



Backcasting Approach Using Energy Modeling for Achieving 100 Percent Renewable Electricity in the New Capital City of Indonesia by 2045



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Cover image from the Official Facebook account of New Capital City Authority (IKN Indonesia)

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EXECUTIVE SUMMARY

The decision to relocate Indonesia's capital city from Jakarta to East Kalimantan is driven by multiple factors. One key reason is to decentralize economic activities, which are currently concentrated in Jakarta. Additionally, Jakarta faces rapid population growth and declining environmental conditions. Consequently, the New Capital City (IKN) is being developed as a sustainable city with the goal of becoming carbon-neutral by 2045. To support this initiative, Law Number 3 of 2022 concerning the National Capital mandates that IKN will use 100 percent renewable energy for its electricity needs by 2045.

However, achieving 100 percent renewable energy in IKN is a complex task that requires a thorough assessment of both energy demand and renewable energy availability. Additionally, the development of renewable energy involves multiple stakeholders across various sectors, including politics, economics, social issues, and environmental concerns. Currently, there is insufficient research focused on the future electricity system in IKN, particularly regarding the analysis of implementation strategies. Therefore, this research aims to develop strategies for renewable electricity development in IKN by addressing the following main question:

What renewable energy sources are the most cost-effective for achieving 100% renewable electricity in the New Capital City of Indonesia by 2045, and what actions and policies are required to facilitate their development and implementation?

This research employs the Backcasting method, which involves analyzing the current situation, envisioning the desired future system, and identifying the necessary changes to achieve this future state. Energy modeling using Calliope software will be utilized to develop future visions for the IKN electricity system for 2045 and to establish interim renewable energy targets for 2030, 2035, and 2040. To achieve these targets, actions and policies will be developed by identifying drivers and barriers through a PESTEL analysis and creating solutions to overcome these barriers using a WHAT-HOW-WHO analysis. Once the actions and policies are developed, scenarios will be created to test their effectiveness in the system.

The projected peak energy demand in IKN by 2045 is 792 MW. Simulation results indicate that the most cost-effective combination of renewable energy sources for electrifying IKN by 2045 is Solar PV and Hydropower, with capacities of 890 MW and 792 MW, respectively. This combination results in the lowest total system Levelized Cost of Electricity (LCOE), which is 4.57 cents per kWh.

Another vision is made by reducing the capacity of hydropower and solar PV in the system by 2045 to explore and incorporate other renewable energy sources. This shift leads to a diversification of the energy system, incorporating more floating solar PV, biomass, and battery storage. The LCOE of the system in 2045 will increase with the reduction in hydropower and solar PV capacity. It starts at 4.57 cents \$/kWh in the base scenario and progressively rises to 4.67, 4.87, and 5.35 cents \$/kWh as the reduction levels reach 10%, 25%, and 50%, respectively.

Developing renewable electricity in IKN offers significant benefits to the cities driving its growth. However, there are also several challenges in implementing renewable energy. An analysis of the drivers and barriers has been conducted across sectors that impact renewable energy development in IKN: Political, Economic, Social, Technological, Environmental, and Legal (PESTEL).

Politically, the development of renewable energy in IKN is supported by a strong legal framework based on the government's commitment to achieving NZE in the city by 2045. Economically, renewable energy will promote a sustainable economy and create more job opportunities. Additionally, the Kalimantan region has abundant hydropower and solar PV resources, which are more than sufficient to meet the city's electricity needs.

However, to fully implement this plan, several challenges must be addressed. The most significant challenges come from the political and economic sectors, which require focused attention. Regulatory uncertainty, existing fossil fuel subsidies, and local content requirement policies are obstacles in these sectors. Additionally, from an economic perspective, the lack of suitable financing poses a critical barrier to renewable energy development. Technologically, another challenge is the current grid infrastructure, which is not yet equipped to handle the high penetration of intermittent solar energy.

To overcome these challenges, several actions and policies need to be implemented. The national government, which holds significant responsibility in the political and economic sectors, must take steps to realize the future vision. One essential step is the immediate establishment of a new renewable energy law aimed at attracting investors. This law should integrate all aspects of renewable energy development, clearly define stakeholder roles, and address regulatory gaps, creating a more favorable environment for investment. Additionally, project financing is a critical factor in the development of renewable energy in IKN, particularly through the use of a low project discount rate. Sensitivity analysis shows that a 5% discount rate can significantly lower annual investment costs and promote the growth of solar PV in IKN.

The local government also plays a significant role in the development of renewable energy in IKN, particularly in the social sector, as it can directly engage with the public. The public can also contribute to the development of renewable energy by using electricity efficiently, adopting energy-efficient household appliances, and making lifestyle changes to reduce daily consumption. This leads to a reduction in peak electricity demand and, consequently, lowers annual investment costs. A 5% reduction in electricity consumption by 2045 in IKN could save approximately \$11 million annually in investment costs. Moreover, fostering public acceptance of renewable energy projects can significantly help prevent delays in project implementation.

Finally, although this research provides a comprehensive overview of strategies across all sectors, it only provides a general analysis of specific actions or policies. An in-depth examination of each action is beyond its scope. However, this study can serve as a solid foundation for future research that aims to conduct a more detailed analysis of each sector related to renewable energy development in IKN.

Table of Contents

ACKNOWLEDGEMENT.....	I
EXECUTIVE SUMMARY	II
List of Figure.....	IV
List of Table	IV
List of Abbreviation.....	V
1. INTRODUCTION.....	1
1.1. Development of New Capital City of Indonesia (IKN).....	1
1.2. Research Gap	2
1.3. Research Objective	3
1.4. Research Question	4
1.5. Research Approach	5
1.6. Thesis Outline	5
2. METHODOLOGY	6
2.1. Integration of Backcasting and Energy Modeling.....	6
2.2. Step 1: Specifying the Strategic Objectives.....	7
2.3. Step 2: Describe the Present Condition	7
2.4. Step 3: Describe Potential Renewable Energy source.....	8
2.5. Step 4: Develop Future Electrical System.....	8
2.5.1. Model Building	9
2.5.2. Model Execution	11
2.6. Step 5: Develop the interim Development target.....	13
2.7. Step 6: Driver and Barrier Analysis Using PESTEL	14
2.8. Step 7: Develop Actions and Policies for Implementation	15
2.9. Step 8: Analysis of Actions and Policies	16
3. CURRENT AND DESIRED FUTURE ELECTRICITY SYSTEM	19
3.1. Energy Transition in Indonesia's Electricity System	19
3.2. Current Electricity System in the Area of IKN	19
3.2.1. Electricity Demand, Distribution Line, and Generator	19
3.2.2. Stakeholder	23
3.2.3. Regulatory Framework.....	26
3.3. Renewable Energy Potential	27
3.3.1. Hydropower	28

3.3.2.	Solar Energy	29
3.3.3.	Wind Energy	29
3.3.4.	Biomass	30
3.3.5.	OTEC.....	30
3.3.6.	Energy Storage	30
3.3.7.	Nuclear	30
3.4.	Desired Future Electricity System	31
3.4.1.	Future Electricity Demand	31
3.4.2.	Future Generation System	32
3.4.2.1.	Least-Cost Renewable Energy Technology	32
3.4.2.2.	Diversification of Renewable Energy Technology	35
4.	DEVELOPING THE STRATEGIES	37
4.1.	Driver and Barrier Analysis Using PESTEL.....	37
4.1.1.	Political.....	37
4.1.2.	Economy.....	39
4.1.3.	Social	40
4.1.4.	Technology	41
4.1.5.	Environmental.....	43
4.1.6.	Legal	44
4.1.7.	Summary of Driver and Barrier Analysis	44
4.2.	Actions and Policies for Implementation	45
4.2.1.	Policy and Regulatory Changes	45
4.2.2.	Financial and Economic Changes	48
4.2.3.	Institutional Changes.....	50
4.2.4.	Technological Changes	51
4.2.5.	Social Changes.....	52
4.2.6.	Summary of Actions and Policies for Implementation.....	55
4.3.	Analysis of The Impact of Actions and Policies	57
4.3.1.	Scenario 1: Implementation of Local Content Requirement Policy (LCR)	58
4.3.2.	Scenario 2: Providing Land Incentive	58
4.3.3.	Scenario 3: Variation of Project Discount Rate	59
4.3.4.	Scenario 4: Using the high efficiency of solar PV module.....	59
4.3.5.	Scenario 5: Implementation Delay of Hydropower Plants.....	60

4.3.6.	Scenario 6: Reduce the electricity consumption.....	60
4.3.7.	Scenario 7: Shifting Electricity Use from Peak Time to Off-Peak Time.....	61
4.3.8.	Comparison of The Scenarios.....	62
5.	DISCUSSION	65
5.1.	Combination of Hydropower and Solar PV is Feasible to Electrify IKN in 2045	65
5.2.	Potential Hydropower Plant for Renewable Electricity in IKN	66
5.3.	Biomass as the Alternative Renewable Energy Source in IKN.....	67
5.4.	Political and Economy Sector as the Major Aspects	67
5.5.	Low Project Discount Rate Will Boost the Renewable Energy in IKN	68
5.6.	Scientific Contribution of the Methodology	69
5.7.	Relevance for Knowledge Users.....	70
5.8.	Limitation on Methodology and Results	71
6.	CONCLUSION.....	72
6.1.	Answering Main and Sub-Research Questions	72
6.1.1.	Answering the Main Questions.....	72
6.1.2.	Answering Sub-question No.1.....	73
6.1.3.	Answering Sub-question No.2.....	73
6.1.4.	Answering Sub-question No.3.....	74
6.1.5.	Answering Sub-question No.4.....	74
6.2.	Recommendations for Stakeholders	75
6.2.1.	Recommendations for National Government.....	75
6.2.2.	Recommendations for Local Government	76
6.2.3.	Recommendations for PLN.....	76
6.3.	Recommendation for Future Research	77
	REFERENCE.....	79
	APPENDIX.....	92

List of Figure

Figure 2-1 Research Flow Diagram.....	7
Figure 2-2 simplified of Kalimantan Island Interconnection point used in the research	10
Figure 2-3 Input and output of the calliope model used in the research	13
Figure 2-4 Demand Profile after Shifting of Demand from Peak time (18-20) to off-peak time (14-16).....	17
Figure 3-1 Location of New Capital City of Indonesia (Widiaryanto et al., 2023)	20
Figure 3-2 The hourly pattern of Kalimantan Island electricity demand use in this Study	21
Figure 3-3 Simplified current interconnection of Kalimantan power system. Red lines represent the transmission lines and Black dots represent the capital city of the province.....	22
Figure 3-4 Local Government role in Indonesia energy sector stakeholder map (Islami & Aditya, 2020).....	25
Figure 3-5 Energy legal Framework in Indonesia (Islami & Aditya, 2020).....	27
Figure 3-6 Projected Renewable Electricity Capacity in IKN for the years 2030, 2035, 2040 and 2045	32
Figure 3-7 The scenario of Renewable Energy Diversification in IKN in 2045 involves reducing the capacity of hydropower and solar PV by 10%, 25%, and 50%.....	35
Figure 4-1 Comparison of Policy and Action Impact on the Capacity Planning of Power Plant in IKN by 2045	62
Figure 4-2 Comparison of the impact of policies and actions on the total investment cost for renewable electricity in IKN up to 2045.....	63
Figure 4-3 Comparison of LCOE for the impact of implementing actions or policies in IKN in 2045.....	64
Figure 5-1 Estimation of IKN Power System Profile on March 10th and 11th, 2045	65
Figure 6-1 Projected Renewable Energy Mix in Power System in IKN	72

List of Table

Table 3-1 Current Electricity Client in IKN Location (Bada Pusat Statistik, n.d.)	20
Table 3-2 Current Electricity Generator in Kalimantan Island (PLN, 2023)	23
Table 3-3 Renewable Energy Potential Capacity in Kalimantan Island.....	27
Table 3-4 Electricity Demand Projection of Kalimantan Island. West, south, central East and North Kalimantan refer to PLN (2021) and IKN refer to Pribadi (2023).....	31
Table 3-5 The projected electricity system in IKN by 2030, 2035, 2040, and 2045	32
Table 3-6 Projected Power Plant Installation and Investment Cost for IKN from 2030 to 2045	33
Table 3-7 Projected Levelized Cost of Electricity (LCOE) in IKN from 2030 to 2045.....	34
Table 4-1 Summary of Driver and Barriers for Renewable Energy Development in IKN.....	44
Table 4-2 Summary of WHAT-HOW-WHO Analysis of Actions and Policies for Implementation	55
Table 4-3 Relationship between Scenarios and action or policies for Implementation.....	57

List of Abbreviation

AGC	: Automatic Generation Control
CAPEX	: Capital Expense
CMEA	: Coordinating Ministry of Economic Affairs
CMMIA	: Coordinating Ministry for Maritime and Investment Affairs (<i>Kementerian Koordinator Bidang Maritim dan Investasi/Kemenkomarves</i>)
GSA	: Global Solar Atlas
IICB	: Indonesia Investment Coordinating Board (Indonesian: Badan Koordinasi Penanaman Modal, BKPM)
IKN	: National Capital (<i>Ibu Kota Negara</i>)
IPPs	: Independent Power Producers
KEN	: <i>Kebijakan energi Nasional</i> (National Energy Policy)
KEN	: Nasional Energy Policy (<i>Kebijakan Energi Nasional</i>)
KPI	: Key Performance Indicator
kV	: KiloVolt
LCOE	: Levelized Cost of Electricity
MoA	: Ministry of Agriculture (<i>Kementrian Pertanian</i>)
MoEF	: Ministry of Environment and Forestry (<i>Kementerian Lingkungan Hidup dan Kehutanan/KLHK</i>)
MoEMR	: Ministry of Energy and Mineral Resources (<i>Kementerian Energi dan Sumber Daya Mineral/KESDM</i>)
MoF	: Ministry of Finance (<i>Kementerian Keuangan/Kemenkeu</i>)
MoFA	: Ministry of Foreign Affair (<i>Kementrian Luar Negeri</i>)
Mol	: Ministry of Industry (<i>Kementerian Perindustrian/Kemenperin</i>)
MoNDP	: Ministry of National Development Planning (<i>Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional – Kementerian PPN/Bappenas</i>)
MoPWH	: Ministry of Public Works and Housing (<i>Kementerian Pekerjaan Umum dan Perumahan Rakyat/Kementerian PUPR</i>)
MoRT	: Ministry of Research and Technology (<i>Kementerian Riset dan Teknologi/Kemenristek</i>)
MoSOE	: Ministry of State-Owned Enterprises (<i>Kementerian Badan Usaha Milik Negara/ Kementerian BUMN</i>)
MoT	: Ministry of Trade (<i>Kementrian Perdagangan</i>)
MVA	: Megavolt Ampere
MW	: Megawatt
NGO	: Non-Governmental Organizations
OIKN	: Nusantara National Capita Authority (<i>Otoritas Ibu Kota Negara</i>)
OPEX	: Operational Expense
OTEC	: Ocean Thermal Energy Conversion
PLN	: <i>Perusahaan Listrik Negara</i> (National Electricity Company)
RE	: Renewable Energy
RPJMN	: National Medium Term Development Plan (<i>Rencana Pembangunan Jangka Menengah Nasional</i>)
RUED	: Regional Energy Plans (<i>Rencana Umum Energi Daerah</i>)

- RUEN : *Rencana Umum energi Nasional* (National Generation Energy Plan)
- RUKD : Local Regional Electricity Plans (Rencana Umum Ketenagalistrikan Daerah)
- RUKN : National Electricity Plan (Rencana Umum Ketenagalistrikan Nasional)
- RUPTL : Electricity Bussiness Plan (Rencana Umum Penyediaan Tenaga Listrik)

1. INTRODUCTION

1.1. Development of New Capital City of Indonesia (IKN)

The decision to relocate the capital city of Indonesia from Jakarta to East Kalimantan has been driven by a multitude of factors. The country's capital was relocated based on the concentration of economic activities in Jakarta and Java, which resulted in an economic gap between Java and outside Java (Sitanggang et al., 2024). Apart from that, there are study results that conclude that Jakarta is no longer able to carry out its role as the National Capital, this is due to the rapid uncontrolled population growth, the decline in environmental conditions and functions, and the level of living comfort which is increasingly decreasing.

To realize these efforts, Law Number 3 of 2022 concerning the National Capital was enacted on February 15, 2022. IKN has a vision to become a sustainable city. The National Capital City (IKN) development is being carried out to achieve the carbon-neutral city target by 2045 by realizing the target of 100 percent of electricity production coming from new and renewable energy (Berawi, 2023). According to Pribadi (2023), the peak electricity demand for the new capital city (IKN) in 2045 is estimated to be around 792 MW.

PT Perusahaan Listrik Negara (PLN), As the sole government-appointed electricity provider in Indonesia, plans to meet this demand in stages by building additional infrastructure, including power plants, transmission lines, and substations (PLN, 2021).

Several studies have been conducted related to the Implementation of 100 percent electricity from renewable energy to electrify a region or a city. In the past decade, researchers have conducted an increasing number of studies on whether 100 percent renewable energy and/or power is technically feasible and economically beneficial (Hansen & Lund, 2019). The cities or regions aiming to achieve 100 percent renewable electricity to meet their demands, along with their strategies for reaching this goal, are detailed in Appendix A.

However, Achieving 100% renewable electricity is a complex task that requires careful planning and consideration of various factors. These challenges include developing and procuring enough renewable energy resources, navigating complex energy regulations, balancing costs with other community priorities, and convincing local citizens of the benefits of renewable energy for their homes and businesses (Skill et al., 2020).

To develop renewable electricity in IKN, a thorough assessment is needed to project energy demand and identify available renewable resources in the region. This data will help estimate the number of renewable energy technologies required for optimal performance, which can be modeled using energy system modelling tools.

Furthermore, integrating renewable energy also faces challenges from other sectors such as politics, economics, social issues, and environmental concerns. Therefore, to achieve 100% renewable electricity in IKN, a comprehensive evaluation of all these sectors is necessary to provide a detailed analysis and develop a clear pathway forward.

1.2. Research Gap

The relevant scientific articles or journals have been conducted by computer search using Scopus and Google Scholar. The keywords used are “Energy AND Transition AND Indonesia” and “electricity AND nusantara”. This keyword combination of "Energy AND Transition AND Indonesia" was chosen to ensure that relevant studies discussing policies, challenges, technologies, and strategies related to the energy transition in Indonesia are included in the analysis. The term “electricity AND Nusantara” was included to narrow down the search to studies and articles specifically related to the new capital city, Nusantara. This ensures that the research addresses the unique energy needs, infrastructure plans, and renewable energy potential in IKN, which may differ from other regions in Indonesia. The subject area is filtered to only energy and the research should be issued from at least 2018 to make it still relevant to the current situation.

In the context of energy transition studies in Indonesia, a total of 17 studies have been explored, focusing on both national and regional levels. The primary focus of these studies revolves around optimizing the integration of renewable energy into Indonesia's future electricity system, predominantly through energy modeling techniques. The complete list of the reviewed studies is presented in Appendix B.

Research on Electricity Systems in IKN

Four specifically addressing the energy transition in East Kalimantan and the IKN. Toontje (2022) utilizes the LEAP software to model the future electricity demand in East Kalimantan, including the IKN. However, this study does not explicitly separate the electricity system analysis for IKN. Given that IKN has been designated as a new administrative region with its energy planning, a separate analysis is crucial. Furthermore, this research lacks a detailed implementation strategy for renewable energy integration in IKN.

Widiaryanto et al. (2023) provide a broader strategy for achieving net-zero carbon emissions by 2045 in IKN, covering various sectors such as energy, waste management, agriculture, and forestry. Similarly, Rino (2022) discusses policy scenarios for net-zero emissions in IKN. While these studies address sectoral strategies, they do not provide a comprehensive view of the future electricity system in IKN and do not specify how renewable energy implementation can be realized in the new capital.

Lastly, De Vries and Schrey (2022) focus on spatial planning for sustainable energy infrastructure in IKN, highlighting the importance of ecological sensitivity in locating energy production facilities. However, this study is limited to spatial analysis and does not address the broader technical or policy-related challenges associated with implementing renewable energy in IKN.

National-Level Studies on Renewable Energy Development

8 of 17 studies regarding the energy transition in Indonesia which explored are conducted on the national-level. Six of the identified studies utilize energy modeling tools to explore the future of Indonesia's energy system, emphasizing the integration of renewable energy sources.

Silalahi et al. (2023), Reyseliani & Purwanto (2021), and Paiboonsin et al. (2023) analyze the feasibility of achieving 100% renewable energy in Indonesia. While these studies provide valuable insights into the technical possibilities, they primarily rely on energy models. For instance, Silalahi et al. (2023) focuses on Indonesia's decarbonization pathway, emphasizing solar photovoltaics, and Paiboonsin et al. (2023) examine alternative pathways for low-carbon energy transitions using the OSeMOSYS model. Despite the comprehensive analysis offered by these studies, a significant gap is identified which is none of these studies delve deeply into the implementation strategies necessary to achieve the proposed energy transitions.

The remaining two national-level studies focus on the role of policies and governance. Alleluia et al. (2022) discuss the importance of government intervention and public policies, proposing mandatory long-term climate and renewable energy targets for Southeast Asia, including Indonesia, to accelerate the energy transition. Moreover, Santika et al. (2020) evaluate current Indonesian policies, concluding that existing frameworks are insufficient to meet renewable energy development targets.

Although these studies contribute to understanding policy implications, they lack a detailed examination of the technical feasibility of renewable energy integration within the power system. Additionally, their analysis is confined to the policy sector, overlooking the interdisciplinary nature of renewable energy implementation, which also involves economic, environmental, and social considerations.

Based on the literature review, the following research gaps have been identified:

1. Insufficient Focus on IKN's Electricity System. Existing studies on IKN either do not provide an explicit analysis of the electricity system or do not differentiate IKN's energy needs from those of East Kalimantan province. A dedicated focus on its electricity system is essential to IKN since its status as a new administrative region with its energy planning
2. Insufficient analysis of implemented actions and policies. While several studies provide technical and policy insights, there is a noticeable gap in the detailed implementation strategies for renewable energy in national and regional contexts, especially in the IKN.
3. Most studies focus on either technical or policy aspects but do not consider the interdisciplinary nature of renewable energy implementation, which requires integration across economic, environmental, and social dimensions.

1.3. Research Objective

To address all the gaps, this research aims to develop strategies for renewable electricity development in IKN. This research is divided into two primary objectives. First, it aims to identify the most cost-effective renewable energy technology by considering both technical and economic factors. This involves evaluating various renewable energy sources and technologies and assessing their feasibility, efficiency, and cost implications. The goal is to determine the most cost-effective

combination of renewable energy technologies capacity to achieve 100 percent renewable electricity in Indonesia's New Capital City by 2045. "The most cost-effective combination of renewable energy technologies" refers to the selection and integration of various renewable energy sources that provide the highest efficiency and energy output at the lowest possible cost.

Second, the research intends to offer a comprehensive strategy and provide actions or policies to the Indonesian Government and all stakeholders in the power sector. It will address potential challenges and propose solutions to ensure the successful implementation of renewable energy initiatives. This pathway will outline the necessary steps, strategies, and policies required to facilitate the transition to a fully renewable energy system in IKN by 2045.

1.4. Research Question

To accomplish the objective of this research, it is necessary to address several interconnected questions, which are organized into a main research question and several sub-questions.

The Main research question to be investigated is:

" What renewable energy sources are the most cost-effective for achieving 100% renewable electricity in the New Capital City of Indonesia by 2045, and what actions and policy measures are required to facilitate their development and implementation?"

To answer the main research questions, 4 sub-research questions have been made. Commencing with an examination of the current electricity system in the New Capital City, to understand the existing infrastructure and its implications. Simultaneously, an evaluation of renewable energy sources potential to determine the feasibility and scale of sustainable power generation. The second sub-question concerns envisioning the desired future of the electricity system. The following sub-questions explore the various factors influencing the energy transition and identify associated challenges and opportunities. Finally, the fourth sub-question identifies an effective transition strategy and describes the action to realize the strategy.

- 1) *What is the current state of the electricity system in the location of the New Capital City of Indonesia, and what renewable energy source potentials are available to support the future electricity system?*
- 2) *What are visions and desirable futures for the electricity system in the new capital city of Indonesia in 2045?*
- 3) *What factors are influencing renewable electricity development in the New Capital City?*
- 4) *What Actions and Policies need to be implemented to achieve the desirable futures for the electricity system by 2045?*

1.5. Research Approach

The research uses the Backcasting method to develop a pathway for renewable electricity in Indonesia's New Capital City (IKN). The Backcasting method involves analyzing the current situation, envisioning the desired future system, and then determining the necessary changes to achieve this future state. This research will combine both qualitative and quantitative methods to gather and analyze data effectively.

To begin, the current situation will be thoroughly analyzed using secondary data sources. This step is crucial for understanding the present state of the electricity system in the area of IKN. Following this, the desired future system will be developed using simulation on energy modeling. This simulation will illustrate the optimal combination of renewable energy technologies, focusing on achieving 100% renewable electricity by 2045 with the highest efficiency and lowest cost.

Next, based on the simulation results, this study will identify the drivers and barriers influencing the development of renewable energy technologies selected by the simulation. The analysis will focus on six key areas: Politics, Economy, Society, Technology, Environment, and Legal (PESTEL analysis). By identifying these factors, the research will highlight the barriers that hinder progress and the drivers that can facilitate it. Strategies, including actions and policies, will then be developed to overcome these barriers, enabling the realization of future visions.

The effectiveness of the proposed actions or policies will then be tested using energy modeling simulations. This step will analyze the impact of the policy and action on the system, helping to determine the impact of the implementation of actions and policies for the power system.

