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RESEARCH ARTICLE

Scenario Planning for Renewable Energy Development towards Net Zero Emission in Indonesia's New Capital City "Nusantara"

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ABSTRACT

It is well-known that the power sector is a major contributor to the world's greenhouse gas emissions, and it is also vulnerable to the effects of climate change. As a result, the global power sector must speed up its decarbonization efforts. This article focuses on Renewable Energy scenario planning in Ibu Kota Nusantara. The paper examines a net-zero emissions scenario, as well as reference and renewable policy scenarios, to determine what additional measures are needed beyond the current trajectory to reach net-zero emissions. Ibu Kota Nusantara must use its underused renewable energy resources to achieve net-zero emissions by 2050. Based on the above considerations, the conclusion that can be drawn is that a scenario combining renewable energy (diesel, bioenergy) with carbon capture and storage technology (CCUS) is the most promising option for carbon neutrality. This combination allows for significant reductions in greenhouse gas emissions while still leveraging existing fossil fuel resources. However, continuing research and development in CCUS technology is vital to overcome the existing cost and implementation challenges. In planning toward carbon neutrality, collaboration between government, industry, and society is essential to transition to a sustainable and environmentally friendly energy system successfully.

Keywords: Bet-zero emissions, CCUS, new renewable energy, scenario planning.

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1. Introduction

Attaining sustainable development requires a focus on energy, as noted by (Khan, 2020). Historically, people relied on biomass like firewood before transitioning to fossil fuels like coal, oil, and natural gas during the Industrial Revolution of the 1900s. However, the widespread use of fossil fuels has resulted in significant environmental pollution and destruction. Burning coal, for example, produces carbon dioxide (CO_2) emissions, which are a primary contributor to greenhouse gases (GHG) according to (Copeland *et al*., 2022).

Research shows that CO_2 emissions have significantly contributed to climate change from 1750 to 2005 (Renné, 2022). The world is paying close attention to the increase in earth's temperature caused by global warming from GHG. The global energy management vision is focused on reducing emissions, including increasing the capacity and utilization of NRE generators, using electric vehicles, and reducing fossil energy sources in all sectors. The Paris Climate Agreement of 2015 embodied this vision, with the parties involved agreeing to keep the rise in the earth's average temperature well below 2 °C above pre-industrial levels and pursue efforts to prevent further temperature increases of 1.5 °C (UNFCCC, 2015). The Paris Agreement's efforts are aimed at achieving Net Zero Emissions (NZE) or the net zero emissions program.

In this article, we examine how the electricity sector of Ibu Kota Nusantara is working towards achieving net-zero emissions by 2050. By taking on the G20 Presidency in 2022 and committing to a net-zero future, Indonesia can demonstrate its strong leadership on climate change and motivate others to do the same. Achieving net-zero emissions will also help Indonesia avoid relying on unstable fossil fuel markets and protect nature, securing its position as a "carbon superpower." Therefore, it is important to recognize that Indonesia's low-carbon pathway is not just a luxury mandated by the Paris Agreement but a necessity

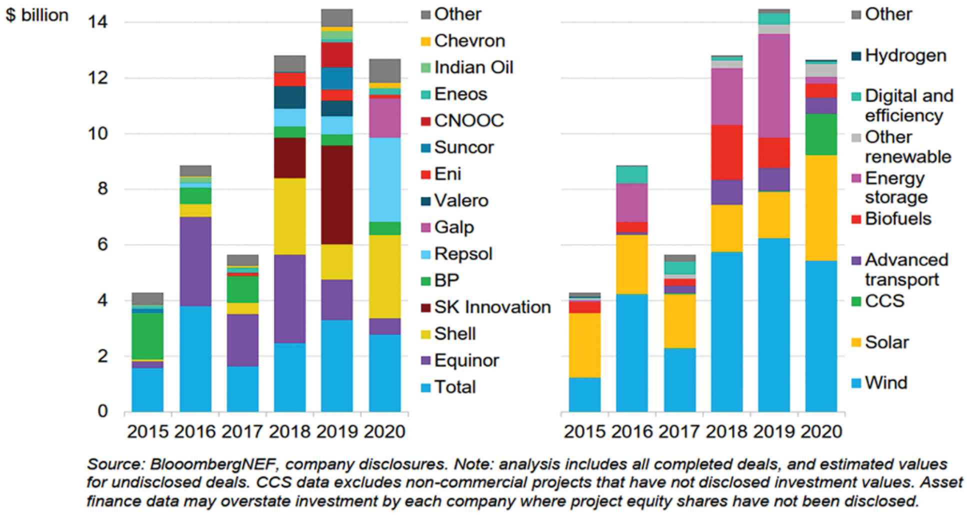

Fig. 1. Clean energy investments by oil and gas companies (Source: BloombergNEF).

in light of the significant impact of climate change on the region.

The NZE program requires developed countries to achieve net zero emissions by 2050. This program also encourages the implementation of new regulations related to electrical energy supply. Transitioning from fossil energy to renewable energy will have a significant impact on various aspects of life, including environmental, social, and economic conditions (Feng & Hu, 2023). Indonesia is also dedicated to developing new renewable energy sources. According to Government Regulation no. 79 of 2014 concerning National Energy Policy and Presidential Regulation no. 22 of 2017 concerning the National Energy General Plan, the country aims to use renewable energy for 23% and 31% of total national energy demand by 2025 and 2050, respectively. However, as of 2020, the actual share of renewable energy has only reached 11.31%.

