	1.78	10.00	0.0019	1997
Exist_KS_2.3MW_OIL_UID2347	0.31	0.50	8.00	1.78	10.00	0.0023	1996
Exist_KS_0.8MW_OIL_UID2348	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KS_0.8MW_OIL_UID2349	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KT_0.7MW_OIL_UID2350	0.31	0.50	8.00	1.78	10.00	0.0007	1996
Exist_KT_0.8MW_OIL_UID2353	0.31	0.50	8.00	1.78	10.00	0.0008	2004
Exist_KI_5MW_OIL_UID2360	0.31	0.50	8.00	1.78	10.00	0.0050	1993
Exist_KI_0.5MW_OIL_UID2365	0.31	0.50	8.00	1.78	10.00	0.0005	2003
Exist_KI_0.5MW_OIL_UID2366	0.31	0.50	8.00	1.78	10.00	0.0005	2003
Exist_KI_0.5MW_OIL_UID2367	0.31	0.50	8.00	1.78	10.00	0.0005	2003
Exist_KI_0.5MW_OIL_UID2368	0.31	0.50	8.00	1.78	10.00	0.0005	2003
Exist_KI_5.5MW_GAS_UID2369	0.30	0.85	23.20	0.00	20.00	0.0055	2009
Exist_KI_5.5MW_GAS_UID2370	0.30	0.85	23.20	0.00	20.00	0.0055	2009
Exist_KI_7.5MW_GAS_UID2371	0.30	0.85	23.20	0.00	20.00	0.0075	2018
Exist_KI_7.5MW_GAS_UID2372	0.30	0.85	23.20	0.00	20.00	0.0075	2018
Exist_KI_7.5MW_GAS_UID2373	0.30	0.85	23.20	0.00	20.00	0.0075	2018
Exist_KI_7.5MW_GAS_UID2374	0.29	0.85	23.20	0.00	20.00	0.0075	2017
Exist_KI_100MW_COA_UID2384	0.32	0.85	56.00	0.04	25.00	0.1000	2017
Exist_KI_100MW_COA_UID2385	0.32	0.85	56.00	0.04	25.00	0.1000	2017
Exist_KI_20MW_GAS_UID2386	0.42	0.85	23.20	0.00	20.00	0.0200	1997
Exist_KI_20MW_GAS_UID2387	0.42	0.85	23.20	0.00	20.00	0.0200	1997
Exist_KI_14MW_GAS_UID2388	0.38	0.85	23.20	0.00	20.00	0.0140	1998
Exist_KI_65MW_GAS_UID2389	0.27	0.85	23.20	0.00	20.00	0.0650	2014
Exist_KI_65MW_GAS_UID2390	0.27	0.85	23.20	0.00	20.00	0.0650	2014
Exist_KI_17MW_GAS_UID2391	0.30	0.85	23.20	0.00	20.00	0.0170	2009
Exist_KI_17MW_GAS_UID2392	0.30	0.85	23.20	0.00	20.00	0.0170	2009
Exist_KI_0.7MW_OIL_UID2393	0.31	0.50	8.00	1.78	10.00	0.0007	2005
Exist_KI_0.8MW_OIL_UID2394	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KI_0.3MW_OIL_UID2395	0.31	0.50	8.00	1.78	10.00	0.0003	2002
Exist_KI_0.3MW_OIL_UID2396	0.31	0.50	8.00	1.78	10.00	0.0003	2002

Technology Name	Thermal Efficiency	Utilization Factor	Fixed O&M Cost	Variable O&M Cost	Lifetime	Capacity	COD Year
Exist_KI_0.2MW_OIL_UID2397	0.31	0.50	8.00	1.78	10.00	0.0002	2002
Exist_KI_0.5MW_OIL_UID2398	0.31	0.50	8.00	1.78	10.00	0.0005	2004
Exist_KI_0.3MW_OIL_UID2400	0.31	0.50	8.00	1.78	10.00	0.0003	2001
Exist_KI_0.8MW_OIL_UID2402	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KI_0.8MW_OIL_UID2403	0.31	0.50	8.00	1.78	10.00	0.0008	1998
Exist_KI_0.4MW_OIL_UID2404	0.31	0.50	8.00	1.78	10.00	0.0004	1998
Exist_KI_0.4MW_OIL_UID2405	0.31	0.50	8.00	1.78	10.00	0.0004	1998
Exist_KI_0.4MW_OIL_UID2406	0.31	0.50	8.00	1.78	10.00	0.0004	1998
Exist_KS_20MW_OIL_UID2435	0.31	0.50	8.00	1.78	10.00	0.0200	2016
Exist_KS_20MW_OIL_UID2436	0.31	0.50	8.00	1.78	10.00	0.0200	2016
Exist_KT_6MW_OIL_UID2437	0.31	0.50	8.00	1.78	10.00	0.0060	2008
Exist_KI_10MW_OIL_UID2439	0.31	0.50	8.00	1.78	10.00	0.0100	2010