1.6. Thesis Outline

The thesis report is divided into six chapters, each addressing a specific aspect of the research. Chapter 2 outlines the methodology used in the research process. It describes the detailed data collection methods and analysis techniques employed to address the research questions. Chapter 3 focuses on the current and future energy systems in the target location. It explores the existing electricity system infrastructure, stakeholders, and regulatory framework. Additionally, this chapter develops a vision for achieving 100 percent renewable electricity in the new capital city by 2045 through energy model simulation.

Chapter 4 is dedicated to developing the strategy to achieve the development of renewable energy targets. It synthesizes findings related to barriers and develops actionable strategies, policies, and interventions to facilitate the realization of future vision. The chapter also discusses the roles and responsibilities of various stakeholders in implementing the proposed actions.

Chapter 5 offers a comprehensive discussion of the research findings, their implications, and contributions to the field. It reflects on the research process and outcomes, discussing the strengths and limitations of the study. Chapter 6 concludes the research by answering the research questions and providing insights gained from the study and recommendations for future research.

2. METHODOLOGY

2.1. Integration of Backcasting and Energy Modeling

This research utilizes the Backcasting method as the primary framework. Backcasting is a strategic planning approach that begins with envisioning a desirable future and then works backward to identify the necessary steps to achieve that future state. This method is particularly effective for developing pathways for energy transitions in the electricity sector, as it helps identify the specific actions, policies, and technologies required to create a sustainable and renewable energy system (Robinson, 1982).

The differences in the overarching methodologies of various backcasting approaches can largely be attributed to their intended applications. Quist & Vergragt (2006) generalized and translated most backcasting approaches found in various studies into a methodological framework consisting of five stages: setting the target, constructing sustainable future visions, conducting backcasting analysis, defining actions to realize the future, and embedding results while generating follow-up and implementation. More elaboration on the backcasting method is detailed in Appendix I.

This research adopts the first four stages of the backcasting method as its primary framework and further develops detailed steps within each stage. The elaboration of those 4 stages results in 8 steps, as summarized in Figure 2-1. The fifth stage is not assessed in this study, as it involves monitoring the implementation of the transition, which falls outside the scope of this research, which focuses on the planning phase.

Energy modeling plays a crucial role in the backcasting method used in this research. It is essential for developing future visions, setting interim targets, and creating scenarios by simulating the sensitivity of actions and policies. To perform this task effectively, the energy model must be capable of simulating a wide range of energy technologies (Bimenyimana et al., 2019) and conducting techno-economic analyses to assess the economic feasibility of renewable energy integration (Aghapouramin, 2023). Additionally, open-source software is preferred due to its flexibility and customization, as the source code can be modified and adapted to meet specific research needs (Hasselbring et al., 2020).

Based on the criteria and the availability of a comprehensive model of Indonesia's power system developed by Langer et al. (2024), this research has selected Calliope software. Calliope is an open-source energy system modeling framework that supports the analysis and optimization of energy systems. It addresses several limitations found in existing models and can compute and compare numerous scenarios (Pfenninger & Keirstead, 2015).

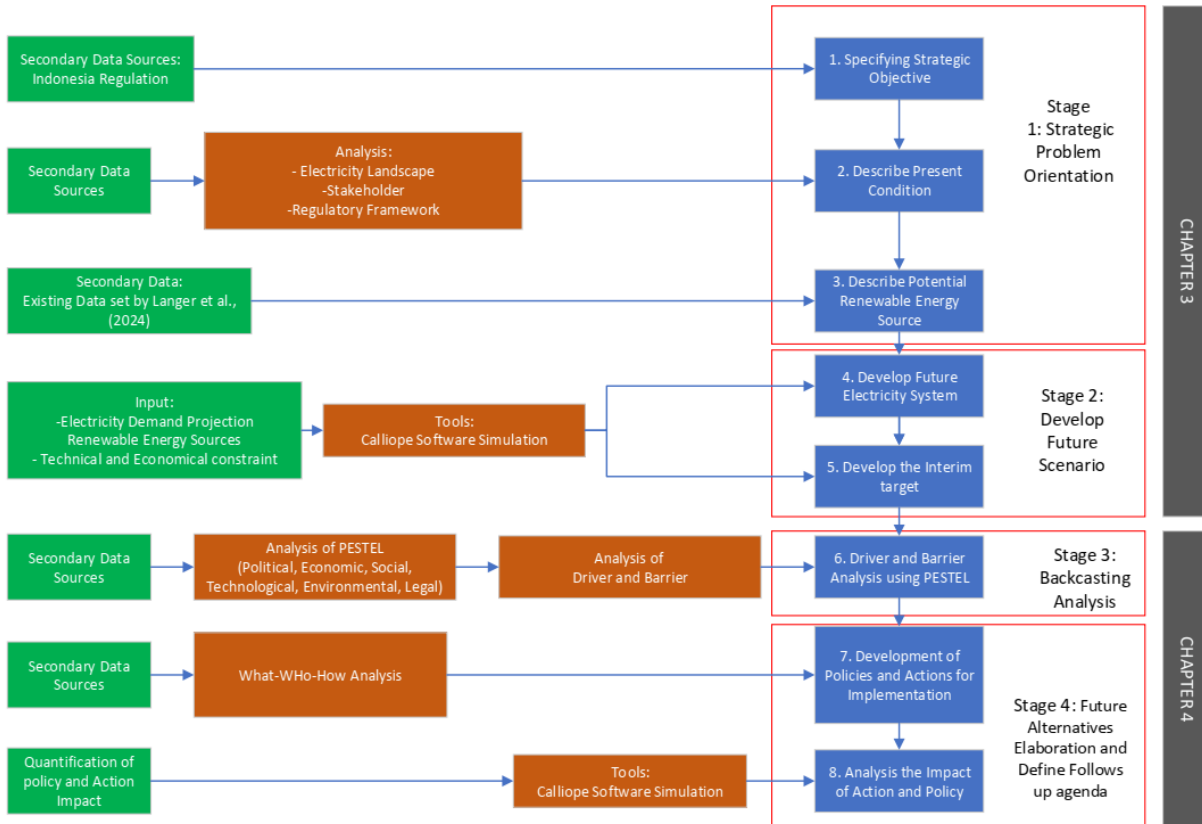


Figure 2-1 Research Flow Diagram

2.2. Step 1: Specifying the Strategic Objectives

The first step is to define relevant sustainability criteria as strategic objectives for the new capital city under this study, based on the principles that are listed as key assumptions. The strategic objective needs to capture the essence of sustainable development while also defining a reasonable set of constraints, both politically and technically. The objective of this research is derived from regulations set forth by the Indonesian government, aiming to achieve 100 percent renewable electricity in IKN by 2045.

2.3. Step 2: Describe the Present Condition

To describe the present condition of the electricity system in the IKN area, three analyses need to be conducted which are the current electrical system assessment, stakeholder analysis, and regulatory framework analysis.

Firstly, the current electrical system conditions are identified by assessing the current state of power generation facilities, transmission, and distribution networks, as well as analyzing energy consumption patterns. The data collection method for this step involves gathering relevant secondary data from the Electricity Business Plan (RUPTL) of PLN and Indonesia’s central

Bureau of Statistics. The analysis of the current electricity system extends beyond IKN to include an understanding of the overall conditions in other provinces of Kalimantan. This broader analysis is necessary because all the electricity systems in Kalimantan, including IKN, will be interconnected in the future.

Moreover, the study analyzes the stakeholder and institutional structure of the energy system by identifying key actors involved in electricity system governance and distinguishing between national and local governments. This analysis is conducted through desk research using secondary data from various organizational reports.

Lastly, it is important to identify the regulatory framework governing the electricity sector. This involves examining the relevant laws, policies, and regulations that shape the electricity system. This step is carried out through desk research, referencing existing government regulations and using secondary data collected from organizational reports.

2.4. Step 3: Describe Potential Renewable Energy source

The next step is to describe the potential renewable energy sources which are available to electrify IKN. The dataset utilized in this study is derived from the publicly available Calliope Indonesia model developed by Langer et al. (2024). The datasets are developed by using tools like the Global Solar Atlas (GSA), ERA5, and Geographic Information System (GIS). These datasets provide the renewable energy potential within each province in Kalimantan Island. For this research, the renewable energy source in East Kalimantan province is used for IKN since the location of IKN is in the East Kalimantan province. The hourly profile of solar, wind, and hydropower energy used in the model is shown in Appendix C.

For renewable energy sources that can't be assessed with these tools, like biomass and nuclear, data is collected from government publications (RUEN).

2.5. Step 4: Develop Future Electrical System

As a non-participatory approach backcasting method, this research uses a quantitative method to describe the future. According to Irsyad & Quist (2024), non-participatory backcasting studies employ quantitative analytical tools to model the desire future objectives and pathways toward these goals. Energy modeling plays a crucial role in the backcasting method for scenario development, identification of interim goals, and identification the effective strategies through sensitivity analysis.

Currently, many energy modeling software packages include features to support the development of pathways for energy transition. According to Irsyad & Quist (2024), various studies have employed quantitative energy models such as Low Emissions Analysis Platform

(LEAP), Extended Snapshot (ExSS), Open-Source Energy Modeling System (OSeMOSYS), and Computable General Equilibrium (CGE).

Researchers from TU Delft have already developed a comprehensive model of a significant portion of Indonesia's power systems (Langer et al., 2024) using Calliope. Therefore, this study is using this existing calliope model by adjusting it to focus on the IKN system.

Calliope is an open-source energy system modeling framework designed to support the analysis and optimization of energy systems. It is a cost-minimization model for energy supply, capable of handling linear programs.

2.5.1. Model Building

According to Pfenninger and Pickering (2018), the operation of a Calliope model consists of supply, transmission, conversion, storage, and demand technologies.

Supply technologies can harness resources from outside the modeled system and transform them into specific energy carriers within the system. The model designates one or more locations and the permissible technologies at those locations. Transmission technologies facilitate the movement of energy of the same carrier between different locations, while conversion technologies enable the conversion of one carrier into another at the same location. Demand technologies extract energy from the system, and storage technologies enable energy storage at specific locations. By incorporating these possibilities, modelers can tailor the complexity of the model to address specific research inquiries as needed.

The model used in this research is derived from an existing model developed by TU Delft PhD researcher Jannis Langer, named calliope-Indonesia. It can be accessed on GitHub via the source JKALanger (n.d). The data utilized as input for the model can be categorized into five types: locations, supply technologies, storage technologies, demand power, and transmission technologies. However, as the focus of this research is solely on optimizing the power system in IKN, certain adjustments have been made to the calliope-Indonesia model.

This research includes five provinces: East, South, North, Central, and West Kalimantan, as well as an additional location for IKN. To simplify the energy model, each province will have a single connection point located in its respective capital city. These connection points are linked together through transmission technologies.

The interconnection line between these points is established following the latest RUPTL (PLN, 2021). Figure 2-2 illustrates the transmission connections as red lines between the reference points for the province locations (black points).

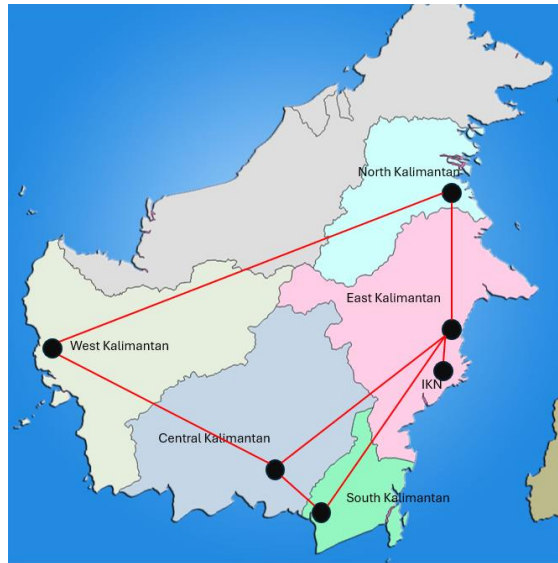


Figure 2-2 simplified of Kalimantan Island Interconnection point used in the research

The supply technology refers to power plants that generate electricity. These plants are categorized into two main types: renewable energy and fossil fuel. The fossil fuel generation plants utilized in this research are the existing technologies in the electricity system in Kalimantan which include Combined Cycle Gas, Diesel Power plants, and Coal Power Plants. This data is gathered from the RUPTL. This study sets a target of achieving zero emissions by 2050. It is assumed that all existing fossil-based power plants (coal, diesel, and gas) will gradually be phased out in 5-year intervals from 2030 to 2050. The reduction of fossil fuel capacity is shown in appendix D. On the other hand, the renewable energy sources for this research are based on the results of renewable energy potential in step 3.

The transmission lines are assumed to be alternating current (AC) lines. Only the active power flows of the lines are considered, omitting aspects such as voltage, frequency, and apparent power. Due to the unavailability of national data on maximum active line capacity, Calliope optimizes transmission capacities up to 50 GW per link (Langer et al., 2024). For AC lines, an efficiency of 98% is assumed (PLN, 2023). As the total length of AC connections between nodes is unknown, the efficiency of the total transmission system is utilized. Consequently, transmission CAPEX is calculated per unit of installed active capacity rather than per unit of length. This approach has limitations due to the distance-dependent and fixed cost components of transmission lines. Additionally, international cost data is used as current local cost data is not publicly available. AC line CAPEX is assumed to be 522 US\$ (2021)/kW, with variable OPEX of 2.5 and 1.3 US\$ (2021)/MWh (Lombardi et al., 2020b) for all scenarios, respectively.

Storage technology refers to the technology capable of storing excess energy when electricity production exceeds energy demand. In this research, the storage technologies employed are pumped storage hydropower plants and batteries.

All technical and economic constraints for the generator and storage technologies used in this study are presented in Appendix E.

Furthermore, the electricity demand for 2030 will be modelled based on the latest RUPTL (2021-2030). For the remaining years (2031-2045), energy demand will be estimated using the average percentage of demand growth in RUPTL for each province in Kalimantan Island. However, the RUPTL projection for East Kalimantan's energy needs already accounts for the development of IKN (PLN, 2021). Therefore, the energy demand for East Kalimantan must be adjusted by subtracting the energy demand for IKN to differentiate between the two regions in this study.

The peak power demand projection for IKN by 2045 in this research is based on an official publication from the Ministry of Energy and Mineral Resources (MoEMR) (Pribadi, 2023). This publication provides peak power demand data for the years 2024 to 2045 at 2-year intervals. Using this data, the demand projections for the years 2030, 2040, and 2045 have been developed.

To integrate energy demand into the model, it is necessary to develop an hourly energy demand profile. This profile is based on the hourly electricity demand for Kalimantan in 2019, as obtained from PLN (Langer et al., 2024). However, the hourly power demand data must first be converted into a pattern to project future electricity demand.

To create this demand pattern, begin by identifying the maximum electricity demand from the available data for the year. Then, calculate the percentage of electricity demand for each hour relative to this maximum value.

For the years 2030, 2035, 2040, and 2045, hourly time series data are generated by multiplying the peak demand by the percentage of electricity demand for each hour. Summing the power required for each hour results in the total annual energy demand in GWh. A detailed description of this electricity demand profile is provided in Appendix C.

2.5.2. Model Execution

The Calliope model can optimize the power system by either minimizing costs or reducing emissions. In this study, the focus is on minimizing costs. Using this cost optimization approach, two future scenarios for the year 2045 will be developed. The first vision will emphasize identifying and utilizing the most cost-effective renewable energy technologies. This vision will determine the combination of renewable technologies that can produce electricity at the lowest Levelized Cost of Electricity (LCOE).

The second vision will emphasize the diversification of renewable energy sources in the Kalimantan area. In this scenario, the capacity of renewable energy technology which results

from the least-cost vision was reduced by 10%, 25%, and 50%. This vision is made to explore and incorporate other renewable energy sources that can meet the demand and fill the gap.

This study analyses four key outputs from the simulation which are installed energy capacity, hourly power plant operation, investment cost, and the levelized cost of electricity (LCOE).

First, the installed capacity is assessed to determine the total renewable energy capacity required to electrify the IKN by 2045. Understanding the necessary installed capacity allows for estimating the capital expenditure needed to develop the power plants.

Next, the hourly operation of the power plants is analysed to evaluate the technical feasibility of the renewable energy mix within the IKN. This analysis reveals fluctuations in supply and demand, as well as how the system manages the intermittency of renewable energy sources. The hourly operation data is also used to calculate the annual energy production.

The study also examines the annual investment cost, which provides insights into the financial requirements needed each year to develop and maintain renewable electricity infrastructure. This annual investment cost includes both the annual capital cost and the annual operation and maintenance (O&M) expenses for the power plants. The annual capital cost is calculated by multiplying the total capital cost by the depreciation rate, which is influenced by the project's discount rate and the lifetime of a power plant. The capital cost, annual O&M cost, project discount rate, and the lifetime of each power plant technology are present in appendix E.

Finally, the LCOE is provided to determine the cost per kilowatt-hour (kWh) of electricity generated. This metric is important for identifying the most cost-effective renewable energy mix within the system. The LCOE for each renewable technology is determined by dividing the annual cost by the annual energy production of that technology. The annual energy production is calculated by summing the hourly energy output of each power plant over a year. This calculation provides a clear comparison of the economic efficiency of different renewable energy sources, helping to guide decisions on the optimal energy mix for the system.

In summary, the input and output of the calliope model for this research are shown in Figure 2-3.

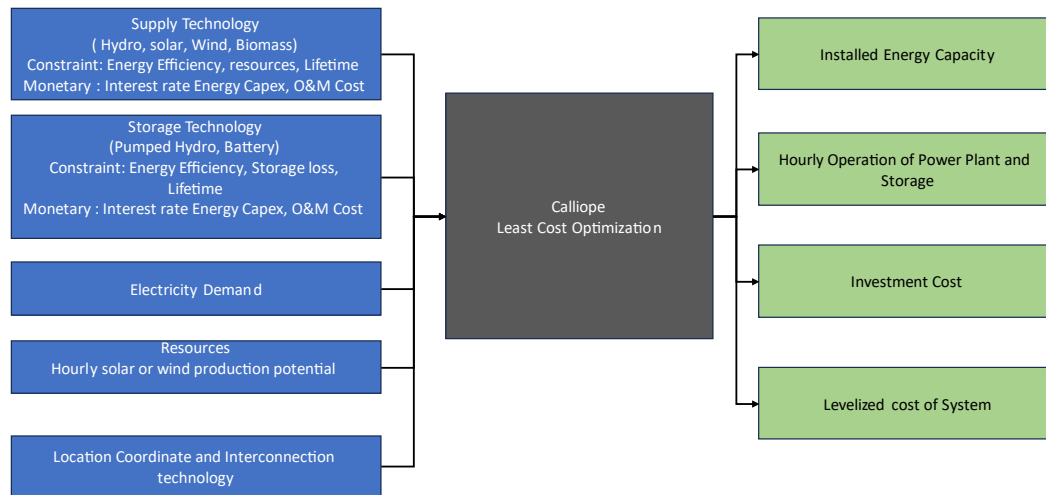


Figure 2-3 Input and output of the calliope model used in the research

2.6. Step 5: Develop the interim Development target

For further analysis, the least-cost vision is selected because it offers the most cost-effective energy production compared to the diversification vision. Consequently, interim development targets are established to achieve this least-cost vision. These interim goals are crucial for the subsequent monitoring phase, as they help determine whether the development is on track to meet the energy demand in IKN.

The International Energy Agency (IEA) recommends regular monitoring and evaluation of energy policies every 3-5 years to ensure alignment with long-term goals and to address any emerging challenges promptly. This approach enables policymakers to identify bottlenecks or inefficiencies in the energy transition process and implement corrective measures promptly.

Therefore, the model is set to develop the expected capacity target of renewable energy mix in the power system of the years 2030, 2035, 2040, and 2045 as the interim target. To develop this, constraints such as demand, reduction of fossil fuel generation capacity, and economic factors such as capital cost, operation and maintenance cost, and fuel cost are set for each milestone year. However, the simulation uses the same hourly energy source profiles—such as solar PV, hydropower, and wind—for each scenario.

For cost inputs, literature values from 2016 onwards are used for Capital Expenses (CAPEX) and both fixed and variable Operational Expenses (OPEX). After gathering all the costs, they are

converted to 2021 US \$ using the U.S. Consumer Price Index (CPI) to account for inflation. The cost values per technology are determined along with their average cost reduction rates until 2050 (Langer et al., 2024). Using these cost reduction rates, the respective costs for 2030, 2040, 2045, and 2050 are calculated. The reduction cost assumption used in this study is described in Appendix D.

To determine the renewable energy capacity target for 2030, all relevant constraints for that year are input into the software, resulting in the renewable energy mix for 2030. The same method is applied to set the goals for 2035. The simulation is not conducted in iterative ways which means the results of the year 2030 are not used as inputs for the 2035 simulation. The model treats each milestone independently.

2.7. Step 6: Driver and Barrier Analysis Using PESTEL

As the future electricity system visions are developed, the next step is to define implementation strategies. The least-cost visions suggest that a combination of large hydropower and utility-scale solar PV is well-suited to meet the electricity demand of IKN. Therefore, the development of an implementation strategy begins with identifying the drivers and barriers to the development of large hydropower and utility-scale solar PV in IKN.

To make this process more systematic, the drivers and barriers are analyzed using the PESTEL framework. By categorizing and analyzing the drivers and barriers within each dimension of PESTEL, organizations can prioritize interventions, allocate resources efficiently, and develop tailored strategies to address specific challenges (Parekh et al., 2023).

To perform a comprehensive PESTEL analysis, data and information relevant to each category—Political, Economic, Social, Technological, Environmental, and Legal—must be collected. Reliable sources such as government reports, industry publications, academic research, news articles, and market analysis reports should be utilized to ensure the information is accurate and up to date.

The brief description of each categorization of PESTLE use in this study is according to Nic Aoidh et al. (n.d.) which are as follows:

- 1) Political factors determine the extent to which a government may influence the economy or certain industries. These include e.g. tariffs, legal frameworks, competition regulation, regulation and deregulation, tax policy (tax rates and incentives), government stability and related changes, government involvement in trade unions and agreements, import restrictions on quality and quantity of products, intellectual property law (copyright, patents), consumer protection and e-commerce, laws that regulate environment pollution. From an energy perspective, the factors may include 2020 targets, grant aid, REFITs, tax regime, etc.
- 2) Economic factors are determinants of an economy's performance that directly impact a company/industry and have resonating long-term effects. They may include inflation rates, interest economic rates, foreign exchange rates, economic growth patterns, etc. From an energy

perspective, the factors may include the cost of renewables, access to finance, and access to funding.

- 3) Social Factor Analyze the social environment of the industry and assess determinants such as cultural trends, demographics, and population analytics. From an energy perspective, the factors may include community structures, level of engagement with communities, acceptance of technologies, tourist impact, NIMBYism, and stakeholder impact.
- 4) Technological factors refer to innovations in technology that may affect the operations of the industry and include the level of automation, research, and development, and also the level of technological awareness. From an energy perspective, the factors may include renewable technologies, grid access, and the planning process.
- 5) Environmental Factors include all those that influence or are determined by the surrounding environment and may include climate, weather, climate change, and environmental offsets. From an energy perspective, the factors may include climate change, planning issues near protected areas, and challenges associated with living in rural areas.
- 6) Legal factors include the laws that affect that industry within a certain country and may include consumer law and safety standards. From an energy perspective, the factors may include planning, access to resources, grid access, ownership models, and local benefit frameworks.

Once the data is gathered, drivers and barriers within each PESTEL category should be analyzed. For example, data related to the political sector is collected first. Data or information that leads to a negative impact is defined as a barrier, while data that has a positive impact and great potential to support renewable energy in IKN is defined as a driver. This process is then applied to the remaining sectors. This analysis will help in understanding all the factors influencing the transition from the current state to the desired state, identifying both opportunities and challenges.

2.8. Step 7: Develop Actions and Policies for Implementation

In the previous step, drivers and barriers in the current conditions were identified and categorized using the PESTEL framework. The next step is to conduct a backcasting analysis to identify potential solutions or actions that can overcome these barriers while considering the identified drivers through the WHAT-HOW-WHO analysis.

Backcasting involves looking backward from the desired future situation to answer key questions: "WHAT changes are needed to achieve the vision?" "HOW can these changes be implemented?" and "WHO could or should contribute to realizing the vision, and what activities should they undertake?" The WHO question can be further expanded to include, "Who might oppose the required changes, and how can this opposition be managed?" (Quist, 2013).

First, for the WHAT analysis, the assessment is divided into five areas: Policy and Regulatory, Financial and Economic, Institutional, Technological, and Social. This division aligns with the categorization of drivers and barriers from the previous step, ensuring that all challenges are comprehensively addressed. This analysis will provide the changes of actions or policies needed for the successful implementation of the future vision in IKN by 2045.

Each potential action or policy is identified through desk research, using data collected from organizational reports, research studies, and official government documents or publications. This process also involves reviewing actions and policies that have been successfully implemented in other countries to overcome similar barriers.

After determining the actions and policies, a "how" analysis is conducted. The "how" analysis outlines the strategies or mechanisms for implementing these actions and policies, which aim to drive the development of renewable electricity in IKN from the current situation to 2045. This involves breaking down each action or policy into more specific strategies. These strategies are developed through desk research, using data collected from organizational reports, research studies, and official government documents or publications.

However, this study does not analyze every detail of the situation between interim goals. For example, it does not examine the period between 2045 and 2035, or between 2035 and 2030. While such an approach could be useful for explaining backcasting, it is hardly applied in professional practice (Quist, 2013).

Furthermore, the "WHO" questions identify the stakeholders responsible for implementing the actions and policies. This analysis clarifies the roles and responsibilities of each stakeholder group, ensuring effective coordination and collaboration in executing the backcasting strategies (Rotmans et al., 2001). The stakeholder analysis conducted in Step 2 is used to address these questions.