2. Business Issue

In order to achieve the best possible electrical energy supply, it is crucial to understand the various aspects of designing a scenario that can reduce our dependency on fossil fuels. This research can benefit various groups, including companies, institutions, policymakers, and investors or shareholders. The study will aim to answer the following research questions:

a) *What is the difference between each scenario scheme?*
b) *What is the appropriate scenario planning for the future strategic scheme to make the energy transition realize the NZE program?*
c) *What is the effect of each scenario and the available solutions in that case?*

This article presents four net-zero emission scenarios: full fossil fuel (coal with oil and gas), fossil fuel scenario with diesel, solar scenario with bioenergy, and mixed energy scenario. These scenarios are compared to existing policy references and trajectories through net-zero path analysis. The analysis identifies additional steps that are required beyond current policies and references for the electricity sector of Nusantara's capital city to achieve net-zero emissions by 2050.

3. Literature Review

According to the 2018–2027 Electricity Supply Business Plan by PT Perusahaan Listrik Negara (PLN, 2020), electricity sales in Indonesia have been consistently increasing since 2011. This growth in sales is accompanied by a rise in the number of customers, which puts a strain on the national electricity supply. The government needs to ensure that there is enough electricity available to meet the demand. Fig. 1 displays the current state of electricity supply in Indonesia, based on the operating system reserves recorded as of June 2, 2021.

Indonesia's demand for electrical energy is predicted to keep rising, in line with the government's goal of achieving 100% electrification across the country. To meet this need, power plant generators must have the capacity and capability to produce sufficient electrical energy. In planning for future requirements, it's important to carefully consider power plant locations in Ibu Kota Nusantara. As of April 2021, Fig. 2 provides a map displaying the distribution and current installed capacity of power plants throughout Indonesia.

Looking at Fig. 1, we can see that electrical energy in Indonesia is supplied by both PLN and non-PLN sources. Despite the common use of fossil fuels for energy production in Kalimantan, Indonesia, with a capacity of 4572 MW, this falls short of the NRE value of 4921.3 MW. As a result, the Director General of Electricity has developed a modeling scheme to achieve the NZE program and reduce reliance on fossil fuels for electricity production.

The actions being taken are aimed at aligning the national electricity supply with the NZE program. The fuel subsidy budget will be transferred to infrastructure, including the construction of NRE and VRE-based power plants is illustrated in Table I. This is part of an effort to increase the number of power plants and achieve a renewable energy mix in Ibu Kota Nusantara. Additionally, the use of waste to produce energy through a Waste Power Plant is being considered as part of the WtE policy (Nurdiansah *et al.*,

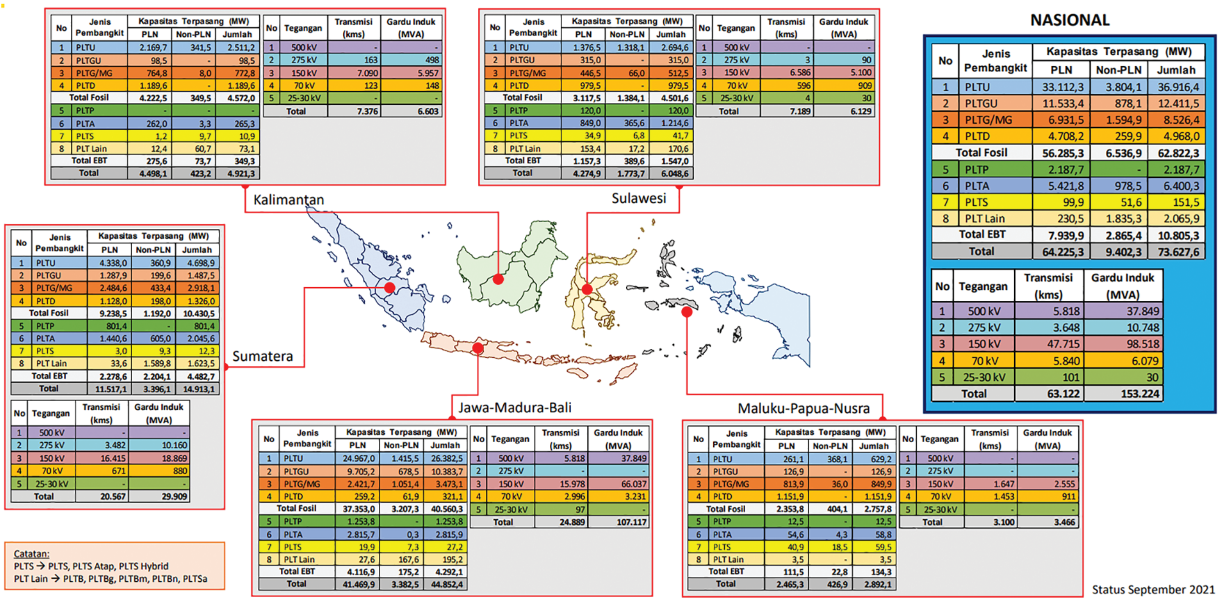

Fig. 2. Map of distribution and existing capacity of electrical energy generation in Indonesia.