Exist_KI_10MW_OIL_UID2440	0.31	0.50	8.00	1.78	10.00	0.0100	2010
Exist_KI_6MW_GAS_UID2441	0.29	0.85	23.20	0.00	20.00	0.0060	2008
Exist_KI_0.4MW_OIL_UID2442	0.31	0.50	8.00	1.78	10.00	0.0004	2002
Exist_KI_0.4MW_OIL_UID2443	0.31	0.50	8.00	1.78	10.00	0.0004	2002
Exist_KI_0.4MW_OIL_UID2444	0.31	0.50	8.00	1.78	10.00	0.0004	2002
Exist_KI_0.4MW_OIL_UID2445	0.31	0.50	8.00	1.78	10.00	0.0004	2002
Exist_KI_12MW_OIL_UID2446	0.31	0.50	8.00	1.78	10.00	0.0120	2016
Exist_KI_4MW_OIL_UID2447	0.31	0.50	8.00	1.78	10.00	0.0040	2016
Exist_KI_0.8MW_GAS_UID2448	0.30	0.85	23.20	0.00	20.00	0.0008	2010
Exist_KI_0.8MW_GAS_UID2449	0.30	0.85	23.20	0.00	20.00	0.0008	2010
Exist_KI_0.8MW_GAS_UID2450	0.30	0.85	23.20	0.00	20.00	0.0008	2010
Exist_KI_0.8MW_GAS_UID2451	0.30	0.85	23.20	0.00	20.00	0.0008	2010
Exist_KI_11MW_COA_UID2457	0.31	0.85	56.00	0.04	25.00	0.0110	2014
Exist_KI_11MW_COA_UID2458	0.31	0.85	56.00	0.04	25.00	0.0110	2014
Exist_KI_8MW_OIL_UID2463	0.31	0.50	8.00	1.78	10.00	0.0080	2009
Exist_KI_8MW_OIL_UID2464	0.31	0.50	8.00	1.78	10.00	0.0080	2009
Exist_KI_8MW_OIL_UID2465	0.31	0.50	8.00	1.78	10.00	0.0080	2009
Exist_KI_8MW_OIL_UID2466	0.31	0.50	8.00	1.78	10.00	0.0080	2009
Exist_KI_8MW_OIL_UID2467	0.31	0.50	8.00	1.78	10.00	0.0080	2009
Exist_KI_27.5MW_COA_UID2469	0.31	0.85	56.00	0.04	25.00	0.0275	2018
Exist_KI_46MW_GAS_UID2474	0.27	0.85	23.20	0.00	20.00	0.0460	2014
Exist_KI_46MW_GAS_UID2475	0.31	0.85	23.20	0.00	20.00	0.0460	2015
Exist_KI_22.5MW_COA_UID2476	0.32	0.85	56.00	0.04	25.00	0.0225	2008
Exist_KI_22.5MW_COA_UID2477	0.32	0.85	56.00	0.04	25.00	0.0225	2008
Exist_KI_50MW_COA_UID2478	0.31	0.85	56.00	0.04	25.00	0.0500	2014
Exist_KT_2MW_OIL_UID2777	0.31	0.50	8.00	1.78	10.00	0.0020	1995
Exist_KT_0.1MW_OIL_UID2778	0.31	0.50	8.00	1.78	10.00	0.0001	2000
Exist_KT_1.9MW_OIL_UID2790	0.31	0.50	8.00	1.78	10.00	0.0019	1997
Exist_KT_1.9MW_OIL_UID2791	0.31	0.50	8.00	1.78	10.00	0.0019	1997
Exist_KT_0.1MW_OIL_UID2796	0.31	0.50	8.00	1.78	10.00	0.0001	2017
Exist_KT_0.8MW_OIL_UID2797	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KT_0.8MW_OIL_UID2798	0.31	0.50	8.00	1.78	10.00	0.0008	1996
Exist_KT_0.8MW_OIL_UID2799	0.31	0.50	8.00	1.78	10.00	0.0008	2004
Exist_KT_0.6MW_OIL_UID2800	0.31	0.50	8.00	1.78	10.00	0.0006	2005
Exist_KT_0.7MW_OIL_UID2802	0.31	0.50	8.00	1.78	10.00	0.0007	1996
Exist_KT_0.8MW_OIL_UID2804	0.31	0.50	8.00	1.78	10.00	0.0008	2004
Exist_KT_0.8MW_OIL_UID2805	0.31	0.50	8.00	1.78	10.00	0.0008	2004
Exist_KT_0.3MW_OIL_UID2807	0.31	0.50	8.00	1.78	10.00	0.0003	2000
Exist_KT_0.3MW_OIL_UID2808	0.31	0.50	8.00	1.78	10.00	0.0003	2000
Exist_KT_1MW_OIL_UID2809	0.31	0.50	8.00	1.78	10.00	0.0010	2000
Exist_KT_1MW_OIL_UID2810	0.31	0.50	8.00	1.78	10.00	0.0010	2000
Exist_KT_0.5MW_OIL_UID2814	0.31	0.50	8.00	1.78	10.00	0.0005	1995

Technology Name	Thermal Efficiency	Utilization Factor	Fixed O&M Cost	Variable O&M Cost	Lifetime	Capacity	COD Year