2.9. Step 8: Analysis of Actions and Policies

The policies and actions developed in the previous step will be evaluated and analyzed to determine their impact on the system. This analysis will focus on policies and actions that can be quantified or translated into input changes for the Calliope software, based on existing research. Each analysis will be referred to as a scenario.

To ensure the impact of action and policy changes can be tested in an energy model, it is crucial to quantify these changes in numerical terms. The initial step involves defining the indicators that need measurement in the IKN model. These metrics may encompass electricity demand, electricity production, and costs.

seven different scenarios will be analyzed as follows:

1. Scenario 1: Implementation of Local Content Requirement Policy (LCR).
In this simulation, the solar PV capital expenditure (CAPEX) for 2045 is increased by 35% to assess the impact of Local Content Requirement (LCR) implementation on the cost of electricity produced by solar PV in IKN by 2045. The LCR policy requires that at least 40% of the components for solar PV projects be sourced locally. According to IESR (2022), the price of domestic modules is still 30–45% higher than that of imported ones.
2. Scenario 2: Providing land Incentive.

The investment cost for medium-scale hydropower plants is estimated to rise by about 6% due to land-use costs, while utility-scale solar PV is expected to see an increase of around 18% (IESR, 2023). To account for this, the sensitivity analysis involves reducing the capital expenditure (Capex) of solar PV by 18% and hydropower by 6%.

3. Scenario 3: Variation of Project Discount Rate.

The base case simulations use a 10% discount rate, which is the average rate applied to renewable energy projects in Indonesia (IESR, 2019). To understand how varying the discount rate affects the cost of electricity production, a sensitivity analysis was conducted with discount rates set at 5%, 7%, 10%, and 15%.

4. Scenario 4: Using High Efficiency of Solar PV Module

In the base scenario, a 15% capacity factor is used. However, being located along the equator, Indonesia experiences consistent solar irradiation, leading to an above-average solar capacity factor ranging from 12% to 19% (IESR, 2023). With the use of high-efficiency solar PV modules, it is possible to increase electricity production by 1% or more. This scenario evaluates the impact of increasing electricity production by 1% compared to the base case on the overall system.

5. Scenario 5: Implementation Delay of Hydropower Plant

This scenario is designed to evaluate the potential consequences of not having hydropower by 2030. The simulation excludes hydropower technology across the entire Kalimantan Island for the year 2030.

6. Scenario 6: Reducing Electricity Consumption

The simulation was conducted by reducing demand by 5% and 10% across all provinces on Kalimantan Island to analyze the impact on the system.

7. Scenario 7: Shifting Electricity Use from Peak Time to Off-Peak Time

This scenario is designed to evaluate the effectiveness of changing consumer behavior to use more electricity during off-peak hours. As present in Figure 2-4, The simulation involves shifting 5% and 10% of electricity usage across the entire Kalimantan Island from the peak period of 18:00 to 21:00 to the off-peak period of 14:00 to 16:00.

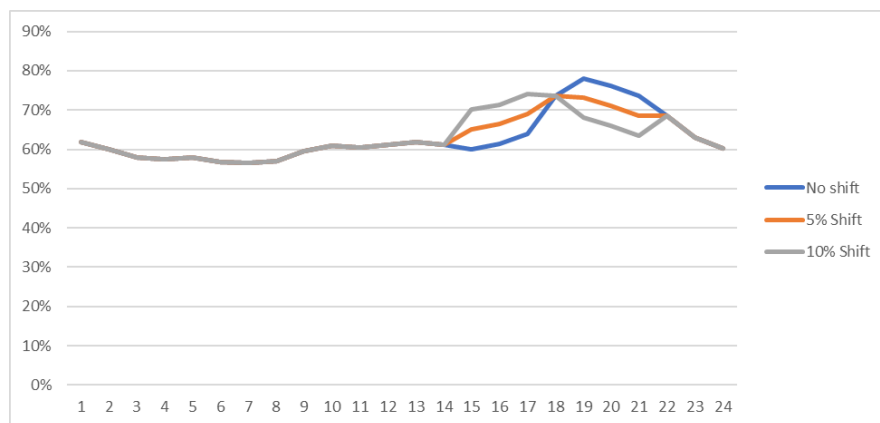


Figure 2-4 Demand Profile after Shifting of Demand from Peak time (18-20) to off-peak time (14-16)

These seven scenarios represent the potential outcomes of implementing the policies discussed in step 7, either directly or indirectly. However, the actions and policies related to grid stability and generator flexibility are not included in the scenario because the transmission and distribution lines are simplified in the model. This model does not perform detailed power system simulations, such as harmonics and short-circuit analyses.

3. CURRENT AND DESIRED FUTURE ELECTRICITY SYSTEM

3.1. Energy Transition in Indonesia's Electricity System

The energy transition in Indonesia's electricity system is crucial as the country strives to shift towards renewable energy sources to address climate change and ensure energy security. Indonesia has set ambitious goals, such as the Indonesia Long Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR 2050) and the National Determined Contribution (NDC 2021), to support this transition (Maharani, 2024). Specifically, Indonesia aims to achieve at least 23% renewable energy in its energy mix by 2025 and 31% by 2050 (Azmi et al., 2022). Moreover, Indonesia announced its ambitious objective to reach net zero emissions by 2060 (IEA, 2022).

Although Indonesia has made some progress in its energy transition efforts, several challenges remain. Notably, non-renewable energy sources still dominate the country's power plants, indicating a need for a more substantial shift towards renewables (Hisamatsu, 2021). For instance, as of December 2020, coal-based power plants contributed 66.3% of the total energy mix (PLN, 2021).

This reliance on coal is due to the young fleet of coal-fired power plants, which will continue to meet a significant share of demand for many years (IEA, 2020). The ongoing dependence on non-renewable energy sources is influenced by high electricity demand, existing infrastructure, subsidies for traditional energy sources, and slow development of alternative energy sources.

Moreover, Indonesia's potential for renewable energy sources, such as hydropower, bioenergy, solar, wind, and geothermal, remains unutilized. For example, the Ministry of Energy and Mineral Resources (ESDM) identified a theoretical hydropower potential of 75 gigawatts (GW) in 1983. However, by 2019, only 7.5% of this potential, or 5.6 GW, had been installed, generating about 21 terawatt-hours of electricity (Langer et al., 2021). Additionally, ESDM estimates the theoretical potential for solar photovoltaic (PV) to be between 1,360 and 3,551 GW and for wind energy to be between 61 and 114 GW. Despite this, the installed capacity for these technologies remains low, with only 0.15 GW each for solar PV and wind energy in 2019 (Langer et al., 2021).

In conclusion, while Indonesia has set ambitious targets for its energy transition and has significant potential in renewable energy sources, considerable efforts are needed to overcome existing challenges. Addressing the dominance of non-renewable energy, improving infrastructure, and accelerating the development of renewable energy projects are essential steps

3.2. Current Electricity System in the Area of IKN

3.2.1. Electricity Demand, Distribution Line, and Generator

Electricity Demand

IKN will be developed into two sub-regions located in East Kalimantan Province: Penajam Paser and Kutai Kertanegara. As shown in Figure 3-1, these two sub-regions are situated between two

major cities, Samarinda (the capital city of East Kalimantan) and Balikpapan. The current electricity demand in Penajam Paser Utara Regency stands at only 15.89 MW, which is supplied by the Petung Substation with a capacity of 90 MW. Similarly, in Kutai Kartanegara Regency, the electricity demand is 117.54 MW, which is met by three substations: Karang Joang, Manggasari, and Senipah, with a combined capacity of 300 MW (PLN, 2021). The electricity client growth in both regions is presented in Table 3-1.



Figure 3-1 Location of New Capital City of Indonesia (Widiaryanto et al., 2023)

However, despite these supply capacities, PLN's electrification ratio in both Kutai Kartanegara and Penajam Paser Utara Regencies is not yet fully achieved. In Penajam Paser Utara, PLN's electrification ratio currently stands at 98.4 percent, leaving 1.6 percent of areas without access to PLN's electricity. Similarly, in Kutai Kartanegara, PLN's electrification ratio is at 91 percent, indicating that 9 percent of areas remain unreached by PLN (Kumparanbisnis, 2019).

Many of these villages are situated in remote interior and border areas, where access remains extremely limited. Consequently, the construction of the electricity network encounters significant challenges. As a result, villages without PLN electricity have had to seek alternative sources independently, such as utilizing generators and receiving assistance from government-sponsored Solar Power Plants (Rohmah, 2023).

Presently, the electricity situation in the East Kalimantan System boasts a surplus of 400 Megawatts (MW), which is allocated to power four regions in East Kalimantan: Balikpapan, Samarinda, Tenggarong, and Bontang (Rohmah, 2023). This electricity surplus cannot be transferred to other provinces, such as West and North Kalimantan, because the transmission lines have not been developed yet.

Table 3-1 Current Electricity Client in IKN Location (Bada Pusat Statistik, n.d.)

Region	Number of Electricity Client			
	2019	2020	2021	2022
Kutai Kartanegara	176,172	199,588	210,197	219,566
Penajam Paser Utara	49,154	49,115	52,618	56,091

Most of the electricity consumption in the region is residential. Energy demand increases between 04:00 and 08:00 as residents prepare for the day. After 08:00, demand continues to rise gradually, reaching a peak around 16:00. A second significant increase occurs in the evening, from 17:00 to midnight, with a sharp peak around 20:00. During this time, people are at home after work, using lighting, TVs, fans, and air conditioners. As a result, the period from 17:00 to 22:00 is considered the peak load time. To manage demand effectively, the government recommends reducing electricity use during these hours. Figure 3-2 provides insight into Kalimantan's daily electricity demand on March 10th and 11th, 2019.

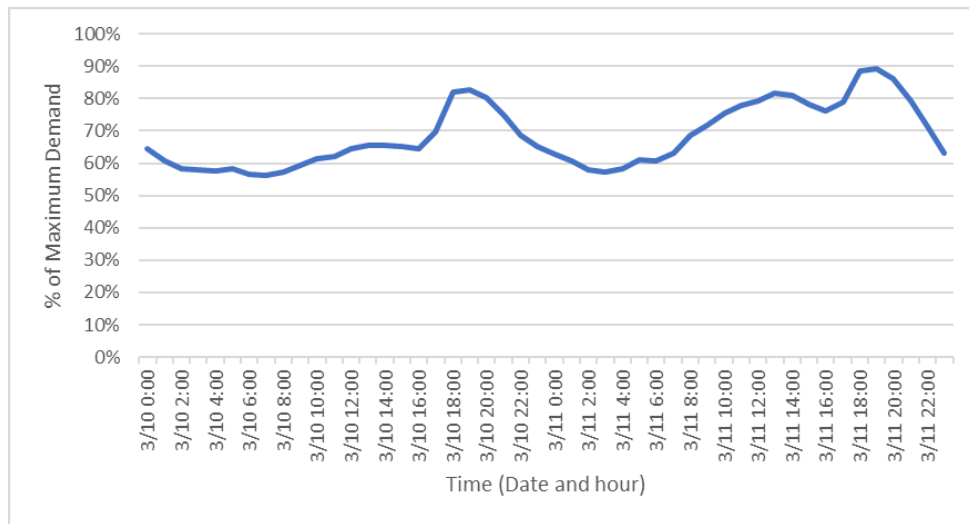


Figure 3-2 The hourly pattern of Kalimantan Island electricity demand use in this Study

Electricity Distribution and Transmission Line

The electric power system in East Kalimantan province is supplied by the 150 kV interconnection system which connects 3 provinces, namely Central, South, and East Kalimantan provinces. The Kalimantan grid connection line is presented in Figure 3-3.

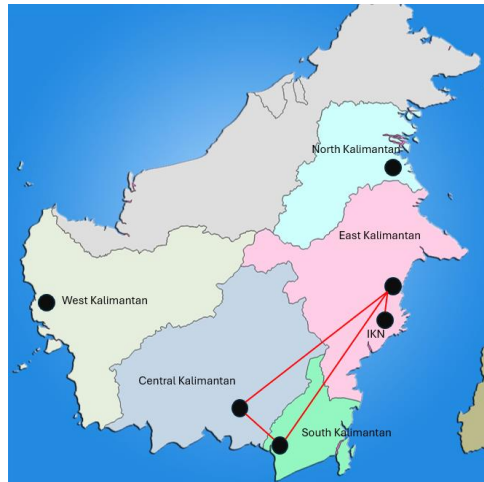


Figure 3-3 Simplified current interconnection of Kalimantan power system. Red lines represent the transmission lines and Black dots represent the capital city of the province.

Connecting this large system allows the previously excess power supply in East Kalimantan to be delivered to the South and Central Kalimantan systems, thereby reducing electricity production costs across the region. This system was planned to be interconnected with the North and West Kalimantan systems in 2022 to form a unified Kalimantan electricity interconnection system (PLN, 2021). However, this connection has not yet been completed.

Penajam Paser Utara Regency and Kutai Kartanegara Regency, the location of the new capital city (IKN), currently receive their electricity supply from the Mahakam system (PLN, 2021). To meet the future energy demands of IKN, the construction of a new substation and the extension of transmission and distribution lines will be necessary.

In West Kalimantan, the electricity system operates independently from other provinces. It comprises a 150 kV transmission line and several isolated systems within the region. This system is linked to Sarawak city in Malaysia via a 275 kV transmission line. This connection has led to a decrease in electricity production costs by reducing reliance on oil-based power plants and improving the stability of the electricity supply in West Kalimantan.

On the other hand, the electricity system in North Kalimantan faces challenges with connectivity. It consists mainly of isolated areas where electricity is primarily generated by Diesel Engine Power Plants and distributed to the consumer through 20 kV distribution line. This setup results in higher production costs for electricity in North Kalimantan compared to other provinces in the region.

To summarize, Kalimantan Island currently operates three distinct electricity systems: the Kalseltengtim System (connecting East, Central, and South Kalimantan), the Khatulistiwa System (linking West Kalimantan to Sarawak, Malaysia), and the North Kalimantan System. In the future, plans are underway to connect these three systems using 150 kV transmission lines (PLN, 2021). This integration aims to reduce production costs across the entire island and enhance the overall reliability of the electricity supply.

Electricity Generator

The current system is mostly supplied from several types of power plants, namely Coal Fired Power Plant, Combine Cycle Power Plant, Natural Gas, Diesel Engine Power Plant. The renewable energy supply system is small hydroelectric power plants with a total capacity of 32 MW located in West and South Kalimantan (PLN, 2021). All These Power Plants in the system are owned by PLN and IPP as well as rental machines and excess power. Rental machines are power plants, generally diesel power plants, which are rented by PLN from other parties to electrify areas that are not connected to the main grid. On the other hand, Excess power is the electrical energy excess from a power plant owned by another party that can be purchased by PLN (PLN, 2021). The current electricity generator in Kalimantan Island is shown in Table 3-2.

Table 3-2 Current Electricity Generator in Kalimantan Island (PLN, 2023)

Province	Power Capacity (MW)					
	Coal	Open Cycle Gas Turbine (OCGT)	Combine Cycle Gas Turbine (CCGT)	Diesel	Hydro power	Solar PV
West Kalimantan	436	100	0	229.3	1.8	0.2
Central Kalimantan	433.1	312.7	0	181.7	0	0
South Kalimantan	571	21	0	118.5	30	0
East Kalimantan	987.1	367.1	89.6	237.1	0	0
North Kalimantan	22	157.9	8.9	163.5	0	0

3.2.2. Stakeholder

National Level

According to Suroso et. Al. (2021), there are 4 groups of stakeholders in the energy industry in Indonesia. The first group which is the most important set of stakeholders is the MoEMR followed by MoF, PLN, National Energy Council, international donors, foreign investors, MoNDP, MoEF, domestic investors, and RE developer associations. These stakeholders must be managed closely as they have important roles in making decisions in the national energy sector.

The Ministry of Energy and Mineral Resources (MoEMR) assumes a central role at the national level within the energy sector, surpassing other coordinating and technical ministries. MoEMR possesses the authority to formulate and implement energy policies and programs. This mandate is crucial for aligning the implementation of energy strategies with the overarching target outlined in the National Energy Policy (KEN) and National Generation Energy Plan (RUEN), both nationally and locally (Islami & Aditya, 2020).

Following initiatives of MoEMR, the MoNDP hold a vital role in integrating energy programs from MoEMR into the National Medium Term Development Plan (RPJMN) (PwC Indonesia, 2023).

Without the involvement of MoNDP, these energy initiatives would fail to materialize into actionable plans on both national and local scales (Islami & Aditya, 2020).

The Ministry of Finance (MoF) and PT. PLN play crucial roles in the energy sector. The approval from MoF is essential for allocating budgets to the RPJMN, which encompasses energy programs. Without this approval, these programs would lack sufficient funding (PwC Indonesia, 2023). Moreover, MoF also provides incentives within the energy sector.

As for PT. PLN, it has a role as the primary player in the electricity sector, holding exclusive authority over energy transmission, distribution, and supply. This pivotal role ensures the reliability and accessibility of energy resources (Islami & Aditya, 2020).

The second group of stakeholders holds some influence but generally has a low interest in engagement. Thus, it's crucial to manage their involvement to maintain their satisfaction. This group includes entities such as Ministry of State-Owned Enterprises (MoSOE), Ministry of Industry (MoI), Coordinating Ministry for Maritime and Investment Affairs (CMMIA), Ministry of Trade (MoT), Ministry of Foreign Affairs (MoFA), Ministry of Research and Technology (MoRT), Coordinating Ministry of Economic Affairs (CMEA), Ministry of Agriculture (MoA), Ministry of Public Works and Housing (MoPWH), and funding managers. Regular updates on the progress of the national energy industry are essential for these stakeholders, as their input is valuable.

The third group of stakeholders needs to stay informed about the engagement, but excessive focus on satisfying their interests isn't necessary as they primarily represent the customer base of the electricity industry. This group includes Independent Power Producers (IPPs) and advisory institutions. The fourth group of stakeholders needs to be monitored but with minimum effort. Furthermore, the stakeholder map in the energy sector is depicted in appendix F.

Regional Level

Regional Governments, through their authority, are expected to provide more optimal support in efforts to achieve national development targets in the energy sector, particularly in the development of new renewable energy to support the acceleration of transition in Indonesia. In general, the role of regional government in the development of renewable energy in Indonesia is presented in Figure 3-4.

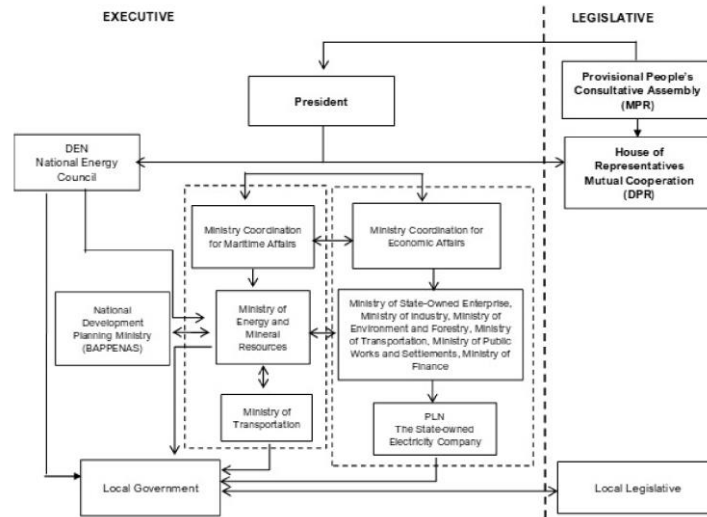


Figure 3-4 Local Government role in Indonesia energy sector stakeholder map (Islami & Aditya, 2020)

Currently, Regional Energy Plans (RUED) have been developed in 34 out of 37 provinces in Indonesia. RUED is a provincial government policy regarding energy management plans at the provincial level, which is a detailed elaboration and implementation plan of the National General Energy Plan (RUEN), which is a cross-sectoral plan to achieve RUEN goal. Even though it is situated in East Kalimantan, IKN has its regional energy planning based on Presidential Regulation No. 63/2022. The energy planning is prepared by the Authority of IKN (OIKN).

OIKN is a ministerial-level agency working directly under the President. Established in March 2022, the Authority is in charge of planning and constructing Indonesia's new capital, Nusantara, as well as overseeing the government's transition to the new city and eventually becoming its administration.

According to Presidential Regulation No. 63/2022, The Head of the IKN Authority has a position at the same level as ministers who will be appointed, appointed, and dismissed by the President after consulting and negotiating with the National Representative Council (DPR). Based on the IKN Law, the head of the authority will be directly responsible to the president, just like the ministers.

Local communities play a vital role as stakeholders in the development of IKN. According to Law No. 3/2022, one of the key indicators of successful development is the level of inclusivity, which underscores the importance of involving local communities as primary contributors to the development process.

In terms of development, OIKN has not directly engaged in any construction activities, as everything is still centralized within the ministry or the central government. It is handled by the ministries and specific institutions. Consequently, development by OIKN will commence once the national capital has been completely relocated (Agustina, 2024).

Therefore, the primary factor influencing the development of renewable energy in IKN is the involvement and support of the National government. The national government plays a crucial role in setting policies, providing funding, and creating a favorable regulatory environment that promotes renewable energy initiatives. On the other hand, the regional authorities mainly contribute during the implementation phase of these projects. Their responsibilities include facilitating land permits, ensuring compliance with local regulations, and engaging with local communities to address their concerns and foster cooperation during the construction phase.

3.2.3. Regulatory Framework

National Level

The Energy Law no 30/2007 is Indonesia's legal framework for the energy sector. It outlines key goals, including achieving energy independence, ensuring the availability of energy sources, optimizing, integrating, and sustaining energy resource management, promoting efficient energy use, facilitating public access to energy, enhancing industry capacity and domestic energy services for greater self-reliance, generating employment opportunities, and safeguarding environmental sustainability.

These laws guide the creation of the National Energy Plan (KEN), a strategic roadmap spanning 2010 to 2050, which outlines the country's energy objectives. Further specifying these objectives, the National Energy Plan (RUEN), formed under Government Regulation No. 22/2017, provides a detailed direction for energy management in Indonesia. It regulated the nation's energy vision, strategies for reducing greenhouse gas emissions, ensuring energy availability, prioritizing energy development, optimizing energy use, and securing energy reserves (Islami & Aditya, 2020). According to RUEN, Indonesia aims to achieve at least 23% renewable energy in its electricity system.

Building upon the RUEN, the National Electricity Plan (RUKN) is developed, ensuring alignment with national energy strategies. Additionally, the RUEN mandates Provincial Governments to draft Regional Energy Plans (RUED), which define provincial energy targets, including renewable energy integration by 2025 and 2050.

The RUKN primarily addresses electricity supply in Indonesia. It provided a roadmap for electricity generation, distribution, and transmission. Additionally, it requires provincial governments to formulate their Local Regional Electricity Plans (RUKD). Moreover, the RUKN is a basis for the development of PLN's Electricity Provision Plan (RUPTL), outlining PLN's strategies for electricity distribution, transmission, and generation.

The main regulations on the energy sector in general is depicted in Figure 3-5 and the general content of the regulation is shown in Appendix G.

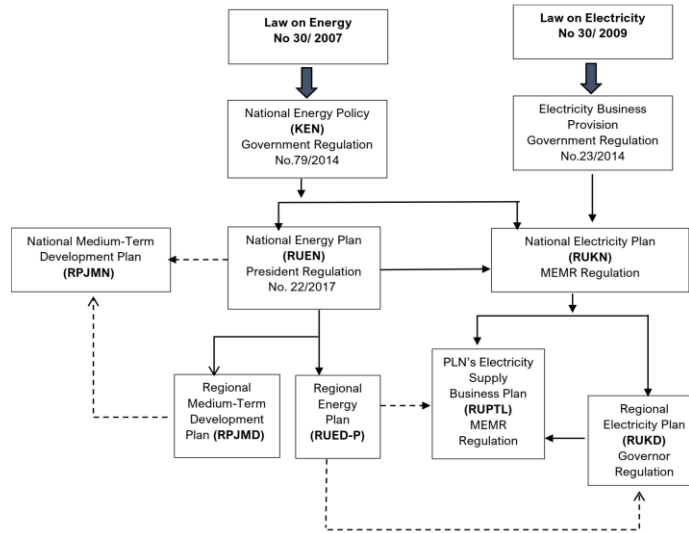


Figure 3-5 Energy legal Framework in Indonesia (Islami & Aditya, 2020)

Regional Level

As per Indonesia's Law No. 3/2022 and Presidential Decree 63/2022, it is mandated that IKN transitions to 100% renewable electricity and achieves net zero emissions by 2045. These legal directives emphasize the urgency of renewable energy adoption and emissions reduction.

Furthermore, Law 3/2022 outlines Key Performance Indicators (KPIs) for IKN, encompassing 8 themes with a total of 24 targets. Among these themes, the "Low Carbon Emissions" theme is particularly pertinent to the energy sector. This theme includes specific targets, such as achieving 100 percent renewable energy capacity to fulfill all of IKN's energy requirements.

3.3. Renewable Energy Potential

Biomass, hydropower, Pumped Hydro, onshore wind, solar energy, and OTEC are identified as promising renewable energy sources on Kalimantan Island. In the model, the maximum installable capacity of each type of renewable energy technology is limited by the power capacity potential per region as described in Table 3-3.