TABLE I: Potency of New Renewable Energy

No	Kind of energy	Potency (MW)	Capacity (MW)	Utilization (%)
1	Solar	207,898	78.5	0.04
2	Wind	60,647	3.1	0.01
3	Hydro	75,091	4,826.70	6.4
4	Mini-microhydro	19,385	197.4	1
5	Bioenergy	32,654	1,671	5.1
6	Geothermal	29,544	1,438.50	4.9
7	Sea wave	17,989	0.3	0002

2020). However, it's important to continue studying the challenges and impacts of these efforts on Indonesia's energy transition. Evaluating the feasibility of Ibu Kota Nusantara's electricity system is a strategic step towards achieving the NZE program.

Indonesia is a major producer of oil and gas, with reserves located in almost every region of the country, as illustrated in Fig. 3. As of 2019, the country's oil reserves (including proved and probable reserves) amounted to 3.8 billion barrels, with a reserves-to-production (R/P) ratio of 9 years. In addition, Indonesia has natural gas reserves equivalent to about 77 TCF or 14 billion barrels of oil, with an R/P ratio of 22 years.

Indonesia currently has 10.6 GW or 14% of RE power plants, with the remaining generators relying on fossil fuels. The country aims to reach a goal of 19,900 MW or 28% of RE by 2030, which means an additional 9,300 MW of NRE generators need to be constructed between 2021 and 2030 (in the next 9 years) (Ardiansyah & Ekadewi, 2022).

According to the PLN Risk Management Division Case Study Book (2021) (Rajbhandari *et al.*, 2023), it was explained that Biomass and Integrated Gasification Combined Cycle (IGCC) + Carbon Capture and Storage (CCS) are technologies that are quite prominent in Ibu Kota Nusantara's energy mix plan. One of the energy mix plans for 2060 shows that biomass has a significant proportion, 250 GW of 600 GW. In another scenario, it can also be seen that the development of IGCC + CCS has been quite significant since 2030 as illustrated in Fig. 1. However, now this technology is still unproven and considered not technically and commercially feasible. These two technologies are new things that have not become proven options to achieve the net zero emission target.

Even though wind and solar capacities are increasing globally, these renewable energy sources are not a primary option in the Ibu Kota Nusantara scenario. Current market conditions are experiencing a momentum of movement toward renewable energy. But not all types of technology are in demand by global investors. Achieving net zero emission conditions requires support globally, so plans that are not in line with market conditions can be a separate risk that has the potential to make it difficult to achieve the target in 2060.

4. Methodology

The purpose of this study is to examine possible scenarios for the electricity industry in Ibu Kota Nusantara from 2021 to 2050, while considering the Paris Agreement, UNFCCC COP26, and G20. Four scenarios were created: a full fossil fuel scenario, a fossil fuel and solar scenario, a renewable energy scenario (including solar and bioenergy), and a net-zero emissions scenario is illustrated in Fig. 4.

The full fossil fuel scenario and the fossil fuel and solar scenario assumes the continuation of current power generation technologies used in the expanding sector from 2021 to 2050. This serves as a reference point for assessing the impact of alternative scenarios on technology usage, costs, and greenhouse gas emissions. The scenario includes limited application of conventional technologies like coal-fired and natural gas power plants. Renewable capacity expansion is also limited while fossil fuel usage has no restrictions. No specific renewable energy deployment targets are set.

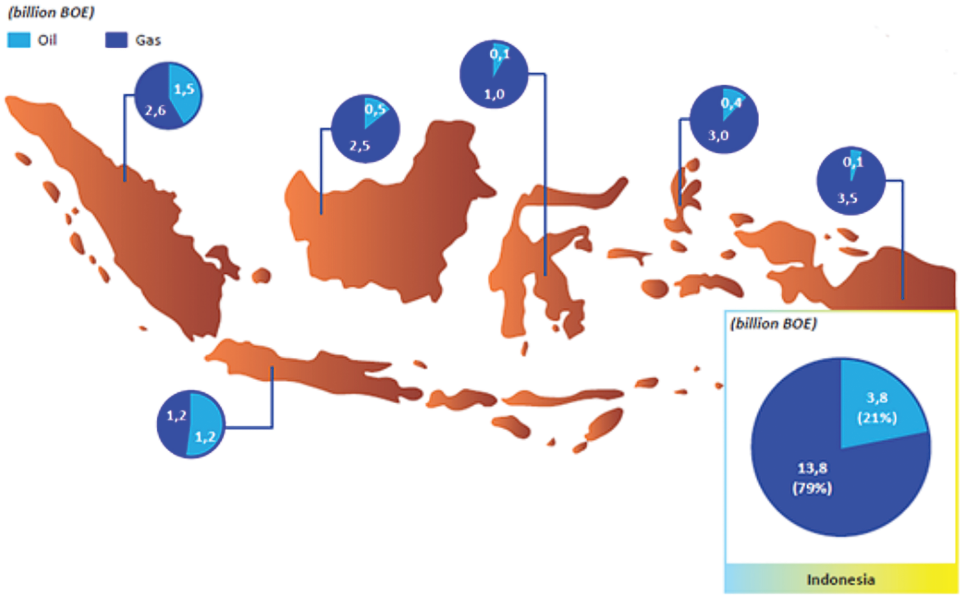

Fig. 3. Distribution of oil and gas energy.