Exist_KT_0.3MW_OIL_UID2815	0.31	0.50	8.00	1.78	10.00	0.0003	1998
Exist_KT_7MW_COA_UID3234	0.31	0.85	56.00	0.04	25.00	0.0070	2013
Exist_KT_2MW_OIL_UID3236	0.31	0.50	8.00	1.78	10.00	0.0020	2010
Exist_KT_6MW_OIL_UID3237	0.31	0.50	8.00	1.78	10.00	0.0060	2011
Exist_KT_2.5MW_OIL_UID3238	0.31	0.50	8.00	1.78	10.00	0.0025	2011
Exist_KS_3MW_OIL_UID3240	0.31	0.50	8.00	1.78	10.00	0.0030	2018
Exist_KI_19MW_ELCTESOL00	0.205	0.16	18.00		20	0.0190	2021
Exist_KI_30MW_ELCTEHYD00	0.8	0.76	66.30	0.18	50	0.0300	2019

Appendix F - Comparison Analysis Between Chosen Scenarios

Outcome	Technical	Socio-economic	Financial	Environmental	Political
A 100% new renewable energy by 2045 with 100% investment **IKN's best-case outcome**	**Highest hydro capacity** at 0.589 GW (6% higher than B) **Most balanced production mix** (almost 50-50) In 2045, all fossil fuel capacities in the region will be decommissioned, it means there is **no back-up when uncertain conditions happen**.	**Moderately efficient** at 0.44% in 2045 (share of electricity costs to GDP) **Highest social impact** due to most potential communities displaced by new hydro plants After prices increase, relatively stable post 2025	Costs $2.39B	**Highest land impact due to largest land required** to deploy solar & hydro (51,054 ha) **Highest total emissions** At 29.2 mt CO_2	**Ongoing resistance from NGOs and activists** due to high environmental and social impact
B 100% new renewable energy by 2035 with 100% investment **Alternate outcome**	**Requires slightly more (3%) total capacity** compared to A 100% renewable production **achieved** in 2035	**Moderately efficient** at 0.44% in 2045 (share of electricity costs to GDP) **Highest electricity prices in 2034 until 2041** (peak at 2040).	**Most expensive** ($2.48B total) but only 4% more than A	48,563 ha required **Lowest total emissions** at 9.5mt CO_2	**Relatively higher resistance anticipated from PLN and industry** due to losses incurred from early phase-out of fossil fuel plants and DMO **Politically risky** given uncertainty around future elected government and their support **Investor support** due to international recognition of green milestones
C 100% new renewable energy by 2045 with 57% investment **IKN's worst-case outcome**	**Least total capacity but highest proportion of solar** in production and capacity **Solar's intermittency issues require addressal** to ensure reliability	**Most efficient** due to lowest share of electricity costs to GDP: 0.26% in 2045 Prices remain low until 2034 and then increase	**Least expensive** ($1.7B)	**The lowest land required** to deploy solar & hydro (28,273 ha) and relatively lesser reliance on hydro 20.8 mt CO_2	**Public trust may deteriorate & government reputation affected** due to unsuccessful development