Table 3-3 Renewable Energy Potential Capacity in Kalimantan Island

Technology	Potential Power Capacity (MW)					Reference
	West kalimantan	Central kalimantan	South Kalimantan	East kalimantan	North kalimantan	
Biomass	1,280	1,487	1,266	473	473	RUEN (2017)

Large Hydro (>30 MW)	4,737	5,165	5,165	5,615	21,580	RUEN (2017)
Small Hydro (1 MW – 30)	4,762	5,512	238	8,586	13,405	Langer et al. (2023)
Onshore Wind	43	8	263	5	-	Langer et al. (2023)
Onshore PV	1,439,383	596,694	258,486	1,530,767	173,990	Langer et al. (2023)
Floating Solar PV	5,552,080	3,775,502	3,419,206	1,183,908	231,264	Maghdavi (2023)
OTEC	-	-	1,088	6,936	680	Langer et al. (2022)
Pumped Hydro	388,944	285,048	55,611	729,603	336,330	Stocks et al. (2021)

Geothermal energy is not considered in the model because confirmed geothermal reserves have not yet been discovered in Kalimantan, as stated by Ahluriza et al. (2021). Kalimantan possesses one of the lowest geothermal energy potentials in Indonesia, with speculative geothermal resources estimated at 151 MW and possible geothermal reserves at 13 MW (Hilman, 2021).

Offshore wind energy is not considered promising on Kalimantan Island. According to Langer et al. (2022), regions where the Levelized Cost of Electricity (LCOE) falls below 20 cents per kilowatt-hour (kWh) for a 2.1 MW-d114 offshore wind turbine, are limited to Papua, Maluku, and the southern part of Kalimantan. Moreover, when considering the local electricity tariffs, only offshore wind farms in Papua, West Papua, and Maluku are economically viable.

3.3.1. Hydropower

Indonesia boasts substantial hydropower potential, attributed to its consistently high rainfall levels year-round. The Energy and Mineral Resources Ministry (ESDM) approximates the country's overall hydropower capacity at 75,091 MW for more than 800 rivers (Hasan et al., 2012). However, only 5.8 GW has been harnessed.

Breaking it down regionally, West Kalimantan alone holds a potential of 4,737 MW, while the combined potential in East Kalimantan, Central Kalimantan, and South Kalimantan is estimated at 16,844 MW (ESDM, 2020). Furthermore, North Kalimantan possesses significant hydropower potential, estimated at 21,580 MW. This observation is consistent with findings by Hoes et al., (2017), who identified North Kalimantan as the region with the highest hydropower potential on Kalimantan Island. The derivation of datasets and the hourly profile of hydropower energy used in the model is shown in Appendix C.

This study categorizes hydropower into two classes which are small and large hydropower plants. The Large hydropower plants have outputs above 30 MW and use the energy in falling water from the reservoir to produce electricity (Indonesian-Danish Energy Partnership Programme (INDODEPP), 2024). They are utilized in this research not only as energy producers

but also as energy storage facilities, leveraging their capacity to store water's energy potential in dams. In this study, the potential of Large Hydro is obtained from RUEN. The ratio between the energy and storage capacity of the large hydropower plants used in this study is 0.15. This means that the reservoir can deliver rated power for 6.67 hours.

Meanwhile, small hydropower plants are run-of-river schemes that have output from 1 MW to 30 MW (Indonesian-Danish Energy Partnership Programme (INDODEPP), 2024). In this study, the potential of small hydro is being analyzed based on research by Hoes et al. (2017) and constrained to being situated more than 15 km from the coastline and outside protected or natural disaster-prone areas.

3.3.2. Solar Energy

In Kalimantan, East Kalimantan has the largest potential for utility solar PV power capacity which is 1,530 GWp. It is followed by West Kalimantan (1,439 GWp), Central Kalimantan (596 GWp), South Kalimantan (258 GWp), and North Kalimantan (174 GWp) (Langer, 2023). This potential data already accounts for various constraints, including outside of water bodies, built-up infrastructure, agricultural land, forests, as well as protected and natural-catastrophe prone areas. This potential data is much higher than the potential estimated by MoEMR.

As outlined in Table 3-3, Kalimantan Island demonstrates a greater potential for offshore solar PV compared to utility-scale solar PV. Technically feasible sites were identified by selecting locations outside marine protected areas, avoiding disaster-prone zones and major shipping routes, and ensuring water depths exceeded 55 meters. The technical potential for each province was calculated by applying a capacity density of 110 MWp per square kilometer to the suitable areas (Langer et al., 2023). Furthermore, the consideration of the technical potential, derivation of datasets, and the hourly profile of the solar energy used in the model is shown in Appendix C.

3.3.3. Wind Energy

Only a small amount of wind energy can be developed on Kalimantan Island. South Kalimantan has the highest potential for onshore wind energy, with 263 MW. This is followed by West Kalimantan with 43 MW, Central Kalimantan with 8 MW, and East Kalimantan with 5 MW. In contrast, North Kalimantan has no potential for either onshore or offshore wind energy (Langer et al., 2023). The consideration of this potential capacity, including the derivation of datasets and the hourly profile of wind energy used in this research, is detailed in Appendix C.

The low wind energy capacity in Indonesia is due to its location near the equator, where warm air and low pressure result in less wind compared to countries in the northern and southern hemispheres. The average annual wind speed in Indonesia is only 4.9 m/s, while in the Netherlands, a representative country in the northern hemisphere, it is 8.8 m/s according to the

Global Wind Atlas. These conditions limit the potential for wind power in equatorial regions (IESR, 2021).

3.3.4. Biomass

Central Kalimantan boasts the highest potential at 1,487 MW, with West Kalimantan and South Kalimantan following closely at 1,280 MW and 1,266 MW respectively, as indicated by RUEN (2017). Biomass considered in RUEN is agricultural waste which consists of palm oil, sugar cane, rubber, coconut, rice, corn, cassava, and wood. This estimate assumes that the biomass power plant will operate as a baseload facility, running continuously 24 hours a day, similar to how a coal-fired power plant operates.

3.3.5. OTEC

Ocean Thermal Energy Conversion (OTEC) is a form of clean marine renewable energy that generates electricity by utilizing the temperature difference between the warm surface water and the cold deep ocean water. Since Indonesia is an equatorial nation situated within latitudes less than 20 degrees and is surrounded by 77% ocean, with numerous islands, straits, and varied topography, it is highly suitable for implementing OTEC systems (Koto, 2016). According to Langer et al., (2022), the technical potential for OTEC is present in South, East, and North Kalimantan, while it is nonexistent in West and Central Kalimantan.

3.3.6. Energy Storage

In this study, two storage options are considered: batteries and closed loop pumped hydroelectric energy storage (referred to as pumped hydro hereafter), alongside the reservoirs of large hydroelectric projects (Langer et al., 2024). While battery storage is not constrained by location or storage capacity, the maximum installable capacity of pumped hydro is limited to areas outside of nature conservation zones, utilizing the global pumped hydro dataset provided by Stocks et al (2021).

Battery storage and pumped hydro have assumed round-trip efficiencies of 92.0% and 75.7% (National Energy Agency, 2021), storage losses of 0.96% per day (National Energy Agency, 2021), and 0% (Lombardi et al., 2020), and lifetimes of 30 and 50 years (National Energy Agency, 2021), respectively. The large hydro reservoirs are assumed to have the same storage efficiencies as pumped hydro.

3.3.7. Nuclear

According to Government Regulation No. 79 year 2014 related to the National Energy Strategy (KEN) and Presidential Regulation No. 22/2017 of 2017 regarding The National Energy General

Plan (RUEN), the use of nuclear energy in Indonesia will be considered after the use of new energy sources and renewable energy has been maximized. The use of nuclear energy should be the last option with Considering the large potential of renewable energy in Indonesia.

In KEN and RUEN, it is stated that nuclear energy is utilized by considering the security of national energy supplies on a large scale, reducing carbon emissions, and still prioritizing the potential for new and renewable energy by its economic value, as well as considering it as a last option with strict attention to safety factors.

3.4. Desired Future Electricity System

3.4.1. Future Electricity Demand

The demand projection in Kalimantan Island used in this study is shown in Table 3-4.

*Table 3-4 Electricity Demand Projection of Kalimantan Island.
West, south, central East and North Kalimantan refer to PLN (2021) and IKN refer to Pribadi (2023)*

Province	Peak Energy Demand Growth Projection/ year	Peak Power Demand (MW)				
		2021	2030	2035	2040	2045
West Kalimantan	6%	586	1,000	1,345	1,808	2,431
South Kalimantan	6%	607	1,029	1,346	1,810	2,433
Central Kalimantan	6%	310	507	669	883	1,165
East Kalimantan	9%	490	748	1,151	1,771	2,725
North Kalimantan	12%	97	283	497	871	1,529
IKN		134	252	427	607	792

IKN demand projections are given for future years according to Pribadi (2023). Starting at 134 MW in 2021, IKN's peak power demand is expected to reach 792 MW by 2045. This significant growth is driven by the infrastructural and residential developments tied to its role as the new capital. Sunarharum (2022) estimates that IKN will have a population of 1.7 to 1.9 million by 2045.

Additionally, electric vehicles are expected to dominate mobility by 2040. By 2045, natural gas will be primarily used for limited household needs, such as cooking (Widiaryanto et al., 2023). The demand nearly doubles between each interval until 2035, after which the growth rate moderates slightly but remains substantial. This pattern suggests that the initial phases of IKN's development (2021–2035) will be especially energy-intensive.

3.4.2. Future Generation System

3.4.2.1. Least-Cost Renewable Energy Technology

The results indicate that by 2045, IKN can be powered by a combination of large hydropower and Utility-Scale solar PV power plants. The hydropower capacity is projected to be 791 MW, while the solar PV capacity is expected to be 870 MW. With this capacity mix, IKN will be self-sufficient and will not require energy imports from other regions. The feasibility of this renewable energy combination will be discussed more in Chapter 5. The result of the simulation is in line with PLN's plan to electrify the IKN with the combination of Hydropower plants and Solar PV (Trianto, 2023).

Figure 3-6 illustrates the projected electricity system for IKN from 2030 to 2045, showing the capacities of hydropower, Utility solar PV, and power from transmission lines. The chart shows a transition over time towards greater self-sufficiency in IKN's electricity system, with a significant shift from reliance on power from transmission lines in 2030 to a robust combination of hydropower and solar PV by 2045. This progression highlights a strategic increase in renewable energy capacities, particularly solar PV, to meet the growing energy demands sustainably.

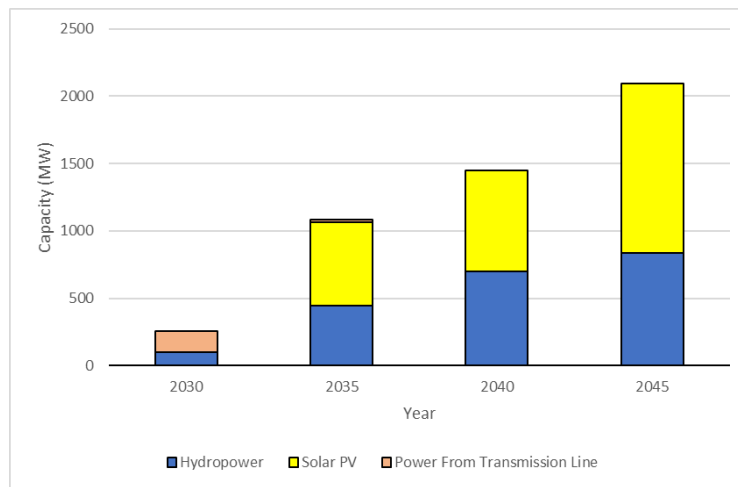


Figure 3-6 Projected Renewable Electricity Capacity in IKN for the years 2030, 2035, 2040 and 2045

Table 3-5 The projected electricity system in IKN by 2030, 2035, 2040, and 2045

Technology	2030		2035		2040		2045	
	Power Capacity (MW)	Energy (GWh)	Power Capacity (MW)	Energy (GWh)	Power Capacity (MW)	Energy (GWh)	Power Capacity (MW)	Energy (GWh)
Transmission Line								
- Absorb	112	896	9	2	0	0	0	0
- Delivery		0		14		0		0

Large Hydro Power Plant	143	693	418	2,030	605	2,947	792	3,841
Utility Solar PV	0		510	673	676	886	870	1,149
Demand	252	1,589	427	2,691	606	3,833	792	4,991

By 2030, the electricity system for IKN will primarily depend on power transmitted from East Kalimantan, absorbing 896 GWh. Hydropower contributes 693 GWh, while no solar PV is installed in the system. This distribution indicates that most of IKN’s energy needs are met through external sources, with renewable energy playing a relatively minor role. According to Rohmah (2023), the current power system in East Kalimantan has a surplus of 400 MW. As a result, the existing power plants will be sufficient to meet the demand through 2030. Table 3-5 represent the projected electricity system in IKN by the year 2030, 2035, 2040, and 2045.

By 2035, there will be a significant shift in the energy mix. The transmission line absorption capacity decreases significantly from 112 MW in 2030 to just 9 MW in 2035, with a corresponding drop in energy absorbed from 896 GWh to 2 GWh. In 2035, IKN not only absorb the electricity but also deliver it to east Kalimantan through transmission line. This happens during the day when solar PV produces more electricity than the demand.

Hydropower capacity increases to 418 MW and solar PV capacity surges to 510 MW. Concurrently, reliance on power from transmission lines drops dramatically to 8.6 MW. This marks a substantial move towards renewable energy sources, reducing dependency on external power. In 2040, the trend toward self-sufficiency continues. Hydropower capacity grows to 605 MW, and solar PV capacity reaches 676 MW. Notably, there is no longer any reliance on power from transmission lines, indicating a complete transition to locally generated renewable energy.

By 2045, the energy system will see further enhancements, with hydropower capacity at 792 MW and solar PV capacity at 870 MW. Solar PV has become the dominant energy source, reinforcing the city's commitment to renewable energy. The elimination of power from transmission lines underscores the region's ability to meet its electricity demands.

Table 3-6 outlines the strategic plan for increasing renewable energy capacity and the projected CAPEX required for hydropower and solar PV over five-year periods in 2030, 2035, 2040, and 2045 to meet future energy demands. The peak CAPEX for the development occurs in 2035, with a total of 777 million \$ allocated for hydropower and solar PV installations, indicating a significant push for renewable energy development that year. While investment levels decrease in the following years, they remain substantial and impactful.

Table 3-6 Projected Power Plant Installation and Investment Cost for IKN from 2030 to 2045

Technology	2030		2035		2040		2045	
	Capacity (MW)	Capex (Mil \$)	Additional Capacity (MW)	Capex (Mil \$)	Additional Capacity (MW)	Capex (Mil \$)	Additional Capacity (MW)	Capex (Mil \$)
Large Hydropower	143	280	276	531	187	354	186	346

Plant								
Utility Solar PV	0	0	510	246	166	74	194	79

Table 3-7 presents the Levelized Cost of Electricity (LCOE) in cents \$ per kilowatt-hour (kWh) for large hydropower plants, solar photovoltaic (PV), and the overall Kalimantan electricity system for the years 2030, 2035, 2040, and 2045. The system refers to the entire Kalimantan Island, as the simulation is conducted for the whole island. LCOE is a measure of the average cost per unit of electricity generated, accounting for the total cost of building and operating a power plant over its assumed lifetime.

Both large hydropower plants and solar PV installations experience a reduction in the LCOE over time, reflecting decreases in investment and operational costs. Additionally, the LCOE for hydropower and solar PV remains consistently lower than that of fossil fuel power plants. For example, based on 2030 cost assumptions, the LCOE for coal, diesel, open cycle gas turbine, and combined cycle gas turbine power plants is 5.44 cents \$ per kWh, 40.75 cents \$ per kWh, 14.35 cents \$ per kWh, and 9.87 cents \$ per kWh, respectively. These values are all higher than the LCOE for both hydropower and solar PV.

Table 3-7 Projected Levelized Cost of Electricity (LCOE) in IKN from 2030 to 2045

LCOE of Technology	Year			
	2030	2035	2040	2045
Large Hydropower Plant (cent \$/kWh)	5.11	4.98	4.86	4.75
Solar PV (cent \$/kWh)	4.31	4.09	3.83	3.51
LCOE of the System (cent \$/kWh)	6.46	5.43	4.94	4.57

3.4.2.2. Diversification of Renewable Energy Technology

To explore the impact of using different renewable energy sources, a simulation was conducted. In this scenario, the hydropower and solar PV capacity in the base scenario (least-cost) was reduced by 10%, 25%, and 50%. The simulation results are shown in Figure 3-7.

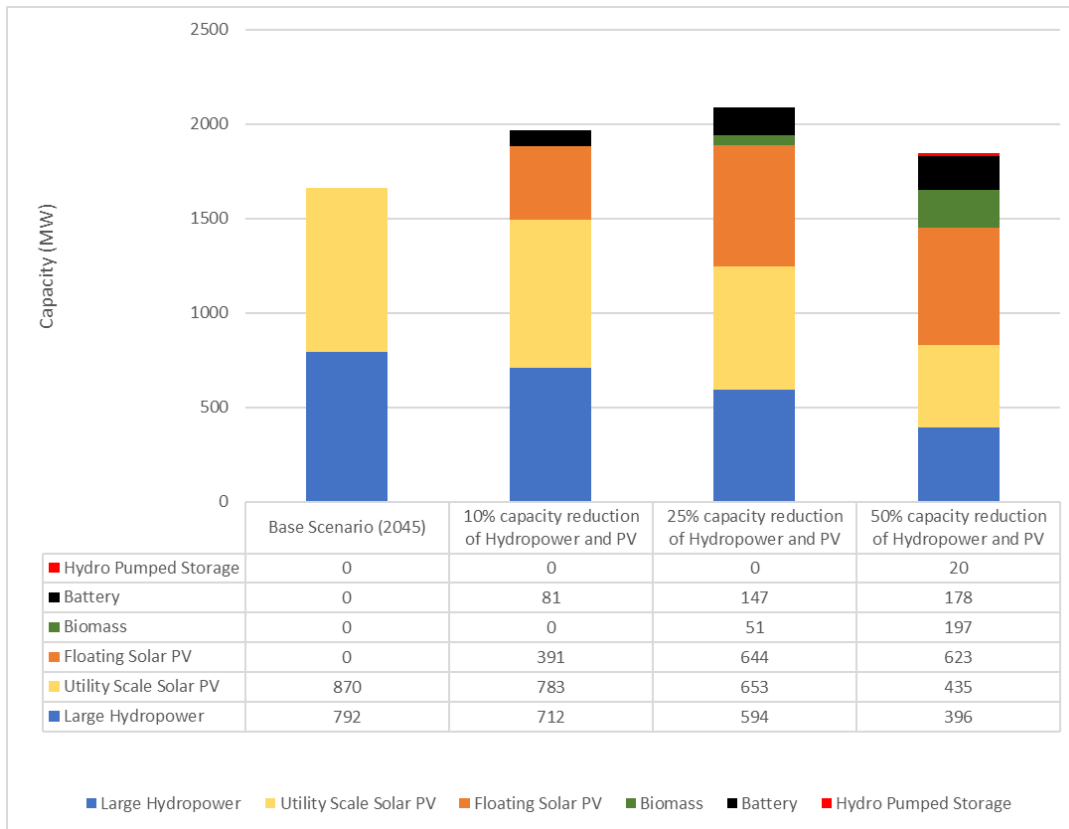


Figure 3-7 The scenario of Renewable Energy Diversification in IKN in 2045 involves reducing the capacity of hydropower and solar PV by 10%, 25%, and 50%.

As the capacity of large hydropower and utility-scale solar PV is reduced, these technologies are gradually replaced by other forms of renewable energy to fill the gap. This shift leads to a diversification of the energy system, incorporating more floating solar PV, biomass, and battery storage. This diversification helps maintain a stable energy supply despite the reduction in hydropower and solar PV renewable sources.

Solar PV systems, whether ground-mounted or floating, can experience varying levels of solar resource potential based on factors such as sunlight intensity, angle of incidence, and seasonal changes. Diversifying the locations of these systems helps optimize solar resource utilization, maximizing overall energy production and enhancing the reliability of the energy supply.

However, this transition has a cost impact. The reduction in hydropower and solar PV capacity leads to an increase in the overall cost of the system. This indicates that large hydropower and utility-scale solar PV are currently more cost-effective compared to the alternative technologies being introduced.

The LCOE of the system in 2045 will increase with the reduction in hydropower and solar PV capacity. It starts at 4.57 cents \$/kWh in the base scenario and progressively rises to 4.67, 4.87, and 5.35 cents \$/kWh as the reduction levels reach 10%, 25%, and 50%, respectively. This increase in LCOE underscores the current cost-effectiveness of hydropower and solar PV compared to the newer renewable energy technologies being integrated into the system

Battery storage and biomass become increasingly significant as traditional sources are reduced. Their growing contribution highlights their potential role in a diversified renewable energy mix. Batteries take over the storage role that large hydropower used to provide, while biomass steps in to provide steady, reliable power. Based on these findings, the Indonesian government could consider biomass as a renewable energy option to help meet the electricity demand in IKN. However, some challenges need to be addressed, which will be discussed further in Chapter 5.

The objective of this research is to identify the most cost-effective renewable technology for electrifying IKN. Therefore, the least-cost renewable energy technology scenario is used for further analysis. The next chapter will discuss the policies and actions necessary to develop this scenario. This will include an analysis of the drivers and barriers, as well as recommendations for overcoming these barriers.

4. DEVELOPING THE STRATEGIES

4.1. Driver and Barrier Analysis Using PESTEL

4.1.1. Political

Driver

Indonesia's Law No. 3/2022 and Presidential Decree 63/2022 mandated that IKN is electrified by 100% renewable electricity and achieves net zero emissions by 2045. This Government commitment is important for the country as it seeks to reduce its reliance on fossil fuels and transition towards cleaner energy alternatives (Guild, 2019).

Another driver for developing renewable electricity in IKN is to enhance energy security. According to Aisyah and Hardiyati (2019), diversifying energy sources by incorporating more renewables, such as geothermal, hydropower, solar energy, and bioenergy, can reduce dependence on imported fossil fuels and strengthen Indonesia's energy independence.

Additionally, the Indonesian government has been actively encouraging research in sustainable energy by offering incentives and promoting related studies. The number of international publications on energy in Indonesia is rising, with most being collaborative research with institutions from other countries (Aisyah & Hardiyati, 2019). This support creates a conducive environment for innovation in renewable energy projects, which drives the sector's growth.

Moreover, PLN has introduced a new Renewable Energy Certificate (REC) service aimed at promoting environmental sustainability. The REC serves as a green energy certification that enables customers to verify their electricity consumption from renewable sources. This innovative product allows customers to receive recognition for using internationally recognized renewable energy. Launched in 2020, the REC service was developed to address the increasing demand for green electricity. The sales of RECs experienced a significant growth of 101% in 2023, and from its inception until the end of 2023, PLN's total REC sales have exceeded 5 TWh (Laoli, 2024).

Barrier

Policy uncertainty is one of the significant barriers to renewable energy development in Indonesia. Frequent policy changes, regulatory delays, and inconsistent implementation of government policies by PLN undermine investor confidence by increasing project development risks and delaying the financial closure of bankable projects (Udemba & Philip, 2021).

Moreover, inconsistent or ambiguous policies related to renewable energy targets, incentives, and regulations create uncertainty for investors and industry stakeholders, leading to hesitancy in committing to long-term renewable energy projects. Many relevant documents outline varying renewable energy (RE) targets for the power sector. For example,

the National Energy Policy (KEN) sets a target of 45.2 GW in 2025, while the General Plan for National Electricity (RUKN) aims for 31.72 GW of installed RE capacity by 2025. These discrepancies make the RE target clauses in these documents insufficiently robust to serve as a reliable reference (IESR, 2024).

Additionally, substantial fossil fuel subsidies pose a challenge to the growth of renewable energy in Indonesia (Maulidia, 2019). These subsidies create market distortions by artificially lowering the cost of fossil fuels, making them more competitive compared to renewable energy sources.

For instance, the Domestic Market Obligation (DMO), which imposes a tariff cap on coal sold domestically for coal-fired power plants, acts as a subsidy that makes it more difficult for renewable energy to compete with existing coal power plant as the lowest-cost power generation option (PWC Indonesia, 2023). Since this is an existing coal power plant, the cost of electricity production is calculated based on fuel expenses and operations and maintenance (O&M) costs. Consequently, new renewable energy projects may face economic challenges, making it harder for them to compete and gain widespread adoption and investment in the system.

Another challenge in the political sector that hampers renewable energy development in Indonesia is the lack of institutional competence (Maulidia, 2019). There is often insufficient analysis of the impacts of new policies and regulations before they are implemented. Consequently, policies are frequently introduced to address immediate concerns without considering long-term effects or the need for a unified strategy across ministries (ADB, 2020).

Renewable energy development in Indonesia is governed by a wide array of policies and regulations across various government agencies. However, interministerial coordination is weak (ADB, 2020). Inadequate institutional capabilities to coordinate among government agencies can impede the design and execution of effective renewable energy strategies, slowing down progress in the sector.

Another factor impeding renewable energy development in Indonesia is the slow progress in land access, government approval processes, and tariff negotiations with PLN, as highlighted by Burke et al., (2019). Additionally, the unclear procurement mechanism for renewable energy power plant projects has been consistently identified as a significant barrier to the development of the sector in Indonesia (PWC Indonesia, 2023).

Furthermore, Presidential Regulation No. 44/2016, known as the “negative investment list,” specifies the maximum allowable foreign investment in various projects (ADB, 2020). For power generation projects, including renewable energy, foreign investment is prohibited for projects under 1 MW, and foreign ownership is limited to 49% of total company ownership for projects between 1 to 10 MW. This restriction increases the average total cost (ATC) of power generation and reduces investment competitiveness in the renewable energy sector (Purba, 2022). Limiting foreign investment to a minority interest in 1 to 10 MW projects discourages participation from sophisticated foreign developers who have access to additional financing sources and better understand risk mitigation. Consequently, a primary

challenge in developing these projects is not securing financing but adequately preparing projects to attract investment (ADB, 2022).

Lastly, the implementation of the Local Content Requirement (LCR) policy, as outlined in Regulation No. 3/2023 issued by the Ministry of Industry, could also impede renewable energy development in IKN. This regulation mandates that at least 40% of the materials used in solar PV projects must be sourced locally. This requirement can increase production costs due to limited local manufacturing capacity and may also lower the availability of high-quality modules (IESR, 2022).