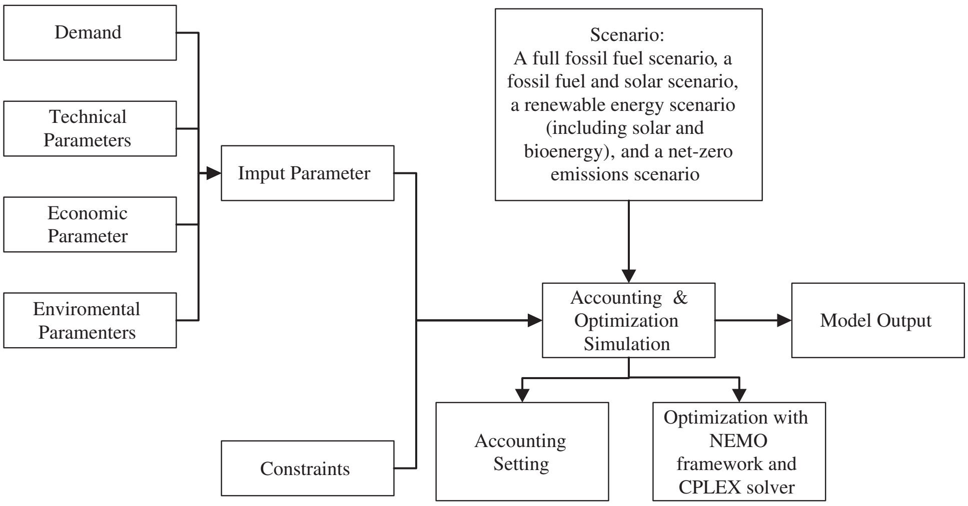

Fig. 4. Methodology.

On the other hand, the renewable energy scenario aims to achieve renewable energy targets while following NDCs and power development plans. The additional capacity is needed to reach the renewable energy target in Ibu Kota Nusantara, which serves as a constraint for the model. Various technologies including coal, natural gas, hydro, wind, biomass, and nuclear are considered for future capacity expansion. The type of technology used is chosen based on cost and goals set.

Finally, the net-zero emissions scenario aims to achieve a net zero emissions target by 2050. Various technologies are considered for expanded future use, including ultra-supercritical coal, natural gas, hydro, wind, biomass, nuclear, and coal with carbon capture and storage. The type of technology used is chosen based on cost and goals set to ensure greenhouse gas emissions are net-zero by 2050.

5. Data Collection Method

Quality data lends itself well to this research because it gives authors more opportunities to gain a deeper understanding of a particular subject and to be flexible and exploratory as they test hypotheses. The research will be supported by quantitative data that can be utilized effectively. So, scenario planning requires corroborating the facts to ensure that complex estimates can reliably address real-world challenges. According to Lindgren and Bandhold (2002), seven techniques are available: actor-oriented, timeline-based, intuitive/generative, interview-based, media-based, consequence-focused, and systems-based. This study will make use of primary data collection through an interview-based methodology, as illustrated in Fig. 6. Additionally, secondary data will be collected from various sources. In this study, the PESTEL analysis tool was used to analyze the external macro-environment that influences renewable energy development (International Energy Agency, 2021), as illustrated in Fig. 5.

6. Results

To analyze the underlying problems and challenges related to identification during the analysis stages. Renewable energy development in Ibu Kota Nusantarais influenced by political factors in Indonesia, including national political stability and global geopolitics, which can affect world trade and fuel prices as illustrated in Table II. In the economic field, several factors can affect operations and performance, including demand for and supply of electricity, fuel prices, exchange rates, energy transition financing, and limited funds for investment (Winanti & Purwadi, 2018).

Fig. 5. PESTEL analysis.

6.1. *PESTEL Analysis*

PESTEL analysis is a framework used to analyze political (Political), economic (Economic), social (Social), technological (Technological), environmental (Environmental), and legal (Legal) factors that can affect the business environment or a particular situation. It helps in understanding the impact of these factors on decision-making and strategic planning.

6.2. *Scenario Planning Analysis*

Based on point 3 Methodology research, five stages will be followed in the scenario planning analysis for Renewable Energy Towards Net Zero Emission in the Capital of the Archipelago: 1) Orientation; 2) Exploration; 3) Scenario Creation; 4) Option Consideration; 5) Integration. The following analysis will be further explained:

6.2.1. *Stage 1: Orientation*

The first stage is orientation, where we identify and understand carefully the ultimate goal of scenario planning to achieve zero emissions. We place long-term goals, available resources, and constraints to steer our analysis in the right direction.

6.2.2. *Stage 2: Exploration*

In the exploration phase, we collect essential data and information about various aspects related to scenario planning. It includes data on current energy consumption, patterns of economic growth, recent technology trends, climate change, and other factors that could influence the path to zero emissions. Based on data collection through in-depth interviews and literature review, the author processed the data and came out with 10 driving forces which can be classified into six groups using the PESTEL framework as shown in Fig. 5.