4.1.2. Economy

Driver

Increasing economic growth in IKN will drive the demand for renewable electricity in the future. As per findings (Purnomo et al., 2023), economic growth in Indonesia from 1990 to 2019 was highly affected by electricity consumption. Additionally, presidential regulation mandates the use of electric vehicles in the new capital city and also, indicates that electricity consumption will rise in the future. Additionally, The Ministry of Energy and Mineral Resources is also encouraging the public to transition from gas to electric stoves to achieve a 17% increase in energy efficiency by 2025 (Purnomo et al., 2023).

Furthermore, increasing the share of renewable energy in the system will not only lower greenhouse gas emissions but also contribute to sustainable economic growth (JETP Indonesia, 2023) and have significant implications for future economic performance in IKN. At present, Indonesia relies heavily on fossil fuels to sustain its economic activities, a dependence that conflicts with the declining trend in fossil fuel production over the past decades (Setiyono, 2023)

Another point to consider as a driver for hydropower and solar PV development in IKN is that large hydropower and solar power plants create 3.8 times and 2.5 times more jobs per GWh, respectively, compared to coal-fired power plants. Equally important, achieving the renewable energy target set for 2030 in the RUKN scenario could potentially add around US\$24 billion in value to the Indonesian economy (Global Green Growth Institute, 2020).

In the same vein, renewable energy has the advantage that it is not subject to global market price volatility like coal, oil, and gas (Singgih, 2018). The integration of renewable energy into the electricity market can stabilize prices, as these sources can provide a consistent supply of energy without the same price pressures faced by traditional energy sources.

Furthermore, the reduction in CAPEX for solar PV has become a significant driver for its development. In 2019, the capital costs of solar PV projects in Indonesia were much higher than those in India or Thailand, averaging above 1,000 \$/kWp. However, recent projects have seen a rapid decrease in capex for utility-scale solar, with average costs now around 800 \$/kWp. Notably, the Cirata Floating PV project has achieved costs of approximately 650 \$/kWp (IRENA, 2022).

Barriers

PLN's limited financial resources restrict its ability to build or upgrade facilities to improve service delivery. This constraint arises from its obligation to keep electricity affordable for consumers. In Indonesia, electricity tariffs are regulated by the government, and the difference between PLN's production costs and the set electricity tariffs is compensated through government subsidies. PLN's financial performance is highly reliant on government subsidies and compensations, which increased by 16.4%, from 123 trillion IDR in 2022 to 143 trillion IDR in 2023 (Yustika, 2024b). Consequently, PLN often prioritizes projects with lower initial costs, even if they result in higher long-term operational expenses, as this strategy helps manage overall costs (Damuri et al., 2023).

Lack of long-term financing options and low rates of return are also challenges for Renewable energy projects which often require long-term financing solutions due to their extended payback periods and operational lifetimes. However, traditional financing institutions may be more inclined towards short-term investments, making it challenging for renewable energy projects to secure the necessary funding. Without adequate funding, renewable energy initiatives may struggle to compete with traditional fossil fuel-based energy sources, which receive substantial government support and subsidies.

Additionally, renewable energy project developers are often more varied, with many being small and medium-sized enterprises. These developers frequently have limited financial resources and, occasionally, insufficient technical expertise, which can hinder their ability to produce high-quality documentation and develop projects. This, in turn, makes it challenging for them to secure the necessary permits, licenses, and financing (ADB, 2019).

Difficulties in getting financial investment from international institutions has been identified as a significant hindrance to realizing the vast potential of the renewable energy sector in IKN. International funding initiatives like the JETP hold promise for bringing in new investments, but proposals relying on government guarantee loans may face hesitation from the Ministry of Finance, as the government seeks to avoid further burdens on the state budget (Damuri, 2023). Moreover, the implementation of the LCR policy can restrict access to financing from international institutions.

4.1.3. Social

Driver

Concerning the development of IKN, the Governor remarked that the local community was very enthusiastic and excited about the project, as it does not disrupt the residents. The local government emphasized that, since the development is taking place in a non-residential area, there will be no negative impact on cultural traditions or the local populace (Muharam, 2021).

Additionally, the installation of the first utility-scale solar PV system with a capacity of 50 MW in the IKN area has not faced any opposition from the local community. However, the developer encounters challenge due to the Local Content Requirement (LCR) policy and the hilly geographical conditions (Rahayu, 2023). Public support for solar PV projects in Indonesia is growing. For example, a study by Jailani et al. (2020) found that 92.1% of people in North Sumatra supported a 100 MWp solar PV project, mainly due to the job opportunities and economic benefits it promised.

In terms of human resources, Indonesia has numerous qualified engineering, procurement, and construction contractors in the renewable energy sector. However, some local developers working on small projects (less than 10 MW) may lack a comprehensive understanding of project risks and development requirements. Nevertheless, this issue could be mitigated by permitting higher levels of foreign investment in small projects, thereby attracting experienced international developers to collaborate with local firms (ADB, 2020).

Barriers

In the context of energy transition, public enthusiasm tends to decline when the costs are high and renewable energy technologies, like electric vehicles, electric stoves, and rooftop solar panels, are not readily available in their local environment (KIC, 2022). Additionally, many Indonesians are hesitant to adopt these technologies because they are accustomed to using conventional fossil fuels such as coal, oil, and natural gas for economic activities (Setiyono, 2023).

Moreover, to successfully promote a shift to renewable energy, the government must meet consumers' expectations that electricity from renewable sources will be cheaper than their current electricity bills (C4C, 2021). This expectation presents a challenge for developing renewable energy in IKN, as the current electricity prices are considered low due to government subsidies.

In terms of the realization of the project, Large-scale renewable energy projects, such as hydropower, frequently encounter opposition from local communities, unlike solar PV projects. This resistance is often due to concerns about potential impacts on ecosystems and local livelihoods, including housing relocation, environmental damage, and disruptions to the water cycle. For example, during its initial phase, the Poso Hydropower project (515 MW) on Sulawesi Island was met with local resistance for these reasons (WALHI, 2022).

4.1.4. Technology

Driver

Kalimantan Island is rich in hydro and solar resources, offering high-potential sites for hydropower development to meet IKN's renewable electricity needs. According to PwC Indonesia (2023), Kalimantan Island presents significant opportunities for large-scale

hydropower projects. Additionally, Indonesia's tropical climate provides abundant solar energy, making solar power a highly advantageous option for the country (Rahmawati et al., 2018).

Moreover, both hydropower and solar PV have reached a mature stage of implementation, both nationally and globally. By the end of 2022, Indonesia had installed 6.7 GW of hydroelectric capacity (PwC Indonesia, 2023) and 0.3 GW of solar PV capacity (Agarwal et al., 2023). Research by Song et al. (2019) indicates that PV technology has significantly matured and grown, making it ready for widespread adoption. Kutlu et al. (2020) also emphasize the advanced state of photovoltaic (PV) cell technology, which efficiently converts solar energy into electricity with efficiency levels ranging from 8% to 25%.

The advanced technology, reliability, and efficiency of hydropower make it a suitable replacement for coal-fired power plants (CFPPs) in meeting the baseload electricity demands in IKN. Furthermore, examining the potential of combining hydropower with photovoltaic systems in Indonesia reveals the benefits of hybrid systems in enhancing energy production and sustainability (Aminuddin et al., 2022). This approach has already been successfully implemented at the Cirata Dam in West Java, where a 192 MWp floating solar PV system is in place, and Indonesia plans to expand this model to other areas with a target of up to 14 GW (Adi, 2024).

Barrier

Nevertheless, Hydropower plant development frequently encounters challenges, notably the long development duration, which complicates competition with non-renewable power plants. Hydropower projects typically take 6 to 7 years from construction commencement to commissioning, whereas coal-fired power plants of comparable capacity require only two years (Damuri, 2023).

Another factor that impedes the competitiveness of renewable energy projects against non-renewable power plants is the land requirement. For example, solar PV projects necessitate 14 m²/kWp space, which is over 100 times bigger than that needed for thermal power plants (IESR, 2023). In addition, land procurement tends to be lengthy with complicated processes, which may cause delays and financing problems (ADB, 2020).

Moreover, the current transmission infrastructure equipped with smart grid technology remains relatively limited (Damuri, 2023). Incorporating intermittent renewable power sources, such as solar energy, requires significant additional investments. These include building an Automatic Generation Control (AGC) system, implementing accurate generation forecasting tools, and establishing a smart grid. Due to these financial demands and the need to keep electricity affordable, PLN tends to avoid using intermittent energy sources (Damuri, 2023).

Additionally, efforts to strengthen transmission capability are hindered by the limited interest from the International Partner Group (IPG) of JETP in financing transmission infrastructure projects. Unlike power generation, where energy is sold to PLN to produce electricity, the profitability of transmission systems remains uncertain (Damuri, 2023).

4.1.5. Environmental

Driver

The development of renewable electricity in IKN will have a significant positive impact on the environment. It will reduce reliance on non-renewable energy sources, which are harmful due to extensive exploitation and emissions that contribute to pollution, global warming, and climate change (Setiyono, 2023). Moreover, green development not only benefits the environment but is also expected to bring social advantages, such as improved air quality, which could potentially prevent annual deaths (Bappenas, 2019).

Furthermore, by using fully renewable electricity, OIKN is committed to achieving net-zero emissions by 2045, which is at least 15 years ahead of the national target. By 2045, total emissions in Nusantara are expected to be negative, reaching -1.1 MtCO₂ (Widiaryanto et al., 2023). This ambitious goal aligns with IKN's vision of becoming a climate-resilient city.

Barriers

However, the implementation of renewable energy projects does not always benefit the environment, which is a concern that must be addressed to ensure the smooth execution of such projects in IKN.

solar PV projects can negatively impact the environment, particularly in dryland areas where large-scale installations can drastically alter vegetation cover, disrupting local ecosystems and biodiversity (Xia, 2023). Conventional PV facilities can also cause deforestation, bird mortality, erosion, runoff, and microclimate changes, which are more severe than those associated with floating photovoltaic systems (Silva & Branco, 2018).

In Indonesia, solar PV use has been suboptimal due to insufficient regulations, highlighting a need for stronger frameworks to ensure environmental standards and best practices are met, thereby reducing potential environmental harm (Setiawan et al., 2021).

Hydropower projects can significantly harm the environment by altering habitats, reducing biodiversity, and affecting water quality. A key concern is the disruption of ecosystems caused by the construction and operation of dams, which can change river flow patterns, fragment habitats, and lead to biodiversity loss (Ansar et al., 2014). Creating reservoirs often destroys valuable habitats and displaces local flora and fauna (Ghimire & Phuyal, 2022).

In Indonesia, hydropower projects also alter river hydrology, disrupting natural flood cycles, sediment transport, and downstream aquatic habitats, which can negatively impact riverbank ecosystems and water quality (Kibler & Tullos, 2013; Rai & Khawas, 2021). These environmental concerns, along with high costs, may discourage countries within the International Partner Group (IPG) of JETP from investing in baseload renewable power plants, particularly hydropower (Damuri, 2023).

4.1.6. Legal

The development of renewable electricity in IKN currently has a strong legal foundation, as it is mandated by Presidential regulation. However, the implementation of renewable energy projects in Indonesia has encountered several challenges, which could also affect the development in IKN. Infrastructure projects often face delays due to difficulties in securing access and permits, and in some cases, these challenges can even bring projects to a halt.

Hydropower projects require a Water Resource Utilization Permit and, for projects in forested areas, Forestry Use approval (Draps et al., 2021). In many cases, obtaining land access and permits involves significant time, effort, and cost (ADB, 2020). The permitting process is often delayed by overlapping and redundant regulations, as well as ambiguous authority (Setyadi et al., 2023).

Additionally, the complexity of land tenure systems in Indonesia further exacerbates these challenges. Overlapping ownership and land control issues complicate the acquisition process for project developers (Purnomo et al., 2022). Unclear land ownership can lead to disputes, conflicts, and legal uncertainties, which further hinder the progress of hydropower projects and complicate the acquisition of necessary land rights (Kumalasari, 2021).

4.1.7. Summary of Driver and Barrier Analysis

Table 4-1 provides a summary of the barriers to renewable energy development as discussed in previous sections.

Table 4-1 Summary of Driver and Barriers for Renewable Energy Development in IKN

Aspect	Driver	Barrier
Politics	Government Commitment to NZE	Policy Uncertainty
	Enhance energy security	Inconsistent or ambiguous Policy
	Government providing incentives for research	Fossil Fuel Subsidies
	Introducing of REC service	Lack of Institutional competence
		Weak Interministerial Coordination
		Slow Land Access Progress
		Slow Government Approval
		Slow Price Negotiation with PLN
		Unclear procurement mechanism
		Negative Investment Policy
Economy	Increasing economic Growth in IKN	Local Content Requirement Policy
	Create Sustainable Economic Growth	PLN's Limited financial resources Lack of Long-term Financing

	Create More Jobs opportunity	Low Return Rates
	Not Subject to global market price	Developers have limited financial sources
	Reduction in CAPEX for solar PV	Challenges in securing international financial investment
Social	The local community is enthusiastic about the development of IKN	Lack of public enthusiasm for energy transition
	Public acceptance is high for solar PV project	Public Demand for Lower Electricity Price
	Abundant renewable energy expertise	comfortable using fossil energy sources
		renewable energy is not a primary concern
		Low Awareness of Fossil Fuel Depletion
		Opposition to Hydropower Projects
Technology	Kalimantan is Rich in Hydro and Solar PV	Intermittency of Solar source
	Mature hydropower and solar technology	Long Development Duration
	Hydropower can replace Coal Plants	Massive land requirement
	Proven hydropower-solar hybrid in Indonesia	Limited Smart Grid Technology
		Additional Investments for intermittent source
		Limited transmission line investment
Environmental	Reduce pollution and improve air quality	Solar PV Impact on Vegetation
		Insufficient Environmental Regulations
		Ecosystem Disruption by Hydropower Dams
		River Hydrology Alteration
Legal	has a strong legal framework foundation	Difficulty Securing Access and Permits

4.2. Actions and Policies for Implementation

4.2.1. Policy and Regulatory Changes

1. Establish New Renewable Energy Law

Driven by the government's commitment to achieving NZE, enhancing energy security, and promoting sustainable economic growth in IKN, this policy change is essential. It addresses barriers such as policy uncertainty, inconsistent or ambiguous regulations, fossil fuel subsidies, and negative investment policies.

Developing a comprehensive renewable energy law is crucial for integrating all sectors of renewable energy development. Such a law should clearly define stakeholder roles, address regulatory gaps, and provide a predictable framework that ensures consistency for investors and developers.

For example, China's Renewable Energy Law, implemented in 2005 and revised in 2009, mandates grid companies to purchase renewable energy and provides financial incentives (Zhang, 2019). Similarly, South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), launched in 2011, encourages private sector investment in renewable energy through competitive bidding and long-term power purchase agreements.

However, in countries like India, the Philippines, and Kenya, renewable energy laws have been less effective due to frequent policy changes and complex administrative procedures. This highlights that beyond enacting laws, effective implementation and stable policies are essential for success.

The National government, through MoEMR, is currently developing a comprehensive renewable energy law. Its effectiveness will depend on careful design, implementation, and the establishment of a stable regulatory environment that provides clear incentives and efficient processes. This law will serve as a broad framework for policies related to new and renewable energy, under which various policy instruments—such as Government Regulations and Ministerial Regulations—will be derived. The proposed law aims to strengthen coordination between national and local governments, adjust renewable electricity pricing, provide financial support, enhance renewable energy research, and focus on low-carbon technologies (HUMAS EBTKE, 2022).

2. Accelerate the Land Acquisition and Permit Process

Driven by the government's commitment to achieving NZE, a strong legal framework, and public enthusiasm for the development of IKN, this action is necessary to overcome barriers such as slow land access progress, lengthy land procurement processes, and difficulties in securing access and permits.

Numerous projects have experienced delays extending over several years due to complications in the land acquisition process. These delays often arise from failed negotiations between project developers and landowners, difficulties in identifying the rightful landowners, and disputes over land ownership. Additionally, in Indonesia, the situation is further complicated by the existence of customary land, which is governed by traditional laws and practices, necessitating resolution through customary law. In East Kalimantan, customary land accounts for 16.34 percent of the province's total area. Of this, an estimated 1.8 percent is located within the IKN area (Zakaria, 2024b).

To overcome these challenges, the National government through the National Land Agency must provide clear guidelines for the land acquisition process. Establishing transparent procedures will help developers and landowners understand their rights and responsibilities, facilitating smoother negotiations (Antara, 2024). When negotiations between developers and landowners fail, local government intervention becomes crucial. By mediating these disputes, the local government can help ensure that fair agreements are reached, preventing prolonged delays. Moreover, involving all relevant stakeholders, including local communities, customary leaders, and government officials, from the very beginning of the project is essential. Early engagement

can help identify and address potential issues before they escalate, thus minimizing the risk of delays.

Moreover, the local government can integrate technology into land management practices and can significantly improve efficiency, reduce costs, and enhance overall project performance. Leveraging big data approaches and advanced technologies can optimize the land acquisition process. By utilizing data-driven insights, stakeholders can inform land procurement strategies, assess project feasibility, and streamline compensation procedures (Berawi et al., 2019).

3. Strengthen Environmental Regulations

Driven by the government's commitment to achieving NZE, supported by a strong legal foundation, and aimed at reducing pollution and improving air quality in IKN, this policy change is necessary. It addresses barriers such as insufficient environmental regulations, the impact of solar PV on vegetation, ecosystem disruption from hydropower dams, and alterations to river hydrology.

Clear guidelines for environmental assessments and consistent enforcement are essential for sustainable project development. The National Government, through the Ministry of Environment and Forestry (MoEF), can enhance environmental regulations by adopting international standards like the World Bank's Environmental and Social Framework (ESF). The ESF promotes sustainable development goals, ensuring that internationally funded projects benefit local communities and ecosystems (Silva et al., 2020). By integrating these standards into new regulations, projects can align with global best practices and become eligible for international funding.

Projects that align with the ESF are more likely to receive funding as they demonstrate a commitment to environmental protection, social responsibility, and sustainability (Kashfi & Hanna, 2022). These requirements are essential for ensuring that projects comply with the high environmental and social standards set by these institutions (Dann & Riegner, 2019).

4. Relaxation of Local content Requirement Policy

Driven by the government's commitment to achieving NZE and supported by a strong legal framework, the relaxation of LCR is needed to overcome the barriers posed by the current LCR policy.

Temporary relaxation of Local Content Requirements (LCRs) could be considered for priority projects until local manufacturing capacities are adequately established. JETP Indonesia (2023) suggests that easing LCRs, along with enhanced support for manufacturers, the formulation of a comprehensive industrial strategy, and coordinated incentive schemes for suppliers and project developers, would significantly facilitate investor attraction, technology, and knowledge transfer, and the advancement of solar PV manufacturing capabilities, thereby fostering a robust solar PV supply chain. Therefore, the Ministry of Industry, in coordination with the Ministry of Energy and

Mineral Resources (MoEMR), should relax or adjust the current policy to accelerate the implementation of solar PV in IKN.

4.2.2. Financial and Economic Changes

1. Provide Government Loan Guarantee

Driven by the government's commitment to achieving NZE, as well as the potential for creating sustainable economic growth and more job opportunities, providing loan guarantees for renewable energy projects in IKN is essential. This action will address barriers such as low private sector involvement, a lack of long-term financing, low return rates, and limited financial resources for developers.

Government loan guarantees can significantly encourage lenders to offer lower interest rates and long-term payback, making it easier to secure financing for renewable energy projects. When the government provides loan guarantees, it essentially promises to cover the lender's losses if the borrower defaults (Ma et al., 2022). This reduces the risk for lenders, allowing them to offer loans at lower interest rates to renewable energy projects, which are often seen as high-risk due to their innovative nature (Ma et al., 2022).

However, one downside of government loan guarantees is the financial burden they can place on the government budget (Flacke & Boer, 2017). If the renewable energy projects supported by these guarantees encounter financial trouble or default, the government may have to cover the losses, potentially leading to fiscal strain.

Government loan guarantees can be an effective way to encourage investment in renewable energy by lowering financial risks for lenders, they also carry potential drawbacks that need careful consideration. The National Government, through the Ministry of Finance (MoF), should carefully evaluate projects before providing loan guarantees. A renewable energy project in IKN could be considered for a loan guarantee, as it is viewed as a strategic and crucial initiative for the country.

2. Finding low-rate financing from international organizations

Driven by the government's commitment to achieving net-zero emissions (NZE) and the potential for creating sustainable economic growth and more job opportunities, this action is necessary. It will help overcome barriers such as PLN's limited financial resources, the lack of long-term financing, limited financial sources for developers, and the need for additional investments to manage intermittent renewable energy sources.

By leveraging the financial support and expertise of international organizations like the World Bank, the government can access grants, concessional loans, and technical assistance to advance renewable energy development agendas. The UNFCCC Green Climate Fund (GCF) aims to provide substantial financial support for large-scale renewable energy projects in developing countries, aligning with global climate goals (Taghizadeh-Hesary & Yoshino, 2020). Additionally,

the European Investment Bank, in collaboration with the European Commission, offers technical assistance to facilitate investments in energy efficiency and renewable energy projects (Simionescu et al., 2022).

To secure funding, the national government, via the Ministry of Energy and Mineral Resources (MoEMR), should promote IKN's renewable projects to international lenders, while the Ministry of Finance (MoF) provides government guarantees for these projects. Additionally, developers like PLN and independent power producers (IPPs) should actively pursue low-interest financing from international organizations.

3. Encourage Domestic Bank to provide Low Loan Interest Rate

Driven by the government's commitment to achieving NZE and the potential to create sustainable economic growth and more job opportunities, domestic banks need to be encouraged to offer low-interest loans for renewable energy projects in IKN. This action will help overcome barriers such as the lack of long-term financing, ensuring electricity affordability, high transaction costs, and developer's limited financial resources.

It is essential to encourage local banks and financial institutions to offer loans at lower interest rates for renewable energy projects. This can be achieved by providing comprehensive training and technical assistance to these institutions. By enhancing their understanding of the renewable energy sector and equipping them with the tools to accurately assess project risks, banks will be more confident in offering favorable loan terms.

Banks must start to include Environmental, social, and governance (ESG) risks in their financing analysis, in addition to financial risks (PRAKARSA, 2022). Such measures will not only reduce the perceived risk associated with renewable energy investments but also facilitate access to capital, ultimately driving the growth of the renewable energy sector in Indonesia. To make the bank more appealing for funding renewable energy development, the government needs to create regulations that support the industry and minimize regulatory uncertainty. For example, implementing a carbon tax with an appropriate tariff could be effective (PRAKARSA, 2022).

4. Providing Land Incentive

Driven by the government's commitment to achieving the NZE and the potential for creating sustainable economic growth and more job opportunities, providing land incentives is a valuable action. It will help overcome barriers such as slow land access progress and massive land requirements.

Using land incentives has proven to be an effective strategy to accelerate project implementation and achieve positive results in various sectors. Specifically, for renewable energy projects, which often require large areas of land, incentives like free land or discounted land prices can significantly speed up development. Countries such as India and Brazil have adopted land incentives to encourage the construction of renewable energy projects. These incentives help to attract investments, speed up project timelines, and support the national goals for expanding renewable energy (Kiesecker et al., 2019). To develop effective land incentive strategies, the National Land Agency needs to coordinate with MoEMR to identify which

categories of renewable energy projects require subsidies. Additionally, it should collaborate with local governments to understand local land use and development needs.

4.2.3. Institutional Changes

1. Build Institutional Competences

Driven by the government's commitment to achieving net-zero emissions (NZE), the availability of abundant renewable energy expertise, and government incentives for research, it is essential to build institutional competence in managing renewable energy development. This will help address barriers such as policy uncertainty, inconsistent policies, and unclear procurement mechanisms by strengthening institutional competences.

Comprehensive training programs are essential to equip government officials and staff with the necessary technical and managerial skills. Alongside training, the allocation of financial and technical resources is vital. Institutions need adequate funding from national budgets and international grants, as well as access to modern tools, software, and technologies to effectively plan, implement, and monitor renewable energy projects.

Moreover, establishing research centers and innovation hubs will drive research and development (R&D) in renewable energy technologies, supported by academic collaboration. Finally, implementing robust monitoring and evaluation frameworks ensures continuous improvement and adaptation to technological advancements and market changes. To achieve these objectives, the national government, through MoEMR, can collaborate with universities and research institutes.

2. Improve Interministerial Coordination

Driven by the government's commitment to achieving NZE, a strong legal framework, and abundant renewable energy expertise, it is essential to increase interministerial coordination. This action is necessary to overcome barriers such as weak interministerial coordination and slow government approval processes.

To improve coordination among different government ministries, one effective method is to set up formal systems for cooperation and information sharing. Phillips et al. (2021) recommend creating subject-specific Interministerial Groups (IMGs), a broad Interministerial Standing Committee (ISC), and a high-level group for enhanced political coordination. These hierarchical structures can help manage issues that span multiple ministries and encourage effective collaboration.

Addressing coordination challenges requires clearly defining needs, choosing suitable policy tools, identifying obstacles, regularly reviewing agendas, and evaluating policy outcomes (Negev, 2015). Additionally, Yang (2023) discusses how the UK government uses a "Gold-Silver-Bronze" three-level response system for extreme weather events and disasters. This structured method improves coordination among different government levels and can be adapted to enhance collaboration in renewable energy projects, helping to reduce implementation delays.

To address the investment coordination problem, the Coordinating Ministry for Maritime and Investment needs to implement these changes in coordination with MoEMR.