The results of semi-structured interviews are also used to identify the level of impact of the driving force on the implementation of Renewable Energy in the Capital City of the Archipelago. The results of this semi-structured interview were obtained from the company's internal and external stakeholders. Different positions and experiences will produce different perspectives on each stakeholder interviewed. During interviews, key stakeholders explored their experiences to gain perspective on the implementation of Renewable Energy in Ibu Kota Nusantaraand energy transition trends. To obtain accurate data, key stakeholders are introduced to data related to the energy transition. Critical uncertainty is obtained by combining the uncertainty level and the driving forces' impact.

Based on the results of semi-structured stakeholder interviews, the critical uncertainty matrix can be seen in Fig. 7. The driving force, critical uncertainty, can be categorized into three variables: Government Regulations, Technological Developments, and Economic Conditions as illustrated in Table II. The technology development variable is a combination of technologies related to renewable energy, energy storage technology, and smart grid technology. At the same time, the economic condition variables consist of issues: electricity supply & demand, fuel prices, and investment, where each of the three points of economic conditions will become a critical uncertainty.

6.2.3. *Stage 3: Scenario and Narrative Creation*

After having a firm understanding of the context and relevant factors, the scenario-creation stage begins. We identify various possible combinations of strategies, policies, and technologies that can be used to achieve zero emissions. These scenarios can involve using renewable energy, energy efficiency, emission reductions, and other measures. The scenario structure for this paper was created using a 2×2 matrix based on the two main uncertainties, Capex and Opex, which were divided into four different quadrants as shown in Fig. 8.

6.2.3.1. *Scenario I: Full Fossil Fuel*

The entire fossil fuel scenario will explain the impact of using fossil fuels in full (coal, oil, and gas) and efforts to achieve zero emissions. However, until now, fossil energy is still the world's primary energy source. It is projected that using full fossil fuels will cause greenhouse gas emissions to increase significantly because the process of burning fossil fuels produces carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x). Climate change is accelerating, causing rising global temperatures, extreme weather patterns, and other negative impacts on ecosystems and

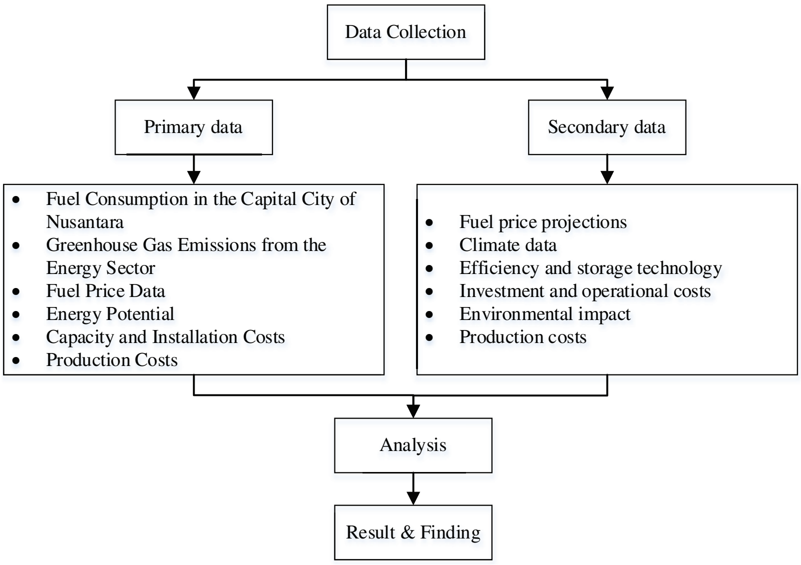

Fig. 6. Data collection.

people. In addition, full dependence on fossil fuels will lead to economic instability due to price fluctuations and supply availability.

However, this scenario can contribute significantly to the country's economy, especially in creating jobs and people's income. The stability of the Full Fossil Fuel scenario is that its availability is still abundant, which is currently available in large quantities in many areas in Indonesia, especially on the island of Kalimantan. In addition, the fossil fuel industry has developed rapidly in Indonesia so that the extraction, production, and distribution technology is mature and efficient. In addition, using full fossil fuels will encourage energy providers to operate consistently and provide a stable electricity supply, helping to maintain the electricity grid's stability in Ibu Kota Nusantara.

This scenario will maintain dependence on non-renewable energy sources and contribute to greenhouse gas emissions. Climate change's environmental costs and impacts may increase in the long term.

6.2.3.2. Scenario II: Fossil Fuel + Solar

In this scenario, we will explore how combining fossil fuels with solar energy can help achieve zero emissions. Projections use a combination of fossil fuels and solar energy, so using solar energy as an additional source will help reduce greenhouse gas emissions because solar power plants produce little or no CO_2 emissions. Solar energy is a renewable and unlimited source of energy, so it can help reduce dependence on fossil fuels that are used up. This combination can help mitigate fluctuations in energy supply from renewable energy sources, such as wind and hydroelectric power because solar energy tends to be more stable and can operate throughout the day.

It should be remembered that this scenario still involves using fossil fuels, which means that greenhouse gas emissions will still be produced. In addition, although the cost of solar panels has decreased, the initial investment in solar energy infrastructure still needs to be improved for the Capital City of the Archipelago. The environment and weather also need attention; the use of solar energy requires ample space for solar panels. In some cases, this may impact the local environment, for example, changing land use or affecting local ecosystems. Solar energy also still depends on sunlight, so its energy production is affected by local weather and climate conditions. During bad weather or at night, solar energy production will decrease, which requires assistance from other energy sources, such as fossil fuels, to meet energy needs. However, introducing new technology and the necessary infrastructure can be costly, although it can result in operational savings in the long run.

Adding solar energy to the mix can reduce greenhouse gas emissions and dependence on fossil fuels. However, variable weather factors can affect the availability of solar energy.

6.2.3.3. Scenario III: Solar + Bioenergy

In this scenario, we will explore the potential of combining solar energy and bioenergy to achieve zero emissions. Combining these two renewable energy sources can significantly accelerate the shift towards a zero-carbon emission society; however, producing bioenergy from certain crops can lead to competition with food production. In addition, the limited resources for raw materials for bioenergy production need to be adjusted to the geographical conditions of Ibu Kota Nusantara. Therefore, it is crucial to ensure that bioenergy production does not interfere with food security and consider non-food crops as a source of raw materials to support the availability of raw materials.

Combining solar energy and bioenergy helps diversify energy sources, reducing dependence on fossil fuels and increasing the stability of energy supplies. Combining clean solar energy and bioenergy can significantly reduce carbon emissions than relying on a single renewable energy source. Using bioenergy can help overcome the problem of organic waste and potentially reduce its negative impact on the environment. This scenario shows how combining solar energy and bioenergy has excellent potential to achieve zero carbon emissions.

TABLE 2: Brief Explanations

Factors	Driving forces	Brief explanation
Political/Legal	Global geopolitics	Global geopolitical factors can influence the course of the transition to zero emissions. Diplomatic relations between countries, regional conflicts and international trade policies can affect the availability of resources, technology and investment needed to adopt renewable energy.
	Government policies and law	Government policies and laws related to electricity and the energy transition are critical in promoting the use of renewable energy and achieving zero emissions. Regulations around electricity rates, incentives for renewable energy, bans on fossil fuel-based power generation, and laws on licensing can have a significant impact on clean energy adoption and investment in renewable infrastructure.
	National political stability	Political stability on a national scale plays an important role in energy transition planning. Internal conflict, political uncertainty, or changes in government policy can affect the consistency and sustainability of a renewable energy plan. Good political stability can create an enabling environment for long-term investment in renewable energy and facilitate the implementation of pro-environmental policies.
Economical	Demand and supply of electricity	The balance between electricity demand and supply has a significant impact on price and supply stability. With increasing demand for electricity due to economic growth or changing consumption patterns, the transition to renewable energy requires a good understanding of how energy supply can meet this need in a sustainable way.
	Fuel prices	Fluctuations in the prices of fuels such as coal, oil and gas can affect energy production costs and the competitiveness of renewable energy. Higher prices of fossil fuels can increase the attractiveness of investment in renewable energy sources.
	Capex and opex	Capex refers to the initial capital outlay required to build, develop, and implement renewable energy infrastructure. Opex refers to ongoing operational costs over the lifecycle of a renewable energy infrastructure.
	Exchange rates	Currency exchange rates can affect the cost of importing renewable energy equipment and technology, as well as affect the price of energy offered to consumers. Changes in exchange rates can have an impact on investment and operational costs.
	World energy transition financing	The financing of the global energy transition is an important factor in planning the transition to renewable energy. Funds available from international financial institutions, private investors, and international support programs will influence the availability and accessibility of funds for clean energy projects.
	Investment funds	The availability of investment funds for the development of renewable energy infrastructure is key in achieving zero emissions. Investment funds from the private sector, financial institutions, and pension funds can support the development of sustainable renewable energy projects.
Social	Social trends	Changes in people's behavior, preferences, and habits can affect the adoption of renewable energy. Social trends such as increasing environmental awareness, consumer demand for clean energy, and societal support for sustainable solutions can influence the demand for and acceptance of renewable energy.
Technological	Clean and renewable energy technologies development	Advances in the development of clean and renewable energy technologies, such as solar panels, wind turbines and fuel cells, have the potential to produce energy sources that are more environmentally friendly and efficient. The development of this technology can accelerate the transition from fossil-based energy sources to renewable energy sources.
	Smart grid technology	Smart grid technology enables more efficient management and distribution of energy. With the use of sensors, smart metering, and automation, smart grid systems can optimize energy supply, reduce energy losses, and support the integration of volatile renewable energy sources.
	Energy storage technologies	Advances in energy storage technologies, such as lithium-ion batteries and thermal storage, allow excess energy storage from renewable energy sources, such as solar and wind, to be used when needed. Energy storage technology can increase the reliability of energy supply and reduce dependence on conventional energy sources.
Environmental	Climate change	Global climate change, including global warming and changing weather patterns, is having a significant impact on the environment and sustainability. The use of fossil energy sources contributes to greenhouse gas emissions that accelerate climate change.

Combining solar energy with Bioenergy can provide a more sustainable alternative. However, it is necessary to consider sustainable sources and management of biomass so as not to have a negative impact on the environment and food.

6.2.3.4. Scenario IV: Mix Energy + CCUS

In this scenario, we will explain how using a mix of energy sources and Carbon Capture and Storage Technologies (CCUS) can contribute to achieving zero emissions in the Capital City of the Archipelago. These strategies combined can be an essential step in reducing greenhouse gas impacts and supporting the vision of carbon neutrality. Providing energy from various sources, such as solar, wind, hydroelectric, and bioenergy, will reduce dependence on fossil fuels and greenhouse gas emissions.