4.2.4. Technological Changes

PLN plays a vital role in driving technological changes in Indonesia's power sector by ensuring safe and reliable operations. The government has tasked PLN with planning, constructing, and maintaining transmission lines and power plants. However, all of PLN's actions must be coordinated with MoEMR the regulator of the electricity sector. Additionally, Independent Power Producers (IPPs) as the other developers, also need to contribute to these technological advancements

The following technical changes are necessary for the implementation of renewable energy in IKN.

1. Using mature Technology

Given Kalimantan's rich resources in hydro and solar PV, the maturity of hydropower and solar PV technologies, the reduction in CAPEX for solar PV, and the potential for hydropower to replace coal power plants, prioritizing these mature technologies in the development of renewable energy in IKN is essential. This approach can help overcome barriers such as the lack of long-term financing and low return rates.

In the short term, efforts toward achieving net zero emissions should center on utilizing existing, economically viable technologies. As a developing nation, Indonesia should prioritize mature technologies to mitigate risks associated with implementation. Lowering implementation risk makes financing institutions more willing to provide funding, even at lower interest rates. Additionally, using mature technology ensures high efficiency, enabling developers to accurately plan electricity production. This reliability in production increases the potential revenue for developers, making renewable energy projects more attractive and profitable.

Technologies like Nuclear, OTEC, and offshore wind, which are still in their early stages in Indonesia and carry high implementation risks, should be approached cautiously. However, in the long term, exploring new technologies is plausible, but thorough study and validation of their success in other countries are imperative before considering their implementation in Indonesia.

2. Increase the Grid Stability

Given the maturity of hydropower and solar PV technologies, the potential for hydropower to replace coal power plants, and the proven effectiveness of hydropower-solar hybrids in Indonesia for grid stability, it is essential to enhance grid stability in IKN. This action can strongly support overcoming barriers such as the intermittency of solar sources and limited smart grid technology.

The variability and intermittency of renewable generation challenge grid management, particularly in balancing supply and demand. To address these issues, implementing smart grid technologies and dynamic demand response strategies can optimize renewable energy integration.

Additionally, employing Grid Monitoring and Control systems can enhance surveillance, quickly detect disruptions, and optimize network operations, which is essential for managing the high intermittency of solar sources.

Assessing the maximum hosting capacity of the transmission network and determining the highest level of renewable energy penetration without compromising grid reliability is also crucial. Regular assessments help stakeholders understand the transmission network's evolving capabilities and limitations, enabling informed decisions on infrastructure investments, policy development, and renewable energy integration. This ensures optimal grid capacity, maintained reliability, and proactive planning for future upgrades, supporting a smoother transition to a sustainable energy system.

3. Increase the Flexibility of the Generator

Given the potential for hydropower to replace coal power plants, it is important to increase the flexibility of hydropower plants in IKN. This will help overcome barriers such as the intermittent of solar sources.

Currently, there are several technologies for controlling active power in power systems, with Automatic Generation Control (AGC) being one of the most advanced. AGC automatically adjusts a generator's active power output in response to frequency changes, relying on centralized energy management to maintain frequency stability. Implementing AGC in the development of hydropower plants in IKN is essential, as hydropower plays a crucial role in stabilizing the grid.

Although AGC requires more frequent adjustments to generator output, which can increase operating costs, it significantly enhances system stability and reliability. Tumiran et al. (2021) found that AGC infrastructure installation in the Java-Bali system after 2020 improved system flexibility, allowing integration of up to 5,884 MWp in 2021, 6,115 MWp in 2022, and 6,447 MWp in 2023. However, some power companies avoid automation due to potential reductions in electricity sales. Therefore, for hydropower development in IKN, it is crucial to include a provision in the Power Purchase Agreement requiring developers to install AGC in their power plants.

4.2.5. Social Changes

1. Reducing the Electricity Consumption

Driven by the need to enhance energy security and the local community's enthusiasm for IKN's development, electricity consumption needs to be reduced. This action can help overcome the barrier of public demand for lower electricity prices.

OIKN is committed to reducing electricity consumption in government offices in IKN by constructing buildings based on green building principles to create a high-performance, eco-friendly office district. Additionally, energy-saving behaviors will be promoted throughout IKN. Combining green building construction with energy-saving practices can potentially reduce overall energy consumption in IKN by 50-60 percent (Alexander, 2022). To implement these changes, the national government, through MoEMR, needs to collaborate with local government (OIKN) to develop and enforce regulations, provide necessary resources, and ensure effective coordination for successful execution.

Several actions can be taken to reduce the electricity consumption in IKN as follows:

- **Provide Feedback on Electricity Consumption**
One effective approach is providing households with personalized feedback on their electricity usage, comparing it with neighborhood averages to raise awareness and promote energy-saving behaviors Ozawa et al. (2017). This feedback mechanism empowers individuals to monitor their consumption habits and make informed decisions to reduce electricity usage. The technology that can be implemented in IKN is the Advanced Metering Infrastructure (AMI), which allows electricity users, both households and industries, to monitor and manage energy consumption in real time. Utilizing smart meters and monitoring systems can provide real-time feedback on electricity consumption, empowering consumers to make informed decisions about their energy usage.
- **Using high-efficiency utensils.**

In Indonesia, many households still use low-efficiency appliances, such as air conditioners. These appliances are often more attractive to consumers due to their lower market prices compared to high-efficiency models.

A study found that 45% of air conditioners on the market are energy-inefficient models imported from countries outside ASEAN, such as China, Japan, and South Korea. These units have low Maximum Energy Performance Standards (MEPS) ratings (Arifin, 2024).

To encourage energy conservation, the Ministry of Energy and Mineral Resources (MoEMR) has implemented regulations for Minimum Energy Performance Standards (MEPS) and Energy Saving Labels (ESL) for appliances. This initiative follows a Clasp study from 2020, which indicated that improving the efficiency of the top 10 electrical appliances by just 15% could reduce energy consumption by up to 10,000 GWh per year, or approximately 10% of annual residential energy use (Clasp, 2020).

- **By behavioral changes**

According to PLN's 2019 statistics, air conditioners (AC) accounted for 4.9% of the country's electricity consumption. Most ACs in the surveyed households are set at an average operating temperature of 20°C. While there is a general recommendation to set ACs at 24 to 25°C to

increase energy efficiency, nearly 70% of ACs are set below 20°C, and only 15% are set above 25°C (CLASP, 2020).

Therefore, air conditioner users should change their habits by setting the temperature to a comfortable level (around 24-26°C), using fans instead of air conditioning when possible, and making sure their homes are well-insulated to keep the temperature stable. India enforced a mandatory default setting at 24°C for all star-labeled room ACs in March 2020,53 while Japan initiated the “Cool Biz” campaign in 2005 to reduce electricity consumption for air conditioning by changing the default office setting to 28°C and introduced dress codes that are suitable for warmer temperatures (CLASP, 2020).

Furthermore, PLN can implement the Time-of-use Pricing (TOU) to change the behavior of the user. TOU is a pricing model where electricity is cheaper during off-peak hours and more expensive during peak times. By lowering rates during off-peak periods, consumers are encouraged to shift their usage to these times, using appliances like dishwashers and washing machines when electricity is less expensive. This shift helps balance the power grid's load and reduces the need for additional energy production, conserving resources and lowering emissions. Adjusting household consumption patterns will also shift the load on power generators from expensive plants to more economical ones, resulting in significant savings on electricity production costs (Setiawan et al., 2021).

2. Increase the awareness and acceptance of the public for renewable energy

Driven by the government’s commitment to achieving NZE, the local community’s enthusiasm for IKN’s development, and the potential of renewable energy to create sustainable economic growth and more job opportunities, it is essential to increase public awareness and acceptance of the energy transition. This action will help overcome barriers such as a lack of public enthusiasm for the energy transition, comfort with fossil energy sources, the perception that renewable energy is not a primary concern, and low awareness of fossil fuel depletion.

To boost public awareness and acceptance of renewable energy, it is essential to involve citizens, social entrepreneurs, and community organizations in the energy transition process. Successful programs like Scotland's Community and Renewable Energy Scheme (CARES) and Germany's Renewable Energy Act (EEG) demonstrate this approach (Spasova & Braungardt, 2021).

Educating people about the benefits of renewable energy and its role in achieving energy independence can enhance acceptance. It's important to understand the attitudes and intentions of users towards renewables to effectively increase awareness and acceptance. Moreover, conducting educational campaigns to address specific preferences and concerns can further promote renewable energy initiatives. To implement these changes, MoEMR needs to collaborate with ministries outside the energy sector, such as the Ministry of Education and Culture, as well as with universities. Additionally, to ensure broader acceptance at the local level, local governments should actively promote renewable energy and involve NGOs in the process.

3. Increase Public Acceptance of Renewable Energy Project

Driven by the local community’s enthusiasm for IKN’s development and the high public acceptance of solar PV projects in Indonesia, it is important to further increase public acceptance of renewable energy projects. This action will help overcome barriers such as opposition to hydropower projects, long development durations, and difficulty securing access and permits.

To gain public acceptance of renewable energy projects, local authorities and developers must build trust with the community (Segreto et al., 2020). This trust can be established by engaging communities for the Renewable Energy Project through a transparent process from the planning stages to the operation of the plant. The public should be provided with high-quality technical information, including details on the economic and environmental impacts and cost-benefit analyses of the technology used in the project. Additionally, the education and income levels of residents significantly influence their acceptance of renewable energy projects (Segreto et al., 2020).

4.2.6. Summary of Actions and Policies for Implementation

Table 4-2 provides a summarized overview of the comprehensive Actions and Policies detailed in the preceding chapter. Each action and policy are analyzed through a What-How-Who framework, which delineates the specific strategies (What), the methods of implementation (How), and the responsible stakeholder (Who).

Table 4-2 Summary of WHAT-HOW-WHO Analysis of Actions and Policies for Implementation

	WHAT	HOW	WHO
	Policy and regulatory changes		
1	Establish Renewable Energy Law	-Clearly define the roles and responsibilities of all stakeholders involved, -Addressing gaps and ambiguities in existing regulations. -Provide clear guidelines and a predictable regulatory framework	National Government (MoeMR)
2	Accelerate the Land Acquisition and Permit Process	-Provide clear guidelines -Transparent procedures -Integrating Technology such as big data	National Government (MoEMR, National Land Agency), Local Government
3	Strengthen Environmental Regulations	-Provide clear guidelines -Ensure consistent enforcement -Adopting International Standard	National Government (Ministry of Environment and Forestry)

4	Relaxation of Local Content Requirement Policy	Temporary relaxation of LCR Policy	National Government (MoEMR, MoI)
Financial and Economic Changes			
1	Provide Government Loan Guarantee	Government guarantee for strategic and crucial Renewable energy project	National Government (MoEMR, MoF)
2	Finding low-rate financing from international organizations	leveraging the financial support from international organizations	National Government (MoEMR, MoF), PLN and IPP
3	Encourage Domestic Bank to provide Low Loan Interest Rate	providing comprehensive training and technical assistance	National Government (MoF), Central Bank
4	Providing Land Incentive	Develop land incentive packages for Strategic and Crucial Renewable energy project	National Government (National Land Agency, MoEMR), Local Government
Institutional Changes			
1	Build Institutional competences	-Comprehensive training programs -establishing research and training canthers -Implementing monitoring and evaluation frameworks	National Government (MoEMR), Universities, Research Institutes
2	Improve Interministerial Coordination	Build clear hierarchical structures	National Government (Coordinating Ministry for Maritime and Investment Affairs (CMMIA), MoEMR)
Technological Changes			
1	Focus on using mature technology	Prioritization of Proven technology in Indonesia	National Government (MoEMR), PLN, IPP
2	Increase the Grid Stability	-Implementation of smart grid technologies and dynamic demand response -Implementation of the Grid Monitoring and Control function -Assess the highest renewable penetration level	National Government (MoEMR), PLN, IPP
3	Increase the Flexibility of Generator	Implementation of Active Generation control (AGC) in the system	National Government (MoEMR), PLN, IPP
Social Changes			
1	Reducing the Electricity Consumption	-Provide Feedback on Electricity Consumption -Using high-efficiency utensils -Behavioural changes	National Government (MoEMR), Local Governments, PLN
2	Increase the awareness and acceptance of the public for renewable energy	-Educational campaign	National Government (MoEMR, Ministry of Education and Culture), NGOs, Universities, Local Governments

3	Increase Public awareness of the Renewable Energy Project	Engage Communities for the Renewable Energy Project	Local Governments, Developers (PLN &IPP), NGOs
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4.3. Analysis of The Impact of Actions and Policies

Seven scenarios will be developed to assess the impact of various actions and policies on the electricity system. This approach allows for a clear visualization and understanding of how different policies might influence the system, enabling informed decision-making for future developments. The seven scenarios are:

1. Scenario 1: Implementation of Local Content Requirements (LCR)
2. Scenario 2: Implementation of Land Incentives
3. Scenario 3: Variation of Project Discount Rates
4. Scenario 4: Implementation of High-Efficiency Solar PV Modules
5. Scenario 5: Implementation Delay of Hydropower Plants
6. Scenario 6: Electricity Consumption Reduction
7. Scenario 7: Shifting Electricity Use from Peak to Off-Peak Times

All scenarios are simulated with constraints based on the year 2045, except for Scenario 5, which is simulated with constraints for the year 2030. The relationship between the actions and policy changes discussed in the previous section and these scenarios is presented in Table 4-3. Furthermore, the detailed results of these simulations are presented in Appendix H.

Table 4-3 Relationship between Scenarios and action or policies for Implementation

	Actions of Changes	Related to the Scenario	Remarks
Policy and regulatory changes			
1	Establish Renewable Energy Law	Scenario 1,2,3,5	Effective Energy law can attract Investment and Drive Development
2	Accelerate the Land Acquisition and Permit Process	Scenario 5	Land acquisition and permit processes often cause delays in hydropower implementation
3	Strengthen Environmental Regulations	Scenario 3,5	Adopting international environmental standards can make projects eligible for international funding
4	Relaxation of Local content Requirement Policy	Scenario 1	
Financial and Economic Changes			

1	Provide Government Loan Guarantee	Scenario 3,5	Government loan guarantees can significantly encourage lenders to offer lower interest rates
2	Finding low-rate financing from international organizations	Scenario 3,5	International organizations like the World Bank can provide grants and concessional loans
3	Encourage Domestic Bank to provide Low Loan Interest Rates	Scenario 3,5	
4	Providing Land Incentive	Scenario 2	
Institutional Changes			
1	Build Institutional Capacity	Scenario 5	
2	Improve Interministerial Coordination	Scenario 5	Slow government approval and weak coordination can delay projects
Technological Changes			
1	Focus on using mature technology	Scenario 4	
2	Increase the Grid Stability	Not related to any scenario	
3	Increase the Flexibility of Generator	Not related to any scenario	
Social Changes			
1	Reducing the Electricity Consumption	Scenario 6	
2	Increase the awareness and acceptance of the public for renewable energy	Scenario 6	Lack of awareness about fossil fuel depletion causes the public to prefer fossil fuels over renewable energy, delaying the development of renewable sources
3	Increase Public Awareness of Renewable Energy Construction Project	Scenario 5	Local public opposition often leads to project delays
4	Consumer Behaviour Changes	Scenario 7	

4.3.1. Scenario 1: Implementation of Local Content Requirement Policy (LCR)

The simulation results show that the implementation of the Local Content Requirement (LCR) policy significantly increases the Levelized Cost of Energy (LCOE) for Solar PV, raising it from 3.51 to 4.23 cents per kWh. Despite this increase in LCOE, the capacity for both Hydropower and Solar PV remains unchanged. Even with the higher LCOE caused by the LCR policy, Solar PV may still be more competitive than other power generation technologies. This suggests that the LCR does not reduce the competitiveness of Solar PV within the system. However, the LCR could hinder the development of Solar PV in IKN by making it more difficult to secure funding from international institutions.

4.3.2. Scenario 2: Providing Land Incentive

Implementing an incentive for land acquisition primarily benefits the solar PV sector by increasing its capacity from 870 MW in the base scenario to 898 MW in this scenario. It also significantly reduces the levelized cost of electricity (LCOE) from 3.51 cents \$ per kWh to 2.74 cents \$ per kWh. In contrast, hydropower experiences a slight decrease in both capacity and

LCOE. The LCOE for hydropower drops from 4.75 cents \$ per kWh to 4.52 cents \$ per kWh. Consequently, the total LCOE for the entire system decreases from 4.57 cents \$ per kWh to 4.22 cents \$ per kWh.

The simulation seems to favor expanding Solar PV capacity and slightly reducing Hydropower capacity to meet demand. This approach is due to the substantial reduction in Solar PV's LCOE, making it a more cost-effective choice. However, it also aims to ensure a reliable, stable, and sustainable energy supply by maintaining a balanced mix of renewable sources by slightly decreasing the capacity of hydropower in the system.

This scenario significantly increases the capacity of solar PV in East Kalimantan, allowing the province to robustly generate more solar power. As a result, East Kalimantan send excess electricity, amounting to 2.7 MW, to IKN during the afternoon. This situation contrasts with the base case, where there is no exchange of electricity between the two regions.

4.3.3. Scenario 3: Variation of Project Discount Rate

Reducing the discount rate to 5% improves the economic attractiveness of both hydropower and solar PV by lowering their LCOEs. However, the capacity changes suggest a shift towards more solar PV installations due to its greater responsiveness to the lower discount rate in terms of cost reductions. Specifically, the LCOE for solar PV drops from 3.51 cents \$/kWh to 2.18 cents \$/kWh, a larger relative decrease than that observed for hydropower. This substantial cost reduction makes solar PV projects more attractive, leading to an increase in projected capacity from 870 MW to 961 MW when the discount rate is lowered.

A lower discount rate enhances the development of solar PV across all provinces in Kalimantan, making electricity exchanges between IKN and East Kalimantan necessary. With a 5% project discount rate, 9 MW of solar PV electricity is transferred to IKN during the day. Similarly, at a 7% discount rate, 8 MW of solar PV electricity is transferred to IKN.

In this scenario, raising the project discount rate from 10% to 15% does not affect the renewable energy technology mix within the system. However, it results in a 29% increase in the annual investment cost and a 12% rise in the system's LCOE.

4.3.4. Scenario 4: Using the high efficiency of solar PV module.

Initially planned for 870 MW, the solar PV capacity slightly decreases to 829 MW when high-efficiency modules, which have a 1% higher efficiency than the base case, are employed. This reduction demonstrates a shift towards more advanced technologies that can generate more electricity with less installed capacity. Additionally, the LCOE for solar PV improves from 3.51 cents per kWh in the initial scenario to 3.35 cents per kWh with high-efficiency modules.

Furthermore, the annual investment cost for solar PV decreases by nearly 2 million \$, from \$40.6 million to 38.7 million \$.

This decrease indicates a lower cost of generating solar electricity, driven by the improved output capabilities of the modules. These changes highlight the economic advantages associated with adopting more efficient technology. This reduction in Solar PV capacity installation can lower the investment costs for future developments.

4.3.5. Scenario 5: Implementation Delay of Hydropower Plants

The introduction of substantial solar PV capacity (389 MW) and battery storage (54 MW) is proposed to compensate for the absence of hydropower in 2030. Solar PV would primarily generate electricity during the daytime, while batteries would be utilized to store surplus energy and help maintain grid stability. This strategic approach aims to mitigate the shortfall left by the absence of hydropower.

Furthermore, the plan includes increasing the capacity of the transmission line from East Kalimantan, which could potentially source electricity from non-renewable sources. This shift suggests a heightened reliance on imported electricity, which may escalate costs and render the grid more vulnerable to external factors. Consequently, the Levelized Cost of Electricity (LCOE) is projected to rise from 4.22 to 6.73 cents \$/kWh without hydropower. This increase underscores the greater expense associated with alternative energy sources or technologies.

In terms of investment cost, the implementation of hydropower in 2030 costs more compared to the no hydropower scenario. This higher cost is attributed to the substantial capital expenditure (Capex) required for hydropower. However, in future developments (2035, 2040, and 2045), the presence of hydropower eliminates the need for batteries in the system. Hydropower can act as load followers and manage the intermittent of solar PV, making the investment in batteries less critical.

In summary, the delayed installation of hydropower by 2030 could result in an electricity supply that is less stable and potentially more costly. It would also lead to increased dependence on external energy sources, thereby heightening vulnerability to external factors. Moreover, foregoing hydropower represents a missed opportunity to harness a dependable renewable energy source, which could offer long-term benefits in terms of sustainability and energy security.

4.3.6. Scenario 6: Reduce the electricity consumption

The reduction in electricity consumption leads to a decrease in peak power demand in IKN. A 5% reduction in consumption lowers peak demand by 40 MW, while a 10% reduction decreases it by 80 MW. Consequently, hydropower capacity is slightly reduced in response to the overall lower

demand. For every 5% reduction in electricity consumption, hydropower capacity decreases by 40 MW, and solar PV capacity decreases by 43 MW. The more significant reduction in solar PV capacity is due to its lower capacity factor, requiring more installed capacity to generate the same amount of energy as hydropower.

Moreover, as electricity consumption decreases, the annual investment cost also declines. A 5% reduction in electricity consumption results in annual savings of approximately \$9 million in hydropower investment costs. Additionally, this same 5% reduction lowers the annual investment cost for solar PV by approximately \$2 million

The LCOE in the system remains unchanged because, although the investment cost decreases due to the reduced capacity of power plants, this also leads to a corresponding decrease in electricity production.

4.3.7. Scenario 7: Shifting Electricity Use from Peak Time to Off-Peak Time

Shifting 5% of electricity consumption from peak (18:00-21:00) to off-peak (14:00 – 16:00) periods results in a decrease in the installed capacity for both hydropower and solar PV. This reduction occurs because the decreased demand during peak hours, now more evenly distributed throughout the day, reduces the need for high-capacity generation during those peak times.

Specifically, peak demand is reduced from 791 MW to 752 MW. Consequently, the required hydropower capacity decreases by approximately 40 MW and the solar PV capacity needed decreases by about 55 MW under this new consumption pattern. These capacity reductions lead to a lower annual investment cost for both technologies. These capacity changes demonstrate how adjusting electricity consumption patterns can impact the optimal use of renewable energy sources and reduce annual investment costs.

However, shifting demand also affects the demand profile and may create a new peak demand at a different time. A simulation of a 10% shift from peak to off-peak periods showed a new peak time with higher demand compared to a 5% shift. This new peak demand necessitates a significantly higher solar PV installation, approximately 267 MW, compared to the base scenario. In contrast, the hydropower capacity in the system is decreased.

This finding supports the work of Setyawan et al. (2021), who observed that load shifting can lead to new peak loads as consumers adjust their usage patterns. Therefore, Time-of-Use pricing (ToP) should be periodically reassessed to reflect changes in demand and tariffs over time.

4.3.8. Comparison of The Scenarios

1. Power Plant Capacity

Figure 4-1 shows the capacity of large hydropower and utility-scale solar PV under different scenarios for the year 2045. Scenario 3 achieves the highest Utility-Scale Solar PV capacity at 960 MW, significantly surpassing the 870 MW in the base case. Scenario 2 also increases solar capacity, whereas Large Hydropower capacity decreases slightly across scenarios, with minor differences. These results suggest that financial incentives, like lower project discount rates and land subsidies, significantly boost solar power development.

Scenarios 6 and 7 are designed to improve electricity efficiency among end-users, leading to a reduction in peak demand. As a result, these scenarios show the most significant decreases in capacities for both Utility-Scale Solar PV and Large Hydropower compared to the base case.

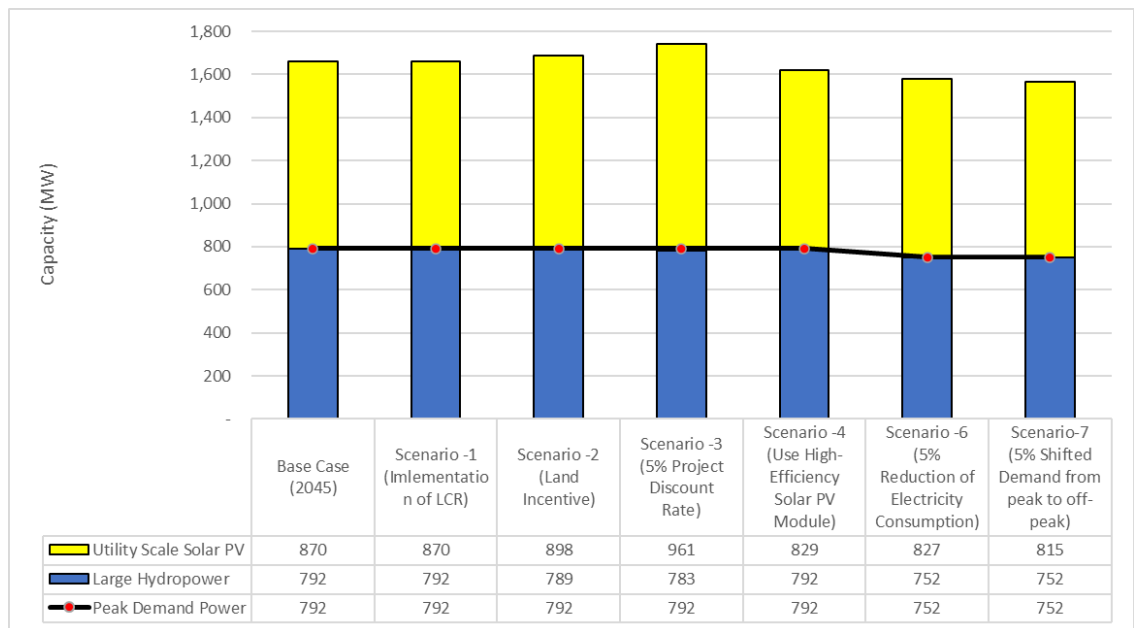


Figure 4-1 Comparison of Policy and Action Impact on the Capacity Planning of Power Plant in IKN by 2045

2. Annual Investment Cost

Figure 4-2 illustrates the annual investment costs for various renewable electricity development scenarios in IKN by 2045, highlighting notable variations from the base case of 217.5 million \$.