Combining renewable energy sources such as solar, wind, and hydroelectric power with Carbon Capture and Storage (CCUS) technology can reduce dependence on a single energy source and increase the resilience of energy supplies. In this scenario, diversifying the energy portfolio

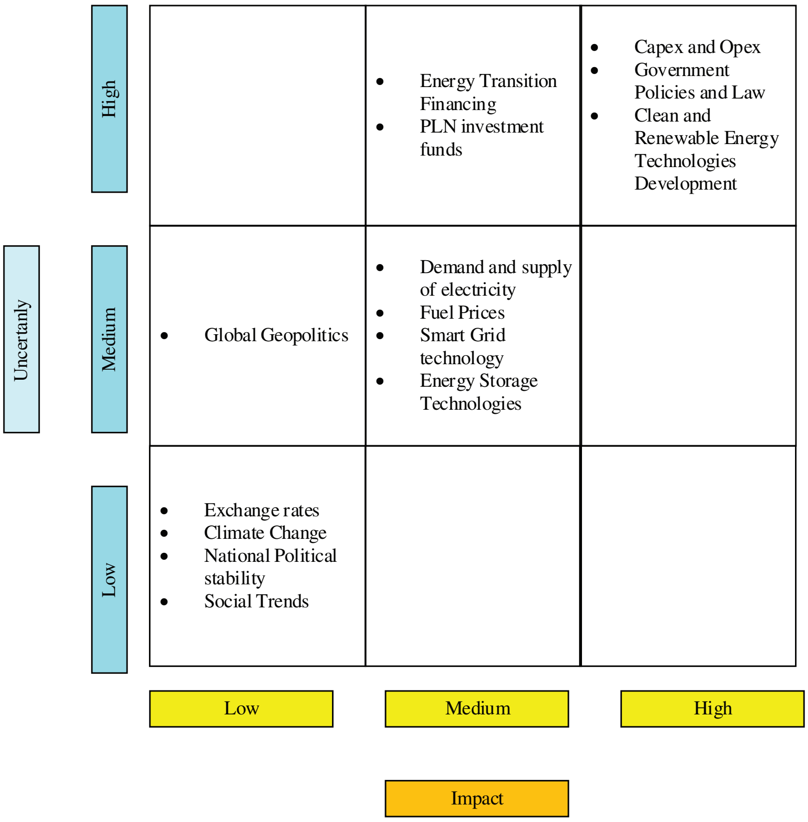

Fig. 7. The critical uncertainty matrix.

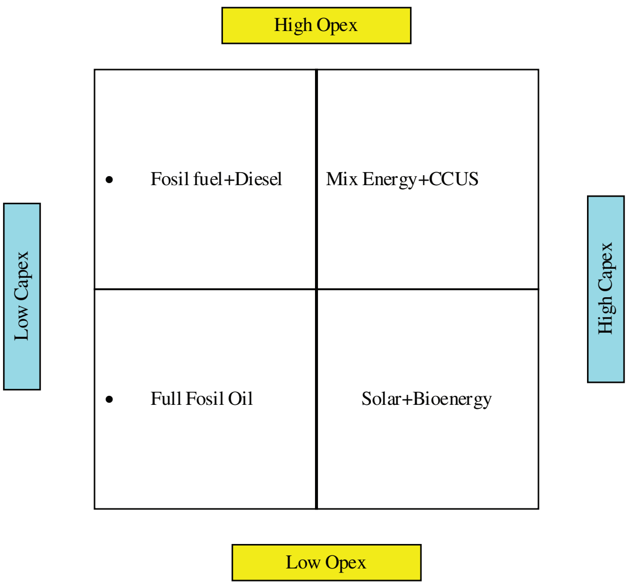

Fig. 8. Scenario alternative.

by including diverse energy sources helps overcome supply risks that may arise from renewable energy production leakage due to weather factors. On the other hand, by integrating CCUS, CO_2 emissions generated from energy sources based on fossil fuels can be managed better to suppress negative contributions to climate change and support the transformation towards a more sustainable energy system. CCUS technology will help capture and store carbon dioxide produced by industry or fossil fuel power plants, preventing it from entering the atmosphere and significantly reducing the carbon footprint. Emissions from crucial sectors such as transportation, industry, and development will be managed more effectively by integrating CCUS technology.

By implementing this scenario, some of the potential positive impacts that can be achieved are significantly reducing greenhouse gas emissions, supporting the goal of zero emissions in the Capital City of the Archipelago, increasing demand and energy independence, reducing dependence on imported fossil fuels, and innovation in energy technology. Renewables and CCUS will stimulate economic growth and job creation in this sector. However, in practice, several things need to be considered, such as investment in development and widespread implementation, where the development of the infrastructure needed to capture, transport, and store CO_2 and address the technical and environmental challenges in the storage process indicates that CCUS requires a sizeable financial commitment beforehand. This technology can be widely adopted in efforts to reduce greenhouse gas emissions.

Combining multiple energy sources with CCUS technology can help reduce emissions significantly. However, the CCUS technology is still in the development stage and requires substantial investment and attention to long-term carbon storage risks. In order to facilitate the reader to compare the pros-cons of each contract strategy, this study prepared Table III, which is based on data collection from in-depth interviews and literature review.

6.2.4. Stage 4: Options Considerations

At this stage, we evaluate each scenario by considering each option's strengths, weaknesses, opportunities, and

TABLE III: Advantages and Disadvantages of Scenario

Type	Advantages	Disadvantages
Full fossil fuel	1. Abundant availability 2. Well-established technology 3. Stable supply of energy 4. Contribution to the economy	1. Greenhouse gas emissions 2. Air pollution and health impacts 3. Dependence on imports 4. Limited resources 5. Not environmentally friendly
Fossil fuel + solar	1. Reducing carbon emissions 2. Available energy all day 3. Potential availability of renewable energy 4. Diversification of energy supply	1. Depends on weather 2. Huge initial investment 3. Energy storage problems 4. Environmental influence
Solar + bioenergy	1. Multiple renewable energy sources 2. Reduction of carbon emissions 3. Potential use of organic waste 4. Energy storage	1. Limited resources 2. Competition with food 3. Energy efficiency 4. Environmental influence
Mix energy + CCUS	1. Can reduce dependence on a single energy source 2. Improved supply resilience 3. CCUS enables the capture of carbon from large pools 4. Some existing infrastructure	1. CCUS technology is still under development and requires a large investment 2. Implementation of CCUS technology and maintenance can be expensive

threats. We analyze the impact on economic, social, environmental, and technological aspects. This stage aims to understand the consequences of each scenario carefully.

6.2.5. *Stage 5: Integrations*

In the final stage, we integrate the analysis results from each scenario to create a comprehensive picture of the path to zero emissions. We identify the best solution that capitalizes on the positive potential of each system while addressing any obstacles and challenges that may arise. This integration helps in formulating a holistic and coordinated action plan to achieve the goal of zero emissions.

In the Renewable Energy Transition (RET) scenario, energy storage will play a crucial role in balancing the fluctuations of renewable energy. By the year 2050, the total storage capacity is expected to reach 41.8 GW, with hydro-pumped storage accounting for 15.8 GW and Li-ion battery accounting for 26 GW. Looking further ahead to 2050, the ASEAN region's renewable electricity generation is projected to increase to 1,466 TWh, accounting for over 40% of the total electricity generation. Solar and hydro will lead the way, with 11.9% and 11.8% shares, respectively, followed by wind (7.7%), biomass (4.4%), and geothermal (4.3%). Meanwhile, the share of coal-generated electricity will decrease from 44% in 2020 to 36.2%. In this scenario, greenhouse gas (GHG) emissions will increase slower than in the Reference (REF) scenario. By 2050, GHG emissions are expected to reach 1,416 million tons of CO2e, which is 31% lower than in REF. Coal will still contribute the most to CO_2 emissions (76%), but its share will be 9% lower than in the REF scenario. Indonesia will remain the highest contributor to ASEAN GHG emission.

7. Conclusions

In facing the challenges of climate change and achieving net zero emission targets, energy scenario planning plays an important role. Here are four scenarios to consider: Scenario Full Fossil Fuel (Coal + Oil & Gas) reflects the continued full use of fossil fuels. Even though this resource is reliable in supplying energy, the environmental impact and resulting greenhouse gas emissions will further exacerbate climate change. Scenario Fossil Fuel + solar can reduce the carbon footprint while maintaining a stable energy supply. However, limitations in solar energy storage and dependence on fossil fuels still exist. This scenario can be practical if the development of advanced battery storage technology supports it. Scenario Solar + Bioenergy can reduce emissions by relying on renewable energy sources. However, paying attention to the sustainability of bioenergy raw materials is necessary so they do not threaten biodiversity or food security. This combination requires careful management to ensure its sustainability. Scenario Mixed Energy + CCUS is promising. This enables diversification of energy supply, reduces emissions, and enables a smoother transition to net zero emissions. CCUS technology development must be encouraged to overcome obstacles in capturing and storing carbon effectively.

The mixed energy scenario emphasizing CCUS offers a comprehensive approach to achieving net zero emissions. By incorporating diverse renewable energy sources and CCUS technology, this scenario can reduce emissions significantly while maintaining a reliable energy supply. However, technical, economic, and regulatory challenges need to be overcome to optimize the implementation of this scenario. Promoting innovation, international cooperation, and supportive policies is essential to achieve a sustainable and environmentally friendly energy future.

8. Limitations

Although this study yielded significant results, it has limitations. Firstly, the electricity demand projections in this study do not encompass assumptions about the electrification of other sectors, which may considerably impact our analysis. Future research should explore various demand scenarios, including the penetration rate of electric vehicles and the increased rate of industrial electrification. On the supply side, this study needs to consider transmission and distribution simulations, and it needs to take into account constraints in transmission and distribution networks. Future studies should consider the transmission and distribution investments needed to achieve net-zero emissions in the Ibu Kota Nusantara power sector.

Additionally, this study does not consider the possibility of additional power exchange between the Ibu Kota Nusantara. An analysis of the net-zero Ibu Kota Nusantara power sector pathway that considers increased interconnectivity between the grids of the Ibu Kota Nusantara is a direction for future work. It could significantly impact the need for energy storage.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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