Scenario 1 incurs the highest investment cost, increasing by \$8.3 million to \$225.8 million, making it the only scenario with a cost increase.

The other scenarios show reductions in investment costs, indicating that the proposed actions and policies can enhance cost-effectiveness. The most significant reductions occur with the implementation of financial incentives, as seen in Scenarios 2 and 3. Scenario 3 achieves the largest reduction, lowering costs by 82.1 million \$, followed by Scenario 2 with a 37.8 million \$ decrease.

While changes in technology, as seen in Scenario 4, also reduce costs, the impact is smaller, with a decrease of \$1.9 million to \$215.57 million. Lastly, changes in end-user behaviour, presented in Scenarios 6 and 7, further reduce investment costs to \$206 million and \$206.6 million, representing decreases of \$11.4 million and \$10.87 million from the base case, respectively.

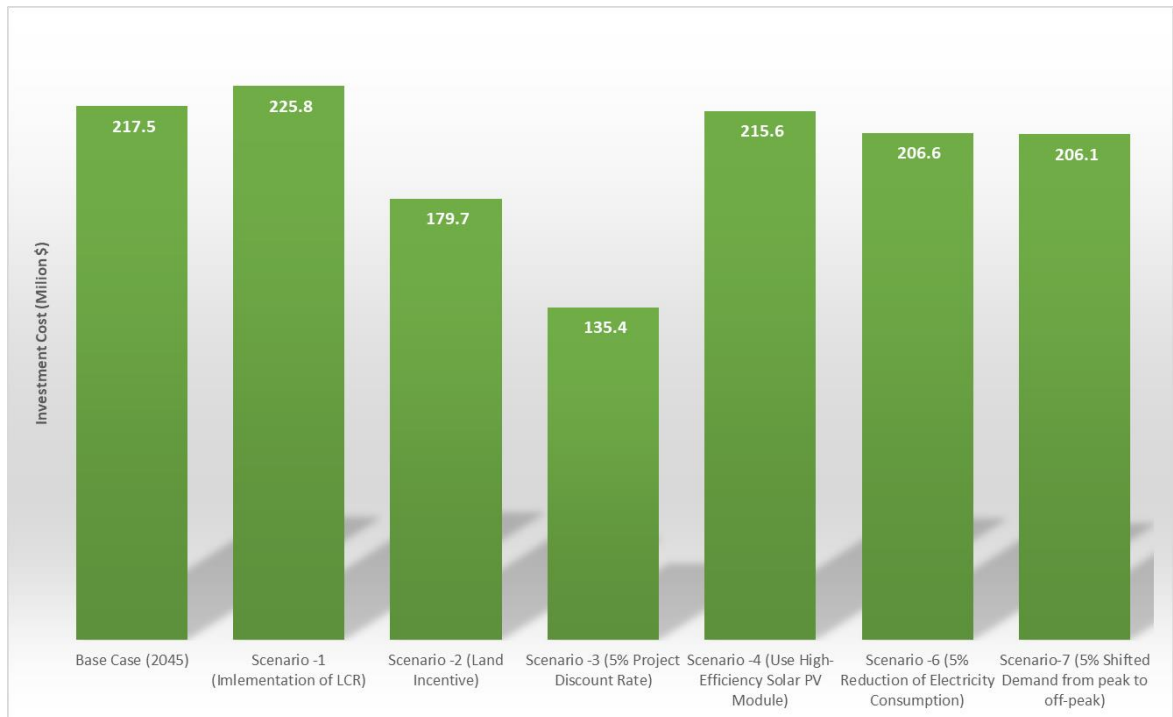


Figure 4-2 Comparison of the impact of policies and actions on the total investment cost for renewable electricity in IKN up to 2045.

3. Levelized Cost of Electricity (LCOE)

Figure 4-3 displays the Levelized Cost of Electricity (LCOE) cent \$/kWh for hydropower and utility-scale solar PV across various scenarios. The comparison shows that scenario 3 results in the most significant decrease in LCOE for both hydropower and utility-scale solar PV. For hydropower, the LCOE decreases by 1.80 cent \$/kWh, from 4.75 to 2.95 cent \$/kWh, and for utility-scale solar PV, the LCOE decreases by 1.33 cent \$/kWh, from 3.51 to 2.18 cent \$/kWh.

Following the increase of investment cost, scenario 1 results in the highest increase in LCOE for utility-scale solar PV, with a rise of 0.72 cent \$/kWh, from 3.51 to 4.23 cent \$/kWh. The Levelized Cost of Energy (LCOE) for hydropower remains unchanged across most scenarios, except when financial incentives are applied, as seen in Scenarios 2 and 3. With a 5% discount rate, the LCOE decreases from 4.75 cents \$/kWh to 2.95 cents \$/kWh. Additionally, when a land incentive is applied, the LCOE decreases by 0.23 cents \$/kWh, from 4.75 cents\$/kWh to 4.52 cents \$/kWh.

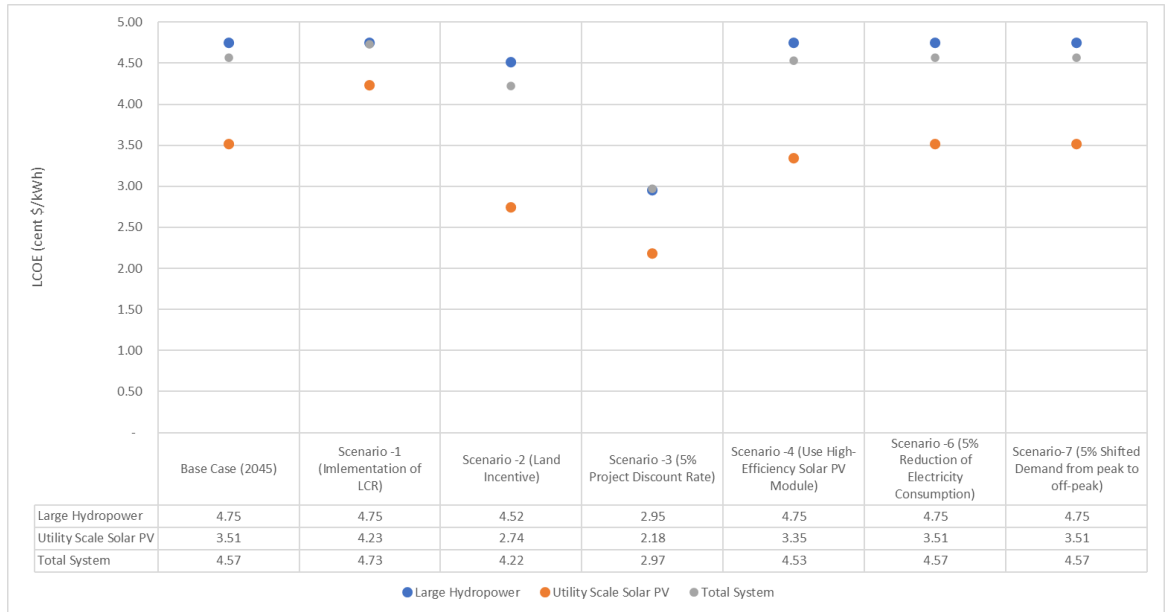


Figure 4-3 Comparison of LCOE for the impact of implementing actions or policies in IKN in 2045

5. DISCUSSION

5.1. Combination of Hydropower and Solar PV is Feasible to Electrify IKN in 2045

The model projects that the future electricity system of IKN will rely exclusively on large hydropower and solar PV, without incorporating energy storage technology. This aligns with PLN's plan to electrify IKN using hydropower and solar energy. From a technical standpoint, this combination is feasible and supported by a study by Al-Ghussain et al. (2020), which indicates that integrating solar PV with hydropower results in a more stable and environmentally friendly energy grid.

Figure 5-1 illustrates the power system in IKN on March 10th and 11th, 2045, where hydropower serves as a stable and sufficient base load electricity, supplemented by solar PV during daylight hours. This arrangement effectively meets the city's energy needs over the two days in March 2045, ensuring a reliable and sustainable power supply.

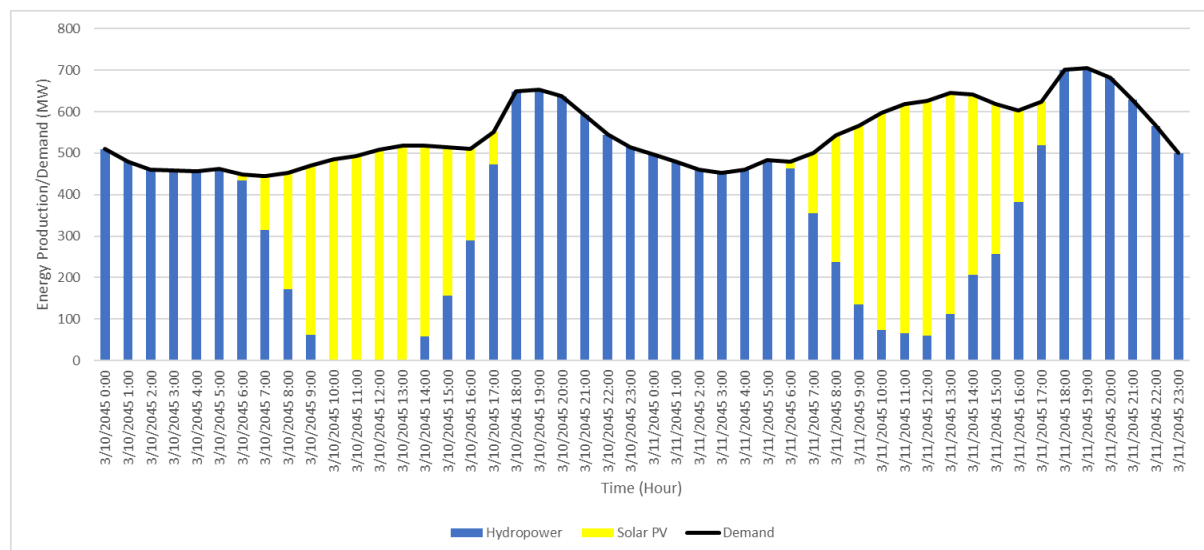


Figure 5-1 Estimation of IKN Power System Profile on March 10th and 11th, 2045

Hydropower production is consistently sufficient to always meet the demand. Even during the evening peak hours (18:00 to 20:00) on both days, the hydropower capacity is adequate to cover the demand without any shortfall. This highlights the reliability of hydropower as a dependable base load energy source capable of handling fluctuations in demand without compromising the energy supply.

During daylight hours, solar PV contributes significantly by reducing the load on hydropower. Solar PV generation starts around 06:00 and ends around 18:00, with peak production at midday (12:00 to 14:00). This solar energy generation provides a substantial portion of the required energy, thereby decreasing the reliance on hydropower and optimizing the use of renewable energy sources.

Over the entire 48-hour period, there is no point where the combined output from hydropower and solar PV falls short of meeting the demand. During nighttime and early morning hours, hydropower alone meets the demand, confirming its sufficient capacity. This seamless energy balance highlights the efficiency of integrating multiple renewable energy sources to ensure a consistent and adequate energy supply for the region.

Stabilizing the electricity system using only hydropower and solar PV, without additional energy storage, is possible by leveraging hydropower's fast ramping capabilities. Hydropower's ability to quickly adjust its output to meet real-time demand makes it an excellent complement to the intermittent nature of solar PV. To compare, hydropower plants can adjust their output at a rate of 50 to 100% per minute. In contrast, gas combustion turbines can change their output by 10 to 20% per minute, and coal units can only manage a 1 to 3% adjustment per minute (Kirby & Hirst, 1998).

The flexibility of hydropower makes it an ideal compensation for fluctuating photovoltaic power due to its rapid response capabilities, enabling it to complement the output power of solar PV generation and ensure smooth power generation for the integrated system (Ren et al., 2022). This flexibility allows hydropower to balance fluctuations in solar generation, thus supporting a stable and reliable electricity grid. Therefore, the role of Hydropower in IKN is very crucial and the development should not be delayed.

5.2. Potential Hydropower Plant for Renewable Electricity in IKN

The development of large hydropower plants is crucial for achieving 100% renewable electricity in IKN. These plants can meet the baseload demand and serve as storage to manage the intermittent energy from solar PV. Any delay in hydropower development, as simulated in scenario 6, would require the installation of additional battery storage, leading to higher LCOE. Therefore, the government must take significant action to avoid delays by accelerating the implementation process.

The interim target indicates that in 2030, 143 MW is needed to electrify IKN. According to the latest RUPTL, there are plans to build a total of 163 MW of hydropower capacity in East Kalimantan. The development is divided into two phases: the first phase, with a capacity of 73 MW, is scheduled to begin operation in 2025, and the second phase, with a capacity of 90 MW, is expected to be operational by 2029. This development aligns with the need for renewable electricity to meet the demand in the new capital city (IKN) in 2030.

By 2035, the total hydropower capacity in the region is expected to increase to 418 MW, necessitating the development of an additional 276 MW over the next five years. To meet this demand, several hydropower plant (HPP) projects in East Kalimantan can be developed. Notable projects include BOH HPP with a capacity of 270 MW, Mentarang 1 HPP with 300 MW, and Tabang HPP with 240 MW (PLN, 2021).

In addition to East Kalimantan, North Kalimantan also has significant hydropower potential. Key projects in this region include the Kayan 1, 2, and 3 HPPs, which together offer 3900 MW, and the Mentarang Induk HPP with a capacity of 1375 MW (PLN, 2021). These projects combined can meet

the hydropower capacity needs of East and North Kalimantan, as well as the new capital city (IKN), which requires a total of 4630 MW.

5.3. Biomass as the Alternative Renewable Energy Source in IKN

In the vision for diversifying renewable energy, where hydropower and solar PV capacities are reduced by 50%, 197 MW of biomass will be introduced into the system by 2045 to replace the base load capacity previously provided by hydropower. This aligns with the study by Reyseliani and Purwanto (2021), which emphasizes that biomass will play a crucial role in achieving 100% renewable energy in Indonesia's electricity sector by 2050. According to their study, biomass power plants are expected to increase in capacity to 33 GW, equivalent to 237 TWh, by 2050.

Kalimantan Island has significant potential for biomass energy due to its extensive oil palm plantations. In 2022, East Kalimantan's oil palm plantations produced 19 million tons of Fresh Fruit Bunches (FFB) annually, which translates to an estimated biomass potential of 7.8 million tons (Zakaria, 2024). According to RUEN, the biomass capacity potential from agricultural waste in East Kalimantan province is estimated to reach 437 MW.

However, developing biomass power plants in the region faces challenges, particularly related to fuel availability and pricing. Ensuring a reliable supply of biomass fuel is problematic due to the lack of a sustainable long-term supply chain model. Unlike fossil fuels, biomass fuel supply chains are not yet well-established.

Site-specific feedstock availability is another critical challenge. Not all power plant developers have support from biomass feedstock suppliers in their intended development locations. Moreover, selecting the appropriate capacity for power plants is highly dependent on the availability of feedstock at the site and the specific system requirements of that location.

Therefore, to optimize the biomass potential in Kalimantan, the Indonesian government needs to develop strategies to address these challenges.

5.4. Political and Economy Sector as the Major Aspects

The political and economic sectors face the most significant challenges, creating major barriers to the development of renewable energy in IKN. This aligns with the study by Santika et al. (2020), which states that the current policy framework is insufficient to meet Indonesia's renewable energy targets. From an economic perspective, the availability of financing is essential for the successful implementation of renewable energy projects. Yasin et al. (2024) highlight that the energy transition in Indonesia faces challenges, particularly the need for substantial and appropriate investments.

These two sectors, politics and economics, are closely interlinked. As Lockwood (2013) noted, political power shapes economic restructuring, and the level of political interest can influence the

performance of financial institutions and actors involved in renewable energy projects. Therefore, policies and regulations that facilitate rapid renewable energy development remain critical.

According to the stakeholder analysis in this study, most changes in this sector need to be initiated and implemented by the national government through the MoEMR. This finding aligns with Setyowati and Quist (2022), who noted that the central government and PLN continue to play a dominant role in the transition toward renewable energy. National-level policies are especially crucial, given that Indonesia's institutional and regulatory frameworks in the electricity sector remain relatively centralized.

5.5. Low Project Discount Rate Will Boost the Renewable Energy in IKN

The simulation using a 5% project discount rate (Scenario 3) shows the most significant impact on cost reduction. Therefore, the policies and actions associated with this scenario should be prioritized and implemented without delay. This includes establishing new regulations to create a solid legal foundation, which is essential for future project development.

The project discount rate, also known as the Weighted Average Cost of Capital (WACC), is determined by the cost of both loans and equity. The WACC is calculated using the following formula:

$$WACC = \left(\frac{E}{V} \times Re \right) + \left(\frac{D}{V} \times Rd \times (1 - T) \right)$$

E : value of equity
D : value of debt
V : total value of capital (equity + debt)
Re : rate of return for equity
Rd : cost of debt
T : the tax rate

Currently, the Weighted Average Cost of Capital (WACC) for projects in Indonesia is set at 10%, which serves as the base scenario in this study. This WACC is calculated based on a 70:30 debt-to-equity ratio, a 15% cost of equity, a 10% cost of debt, and a 25% tax rate (IESR, 2019).

However, it is possible to achieve a lower project discount rate of 5% by securing loans with lower interest rates from international institutions and by reducing the equity proportion in the project.

For the rate of return for equity, the Private sector targeted a cost of equity of 15% to 20% for investing in IKN (Juwita, 2024). Moreover, the ratio of equity in the project can be minimized to 20% since the International Bank for Reconstruction and Development (IBRD) has established a minimum Equity-to-Loans ratio of 19% ((International Bank for Reconstruction and Development, 2023).

To further reduce the WACC, concessional financing can be utilized. Concessional financing provides loans at interest rates below market levels and has been instrumental in supporting renewable energy projects. For example, the World Bank Group and its partners have provided cornerstone capital for new renewable energy projects at interest rates between 1% and 2% (World Bank Group, 2021).

By adjusting the equity-to-debt ratio to 80:20, securing a 15% return on equity, and utilizing a 2% interest loan, the WACC can potentially be reduced to 4.2%. However, to access such favourable financing, borrowers must typically meet strict lender requirements. These often include securing government guarantees and complying with stringent environmental regulations.

5.6. Scientific Contribution of the Methodology

Backcasting methodology is categorized into two approaches: participatory and non-participatory. This study employs the non-participatory approach, as it does not directly involve stakeholders. The backcasting framework used in this study integrates both quantitative and qualitative methods, leveraging their strengths while addressing their weaknesses. This approach provides a deeper understanding of complex issues by contextualizing numerical data (Bryman, 2006). Additionally, the study utilizes energy modeling to develop future systems and simulate the impacts of actions and policies.

Energy modeling in backcasting framework allows researchers to develop various scenarios based on different assumptions, broadening the study and providing deeper insights into potential future systems. This approach offers advantages that are not attainable through participatory backcasting methodologies, which involve a wide range of stakeholders and gather their assumptions or interpretations through interviews or group discussions.

This research uses energy modeling to develop two future visions: the least-cost vision and the diversification vision. The energy model simulates the entire Kalimantan Island, optimizing renewable energy sources and selecting the least-cost combination to meet demand. This approach provides detailed information on the power plant capacities needed for each province, including IKN. This approach provides detailed information on the power plant capacities needed for each province, including IKN. It addresses a gap in current research by offering projections for the electricity system in IKN by 2045.

To develop actions and policies for transitioning from the present to the future, this study employs a Driver and Barriers analysis using PESTEL. PESTEL offers a comprehensive view of all sectors affecting the energy transition in IKN. Integrating PESTEL analysis within the backcasting framework provides a broader perspective on challenges and helps in developing more accurate solutions by addressing issues across all PESTEL sectors. This methodology can also be applied to other fields, such as transportation, healthcare, and education, where changes depend on integrating PESTEL sectors.

The Driver and Barriers analysis using PESTEL reveals comprehensive challenges across all sectors. This addresses a gap in current research, which often focuses only on one or two sectors, such as politics and economics. The results provide insights into which sectors present the greatest challenges and where attention should be focused. In the context of renewable energy development in IKN, the political and economic sectors pose the most critical challenges. These findings offer valuable insights into the actions and policies needed for more effective implementation

Lastly, energy modeling enhances the backcasting approach by simulating the interactions between policies, actions, and the system. This allows researchers to assess the effectiveness of various actions and policies and compare their impacts. Energy modeling also facilitates sensitivity analysis by adjusting parameters to identify necessary changes to achieve the study's goals. This study tests seven scenarios to evaluate the effectiveness of actions and policies. The results indicate that establishing new renewable energy laws and providing low discount rates will significantly boost renewable energy development in IKN.

5.7. Relevance for Knowledge Users

The objective of this study is to establish a future vision for the electricity system in IKN by 2045 and to develop actions and policies that support the transition from the current conditions to this future state. The insights gained from this research are valuable for relevant stakeholders, including national and local governments as well as PLN, the key utility company.

The interim targets established in this study provide critical insights into the capacity requirements and capital expenditures (CAPEX) necessary for implementation. These targets serve as benchmarks for monitoring the progress of development and ensuring that milestones are met.

Additionally, the recommended actions and policies from this research offer guidance to the national government on accelerating development efforts. These recommendations are based on a thorough analysis and aim to address key challenges and opportunities in the transition process.

The energy model employed in this study is also applicable to future electricity system planning in other provinces of Kalimantan. The model includes hourly data series for each province, such as electricity demand and renewable energy sources like solar, wind, and hydropower. Since IKN is interconnected with other provinces, the simulation and sensitivity analysis consider the entire Kalimantan Island.

Most results from the PESTEL analysis, particularly those related to political, economic, and legal factors, have national relevance due to their alignment with overarching national policies. However, technology, environmental, and social factors may vary regionally but are generally consistent across Kalimantan.

Lastly, the PESTEL analysis provides a foundation for further research focused on the detailed examination of actions and policies in IKN or other regions in Kalimantan. For example, it can guide in-depth analysis of specific sectors, such as the examination of articles or clauses needed in the new renewable energy law in Indonesia.

5.8. Limitation on Methodology and Results

1. Limitation on Backcasting Framework

A limitation of the backcasting framework used in this research is its reliance on secondary data, primarily collected from desk research, including scientific articles, government documents, reports, and news sources. While these sources provide valuable information, they may not fully capture the perspectives and vested interests of the stakeholders involved. The lack of direct input from stakeholders could result in an incomplete understanding of the current situation, especially considering the dynamic and rapidly changing nature of renewable energy development.

Moreover, this backcasting framework does not deeply analyze specific solutions for change. Instead, it develops solutions by exploring drivers and challenges through PESTEL analysis. As a result, the solutions are relatively general and address the broad challenges identified in the PESTEL analysis. This methodology was chosen because the study aims to perform a backcasting analysis by examining the various aspects affecting the transition in IKN.

2. Limitation on the Energy Model

1. Reduction of Fossil Fuel Power Plant

This research simulates the future system by gradually decreasing the capacity of existing fossil fuel power plants on Kalimantan Island. However, the strategy for implementing this reduction is not detailed.

2. The hourly data for solar, hydro, and wind used in the simulations for 2030, 2035, 2040, and 2045 are the same. However, in reality, this data should vary across the years.

3. Simplification of transmission and distribution line

In this research, the transmission and distribution aspects are simplified due to the complexity of actual power lines. Modeling the detailed network of transmission and distribution lines would require considerable effort and time. Instead of accounting for every specific line and its characteristics, a more straightforward representation is used. This simplification is necessary because incorporating the detailed network into the Calliope software would be highly time-consuming and computationally intensive.

4. Cost constraint for Transmission line

The costs for transmission line infrastructure are determined based on energy capacity costs per megawatt, as derived from academic sources. This method is utilized because the total length of AC connections between nodes is unknown. Consequently, the capital expenditure (CAPEX) of transmission lines is calculated per unit of installed active capacity rather than per unit of length. However, this approach has limitations since transmission line costs are distance dependent.

6. CONCLUSION

6.1. Answering Main and Sub-Research Questions

6.1.1. Answering the Main Questions

What renewable energy sources are the most cost-effective for achieving 100% renewable electricity in the New Capital City of Indonesia by 2045, and what actions and policy measures are required to facilitate their development and implementation?"

The simulations indicate that by 2045, IKN can be powered most cost-effectively by a combination of large hydropower and solar PV power plants. With an expected demand of 792 MW, the hydropower capacity is projected to be 791 MW, while the solar PV capacity is estimated at 870 MW. This combination will be sufficient to meet the demand and ensure grid stability. illustrates the projected electricity system for IKN from 2030 to 2045. Figure 6-1 present the projected electricity system in IKN which is produced by the least-cost renewable energy mix.

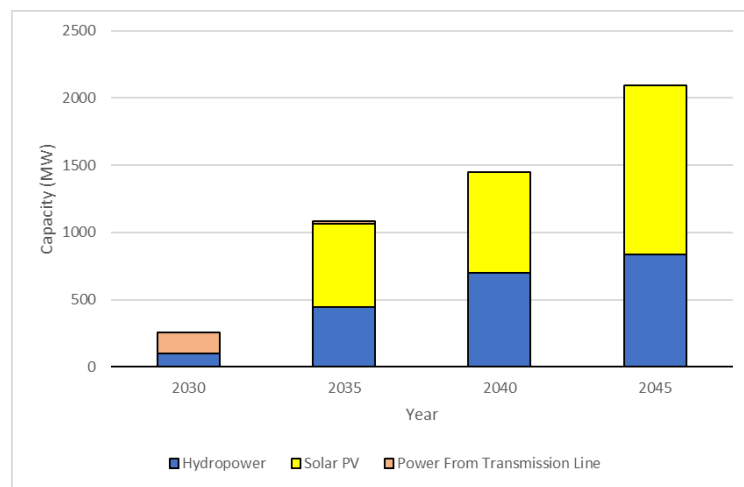


Figure 6-1 Projected Renewable Energy Mix in Power System in IKN

Several factors affect the implementation of renewable energy projects in IKN, including political, economic, social, technological, environmental, and legal aspects. Among these, political and economic factors pose the greatest challenges. Therefore, the national government must address these barriers through targeted changes.

In the policy and regulatory sector, establishing new renewable energy laws is crucial to attracting investors. Economically, essential strategies to ensure project viability include providing government loan guarantees, leveraging grants and concessional loans from international organizations, and encouraging participation from domestic banks.

6.1.2. Answering Sub-question No.1

What is the current state of the electricity system in the location of the New Capital City of Indonesia, and what renewable energy source potentials are available to support the future electricity system?

IKN developed in two regencies in East Kalimantan: Penajam Paser Utara and Kutai Kertanegara. The electricity demand in Penajam Paser Utara is 16 MW, while in Kutai Kertanegara, it is 118 MW. Currently, the systems are mainly powered by coal-fired, combined Cycle, Natural Gas, and Diesel Engine Power Plants.

The development of renewable energy in IKN is primarily driven by the National Government. Meanwhile, regional authorities assist during the implementation phase by managing land permits, ensuring compliance with local regulations, and engaging with local communities.

Kalimantan Island has significant potential for solar and hydropower. Additionally, biomass, onshore wind energy, and ocean thermal energy conversion (OTEC) are viable options given their availability and economic feasibility. However, geothermal energy reserves are limited, and offshore wind energy is not economically viable.

6.1.3. Answering Sub-question No.2

What are the visions and desirable futures for the electricity system in the new capital city of Indonesia in 2045?

By 2045, the electricity demand in IKN is projected to reach 792 MW. To meet this demand, IKN is supplied by several Extra High Voltage Substations (GITET) at 500/150 kV, which then distribute the electricity to various 150/20 kV substations around IKN. Additionally, by that time, the entire Kalimantan electricity system had been interconnected, including IKN.

In addressing how to meet this demand, two future visions have been developed: the least-cost vision and the diversification vision. In the least-cost vision, IKN's electricity needs are met primarily by hydropower and solar PV. This combination is sufficient to fulfill the demand and ensure grid stability. In 2045, The hydropower capacity is projected to be 791 MW, while the solar PV capacity is expected to be 870 MW.

On the other hand, the diversification vision reduces the reliance on hydropower and solar PV. As their capacities are lowered, battery storage and biomass become increasingly important. Batteries assume the storage role previously provided by large hydropower, while biomass supplies steady, reliable power. However, this shift results in higher costs. The Levelized Cost of Electricity (LCOE) increases from 4.57 cents \$/kWh in the base scenario to 4.67, 4.87, and 5.35 cents \$/kWh as hydropower and solar PV capacities are reduced by 10%, 25%, and 50%, respectively.

In conclusion, while both visions offer solutions to meet the projected electricity demand in IKN by 2045, they present different approaches and cost implications, highlighting the need for strategic planning and investment.

6.1.4. Answering Sub-question No.3

What factors are influencing renewable energy development in the New Capital City?

The development of renewable electricity in Indonesia's new capital city (IKN) is driven by several factors but also faces significant barriers across various sectors.

Politically, the government's commitment to achieving NZE by 2045 strongly drives the development of renewable energy in IKN. However, challenges include policy uncertainty, inconsistent regulations, and subsidies favoring fossil fuels. Institutional weaknesses, poor interministerial coordination, and slow government processes, such as land access and price negotiations, further hinder progress. Negative investment policies and local content requirements also complicate the renewable energy landscape.

Economically, the drive for sustainable growth and job creation supports renewable energy development. Yet, obstacles such as the lack of long-term financing, low return rates, and limited financial resources for PLN and other developers need to be addressed. Socially, while the local community is generally supportive, there is resistance to renewable energy due to demands for lower prices, comfort with existing fossil fuels, and low awareness of fossil fuel depletion. Specific opposition to hydropower projects highlights these social challenges.

Technologically, Kalimantan has abundant hydropower and solar PV resources, and the technology is sufficiently mature. However, issues such as intermittent solar output, lengthy development timelines, extensive land requirements, and the need for additional investments to manage intermittent renewables present significant challenges. Limited smart grid technology in IKN also slows the transition to renewable electricity.

Environmentally, despite improvements in air quality, concerns include the impact of solar PV on vegetation, inadequate environmental regulations, and ecological disruptions from hydropower dams, such as alterations in river hydrology. Legally, securing access and permits for renewable energy projects remains complex despite a strong legal framework.

6.1.5. Answering Sub-question No.4

What Actions and Policies need to be implemented to achieve the desirable futures for the electricity system by 2045?

The policy and action to develop renewable energy in IKN encompass a comprehensive approach, addressing the need for changes in Policy and regulation, financial and economic, institutional, technological, and social sectors.

Firstly, the establishment of a Renewable Energy Law is a crucial step in creating a robust legal framework. This new law clearly defines the roles and responsibilities of all stakeholders involved, addressing gaps and ambiguities in existing regulations. Moreover, Relaxing local content requirement policies will critically accelerate the development of solar PV. Strengthening environmental regulations will further support the adoption of renewable energy projects.

Financial and economic measures play a crucial role in this transition. Providing government loan guarantees, utilizing grants and concessional loans from international organizations, and

encouraging domestic banks to offer low-interest rates are considered essential strategies to make renewable energy projects financially viable. The project with have low discount rate can significantly reduce the annual cost of investment and boost the development of solar PV.

Institutional changes are also essential. Strengthening institutional capacity and improving coordination between ministries will help ensure cohesive policy implementation. This can prevent delays in the construction of renewable energy projects, particularly hydropower plants, which play a crucial role in IKN's energy plan.

Technological advancements are crucial for integrating renewable energy into IKN's electricity system. Emphasizing mature technologies can mitigate project risks, making them more attractive to investors and easier to finance. Utilizing proven technologies, such as high-efficiency solar PV, can boost electricity production and reduce annual investment costs. Additionally, addressing the intermittent nature of solar energy and implementing grid monitoring and control functions will improve grid reliability and efficiency. Regular assessments of renewable energy penetration and the use of active generation control (AGC) in power plants will further optimize system performance.

Finally, reducing electricity consumption, increasing public awareness and acceptance, engaging communities, and encouraging behavioral changes are essential for supporting renewable energy development in IKN. Lower electricity consumption can reduce peak demand and, consequently, lower annual investment costs.

6.2. Recommendations for Stakeholders

6.2.1. Recommendations for National Government

The primary factors influencing the development of renewable energy in IKN are rooted in the political and economic sectors, both of which fall under the jurisdiction of the national government. The national government plays a crucial role in shaping policies, providing funding, and creating a favorable regulatory environment to support renewable energy implementation. Therefore, establishing a new Renewable Energy Law is essential to provide a clear and comprehensive legal framework. This law should clearly define stakeholder roles, address regulatory gaps, and offer a predictable framework that ensures consistency for investors and developers.

Moreover, improving coordination among institutions and enhancing their competencies is essential, as renewable energy development in Indonesia is governed by a complex array of policies and regulations across various government agencies. Strengthening these areas will ensure a more cohesive and effective approach to accelerate the renewable energy implementation in IKN.

Additionally, financial incentives are crucial for accelerating renewable energy development in IKN, as they can lower investment costs, such as through land incentives and reduced project

discount rates. Therefore, the government should implement policies like providing guarantees for strategic projects like IKN, securing low-interest loans from international institutions, and encouraging local banks to participate in renewable energy development.

6.2.2. Recommendations for Local Government

In the development of IKN, the local government plays a crucial role in supporting the implementation of national renewable energy regulations and, most importantly, in facilitating renewable energy projects during construction. The local government can engage in direct communication with the local community and provide valuable insights into the project's environmental context.

Furthermore, to accelerate renewable energy development in IKN, the local government can expedite land acquisition and streamline the permitting process. This can be achieved by integrating advanced technology, such as land database management systems, to optimize and speed up the land acquisition process.

In addition to that, to ensure the project runs smoothly, the local government should engage the local community in the renewable energy project through a transparent process that involves them from the planning to the operation stages. Additionally, to increase public acceptance of the energy transition, the local government can educate the community about renewable energy using methods tailored to the region's social conditions, while also encouraging the adoption of high-efficiency appliances and the efficient use of electricity.

6.2.3. Recommendations for PLN

PLN is responsible for driving technological changes as the company leading the development of renewable electricity in IKN. Therefore, for the renewable energy in IKN, PLN needs to focus on Mature Renewable Energy Technologies which ensure high efficiency, allowing developers to plan electricity production more accurately such as Hydropower and Solar PV.

To enhance grid stability, which is crucial as IKN's future electricity system will rely more on solar energy, PLN should begin implementing smart grid technologies and dynamic demand response strategies. In the generation system, automatic generation control (AGC) needs to be implemented in all power plants to increase flexibility and manage intermittent solar source effectively.

Additionally, PLN can promote changes in end-user behavior by introducing Time-of-Use (ToU) pricing, where electricity is cheaper during off-peak hours and more expensive during peak times. This pricing strategy encourages consumers to shift their usage to off-peak periods, helping to balance the grid's load, reduce the need for additional energy production, conserve resources, and lower emissions.

6.3. Recommendation for Future Research

1. Stakeholder Engagement

Future research can involve direct engagement with key stakeholders to gain a comprehensive understanding of their perspectives and vested interests. This engagement can significantly enrich the research by incorporating a wider range of viewpoints and experiences. To achieve this, researchers should consider employing various qualitative methods such as conducting in-depth interviews, surveys, and focus groups. These methods allow for detailed exploration of stakeholders' opinions, motivations, and concerns. Additionally, organizing workshops or participatory sessions can facilitate interactive discussions and collaborative problem-solving, providing valuable insights directly from the actors involved. Such direct interactions are crucial for capturing the nuances and complexities of stakeholder dynamics that secondary data sources may overlook.

2. Deep Analysis of Specific Solutions

Future research could focus on a more detailed examination of specific solutions or interventions for the transition in IKN. While this study provided general solutions based on PESTEL analysis, future studies could explore these solutions in greater depth, assessing their feasibility, potential impact, and implementation strategies. This could involve existing energy modeling approaches to test the potential outcomes of different strategies of specific solutions.

3. Strategies for Retirement of Coal Power Plant in Kalimantan Island

This research proposes gradually reducing the capacity of fossil fuel power plants to zero by 2050, as shown in the simulation. However, the strategies for reducing fossil fuel capacity were not evaluated in this study, as the focus was on developing renewable electricity for the new capital city. Nevertheless, reducing fossil fuel use on Kalimantan Island is important because IKN is integrated with the entire island and may rely on electricity from other provinces. Therefore, future research on strategies for reducing fossil fuel use is crucial.

4. Incorporation of Climate Change Projections

Since this study uses the same data source for simulations of solar, hydro, and wind resources across the years 2030, 2035, 2040, and 2045, future research should incorporate climate change projections to better estimate how these resources will vary over time. By using time-varying data, future simulations can more accurately reflect the evolving nature of renewable energy resources. This approach will enhance the accuracy of energy availability assessments and provide more reliable information for decision-making.

5. Simulation of Detail Transmission and Distribution Line in IKN

The current research simplified the modeling of transmission and distribution lines due to the inherent complexity and computational intensity of detailed simulations. While this approach made the analysis more manageable, it may have compromised the accuracy and reliability of the findings. To address this, future studies should consider building more detail that

incorporates detailed characteristics of transmission and distribution networks, allowing for a more precise representation of the energy infrastructure in IKN.

REFERENCE

- Adistia, N. A., Nurdiansyah, R. A., Fariko, J., Vincent, V., & Simatupang, J. W. (2020). POTENSI ENERGI PANAS BUMI, ANGIN, DAN BIOMASSA MENJADI ENERGI LISTRIK DI INDONESIA. *TESLA: Jurnal Teknik Elektro*, 22(2), 105. <https://doi.org/10.24912/tesla.v22i2.9107>
- Agarwal, V., Anand, K., Furnari, E., & Purba, B. (2023, October 19). *How to power Indonesia's solar PV growth opportunities*. McKinsey & Company. <https://www.mckinsey.com/id/our-insights/how-to-power-indonesias-solar-pv-growth-opportunities>
- Aghapouramin, K. (2023). Techno-economic assessment of hybrid renewable energy systems for residential complexes of tabriz city, iran. *Strategic Planning for Energy and the Environment*. <https://doi.org/10.13052/spee1048-5236.4115>
- Agustina, N. (2024, March 26). Tak semua jadi usursan Otorita IKN, Alimuddin; Ada 4 tugas pokok - RADAR IBUKOTA. <https://radaribukota.com/>. <https://radaribukota.com/tak-semua-jadi-usursan-otorita-ikn-alimuddin-ada-4-tugas-pokok/#:~:text=Alimudin%20menjelaskan%20bahwa%20secara%20singkat,Pembangunan%2C%20Pemindaahan%2C%20dan%20Penyelenggaraan.>
- Aisyah, S. and Hardiyati, R. (2019). Co-authorship pattern in research on energy sector: social network analysis. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi Dan Pembangunan*, 20(1), 50-59. <https://doi.org/10.23917/jep.v20i1.7735>
- Aisyah, S. and Hardiyati, R. (2019). Co-authorship pattern in research on energy sector: social network analysis. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi Dan Pembangunan*, 20(1), 50-59. <https://doi.org/10.23917/jep.v20i1.7735>
- Aisyah, S. and Hardiyati, R. (2019). Co-authorship pattern in research on energy sector: social network analysis. *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi Dan Pembangunan*, 20(1), 50-59. <https://doi.org/10.23917/jep.v20i1.7735>
- Aleluia, J., Tharakan, P. J., Chikkatur, A. P., Shrimali, G., & Chen, X. (2022). Accelerating a clean energy transition in Southeast Asia: Role of governments and public policy. *Renewable & Sustainable Energy Reviews*, 159, 112226. <https://doi.org/10.1016/j.rser.2022.112226>
- Alexander, H. B. (2022, March 18). Green Building IKN dicapai lewat penghematan energi. *KOMPAS.com*. <https://www.kompas.com/properti/read/2022/03/18/143000921/green-building-ikn-dicapai-lewat-penghematan-energi>
- Aminuddin, A., Pranoto, B., Irsyad, M. I. a., Sihombing, A. L., & Nurliyanti, V. (2022). Hybrid floating photovoltaic - hydropower potential utilization in indonesia. *IOP Conference Series: Earth and Environmental Science*, 1105(1), 012004. <https://doi.org/10.1088/1755-1315/1105/1/012004>
- Anderson, K. (2001). Reconciling the electricity industry with sustainable development: backcasting — a strategic alternative. *Futures (London)*, 33(7), 607–623. [https://doi.org/10.1016/s0016-3287\(01\)00004-0](https://doi.org/10.1016/s0016-3287(01)00004-0)
- Ansar, A., Flyvbjerg, B., Budzier, A., & Lunn, D. (2014). Should we build more large dams? the actual costs of hydropower megaproject development. *Energy Policy*, 69, 43-56. <https://doi.org/10.1016/j.enpol.2013.10.069>
- Antara. (2024, July 7). IKN Berpotensi Ciptakan Konflik Tanah Ulayat, Guru Besar Unissula Ungkap Empat Solusinya. *tempo.co*. <https://metro.tempo.co/read/1888472/ikn-berpotensi-ciptakan-konflik-tanah-ulayat-guru-besar-unissula-ungkap-empat-solusinya>
- Ardiansyah, H. (2022). Hydropower Technology: potential, challenges, and the future. In *Penerbit BRIN eBooks*. <https://doi.org/10.55981/brin.562.c6>
- Arifin, N. (2024, May 13). Tantangan mencari AC hemat energi dan ramah lingkungan melawan panas Jakarta. *Ekuatorial*. <https://www.ekuatorial.com/2024/05/tantangan-mencari-ac-hemat-energi-dan-ramah-lingkungan-melawan-panas-jakarta/>
- ASIAN DEVELOPMENT BANK. (2020). *RENEWABLE ENERGY TARIFFS AND INCENTIVES IN INDONESIA REVIEW AND RECOMMENDATIONS*. Asian Development Bank.

<https://www.adb.org/sites/default/files/publication/635886/renewable-energy-tariffs-incentives-indonesia.pdf>

- Ayyubi, S. A., & Fitriani, F. F. (2023, August 21). 5 Tahap Pemindahan Ibu Kota ke IKN, PNS Kapan Pindah? *Bisnis.com*. <https://ekonomi.bisnis.com/read/20230821/9/1686775/5-tahap-pemindahan-ibu-kota-ke-ikn-pns-kapan-pindah>
- Bagaskara, A. (2022b). Enabling high share of renewable energy in Indonesia's power system by 2030. In Fabby Tumiwa (Ed.), *Enabling High Share of Renewable Energy in Indonesia's Power System by 2030*. Institute for Essential Services Reform. <https://iesr.or.id/wp-content/uploads/2022/11/Enabling-High-Share.pdf>
- Bai, W., Zhang, L., Lu, S., Ren, J., & Zhou, Z. (2023). Sustainable energy transition in Southeast Asia: Energy status analysis, comprehensive evaluation and influential factor identification. *Energy (Oxford)*, 284, 128670. <https://doi.org/10.1016/j.energy.2023.128670>
- Bappenas. (2019). *Low Carbon Development: A paradigm shift towards a green economy in Indonesia*. <https://lcdi-indonesia.id/wp-content/uploads/2022/03/Low-Carbon-Development-A-Paradigm-Shift-Towards-a-Green-Economy-in-Indonesia-Policymakers-Summary-2019.pdf>
- Bayissa, M., Lauwers, L., Mitiku, F., de Graaf, D. C., & Verbeke, W. (2024). System mapping of the production and value chain to explore beekeeping potential in southwest ethiopia. *Insects*, 15(2), 106. <https://doi.org/10.3390/insects15020106>
- Belinda, Y. (2023, December 22). *Local content rules holding back 9 renewable energy projects, PLN says*. Asia News Network. <https://asianews.network/local-content-rules-holding-back-9-renewable-energy-projects-pln-says/>
- Bengtson, D. N., Westphal, L. M., & Dockry, M. J. (2020). Back from the Future: The Backcasting Wheel for Mapping a Pathway to a Preferred Future. *World Futures Review*, 12(3), 270–278. <https://doi.org/10.1177/1946756720929724>
- Berawi, M. A., Suwartha, N., Salsabila, F. S. F., Gunawan, G., Miraj, P., & Woodhead, R. (2019). Land value capture modeling in commercial and office areas using a big data approach. *International Journal of Technology*, 10(6), 1150. <https://doi.org/10.14716/ijtech.v10i6.3640>
- Bimenyimana, S., Asemota, G. N. O., Niyonteze, J. D. D., Nsengimana, C., & Ihirwe, J. P. (2019). Photovoltaic solar technologies: solution to affordable, sustainable, and reliable energy access for all in rwanda. *International Journal of Photoenergy*, 2019, 1-29. <https://doi.org/10.1155/2019/5984206>
- Bitoun, R. E., David, G., & Devillers, R. (2022). Strategic use of ecosystem services and co-benefits for sustainable development goals. *Sustainable Development*, 31(3), 1296-1310. <https://doi.org/10.1002/sd.2448>
- Bitoun, R. E., David, G., & Devillers, R. (2022). Strategic use of ecosystem services and co-benefits for sustainable development goals. *Sustainable Development*, 31(3), 1296-1310. <https://doi.org/10.1002/sd.2448>
- Blum, N. U., Wakeling, R. S., & Schmidt, T. S. (2013). Rural electrification through village grids—Assessing the cost competitiveness of isolated renewable energy technologies in Indonesia. *Renewable & Sustainable Energy Reviews*, 22, 482–496. <https://doi.org/10.1016/j.rser.2013.01.049>
- Boediman, N. A., Rahadi, N. R. A., & Nugraha, N. B. A. (2021). An overview of Indonesian renewable energy studies and its investment opportunities. *Indonesian Journal of Energy*, 4(2), 87–100. <https://doi.org/10.33116/ije.v4i2.123>
- Bushe, B. (2019). The causes and impact of business failure among small to micro and medium enterprises in south africa. *Africa's Public Service Delivery and Performance Review*, 7(1). <https://doi.org/10.4102/apsdpr.v7i1.210>
- CASE Indonesia. (April 2024). Coal's endgame: Cost-benefit analysis (CBA) of early retirement coalfired power plant (CFPP) versus CFPP with carbon capture and storage (CCS). Clean, Affordable and Secure Energy for Southeast Asia (CASE) in Indonesia (CASE Indonesia).
- CASE Indonesia. (April 2024). Coal's endgame: Cost-benefit analysis (CBA) of early retirement coalfired power plant (CFPP) versus CFPP with carbon capture and storage (CCS). Clean, Affordable and Secure Energy for Southeast Asia (CASE) in Indonesia (CASE Indonesia)

- Casey, J. (2023, May 8). PLN signs PPA with Total Eren, Adaro Power and PJB for wind project in Indonesia. *Energy Global*. <https://www.energyglobal.com/wind/08052023/pln-signs-ppa-with-total-eren-adaro-power-and-pjbi-for-wind-project-in-indonesia/>
- Centre for strategic and International Studies. (2023). Economic impacts of local content requirements in Indonesia. In *CSIS.or.id*. CSIS Indonesia. <https://www.csis.or.id/publication/economic-impacts-of-local-content-requirements-in-indonesia/#:~:text=The%20use%20of%20LCRs%20was,production%20costs%20and%20consumer%20prices.>
- Chan, H. Y., & Sopian, K. (2022). Transitioning to a high renewable net-zero power generation system in Malaysia. *Philosophical Transactions of the Royal Society A*, 380(2221). <https://doi.org/10.1098/rsta.2021.0132>
- CLASP. (2020). *Indonesia Residential End Use Survey*. <https://www.clasp.ngo/wp-content/uploads/2021/01/Indonesia-Residential-End-Use-Survey.pdf>
- Communication for Change (C4C). (2021). *Penelitian persepsi kaum muda urban mengenai energi terbarukan*. <https://www.energi hijau.id/wp-content/uploads/2021/11/Penelitian-persepsi-kaum-muda-Indonesia-terhadap-energi-terbarukan.pdf>
- Cook, D. (2004): The Natural Step – towards a sustainable society. Schumacher briefing no. 11. Published by Green Books for The Schumacher Society, Devon (UK)
- Damsø, T. N. J., Christensen, T. B., & Kjær, T. (2014). Back to the Future: A Backcasting based Approach to Planning for an Energy System Transition in the Danish Region of Zealand. *The Journal of Transdisciplinary Environmental Studies*, 13(2), 12–23. http://journal-tes.dk/vol_13_no_2_page_23/no_3_Tue_Damsoe.pdf
- Damuri, Y. R., Xu, N., Suparno, R., Karina, E. N., Kusumawardhani, S., & Putra, B. A. (2023). Risks and Challenges of the Just Energy Transition Partnership (JETP) Indonesia. In *Tenggara Strategics*. [https://asset.tenggara.id/assets/source/file-research/Renewable/\[ENG%20version\]%20JETP%20Policy%20Paper.pdf](https://asset.tenggara.id/assets/source/file-research/Renewable/[ENG%20version]%20JETP%20Policy%20Paper.pdf)
- Dann, P. and Riegner, M. (2019). The world bank's environmental and social safeguards and the evolution of global order. *Leiden Journal of International Law*, 32(3), 537-559. <https://doi.org/10.1017/s0922156519000293>
- De Vries, W. T., & Schrey, M. (2022). Geospatial approaches to model renewable energy requirements of the new capital city of Indonesia. *Frontiers in Sustainable Cities*, 4. <https://doi.org/10.3389/frsc.2022.848309>
- Derbyshire, W., Wright, W., Mudiantoro, B., & Pranadi, D. (2021). Indonesia Local Content Requirement Review. In *MENTARI*. <https://mentari.info/2022/09/09/indonesia-local-content-requirement-review/>
- Dewi, R. G., Siagian, U. W. R., Asmara, B., Anggraini, S. D., Ichihara, J., & Kobashi, T. (2023). Equitable, affordable, and deep decarbonization pathways for low-latitude developing cities by rooftop photovoltaics integrated with electric vehicles. *Applied Energy*, 332, 120507. <https://doi.org/10.1016/j.apenergy.2022.120507>
- Draps, F., Sidabutar, E., & Yuliandhini, K. (2021, September 21). *Indonesia Renewable Energy Laws and Regulations 2022*. Ashurst. <https://www.ashurst.com/en/insights/indonesia-renewable-energy-laws-and-regulations-2022/>
- Dutt, A., Dutt, A., & Chawla, K. (2020). *Cheaper finance is key to lowering RE tariffs in Indonesia*. Centre for Energy Finance. Retrieved February 22, 2024, from <https://www.ceew.in/cef/publications/cheaper-finance-is-key-to-lowering-re-tariffs-in-indonesia>
- Energy backcasting: A proposed method of policy analysis. *Energy Policy*. [https://doi.org/10.1016/0301-4215\(82\)90048-9](https://doi.org/10.1016/0301-4215(82)90048-9)
- Engel-Cox, J. and Geocariss, M. (2023). Future low-carbon technology options for a 100 percent decarbonized power sector. *Climate and Energy*, 39(8), 1-10. <https://doi.org/10.1002/gas.22333>
- Executive summary – Enhancing Indonesia's Power System – Analysis - IEA. (n.d.). IEA. <https://www.iea.org/reports/enhancing-indonesias-power-system/executive-summary>
- Fareed, Z., Salem, S., Adebayo, T. S., Pata, U. K., & Shahzad, F. (2021). Role of export diversification and renewable energy on the load capacity factor in indonesia: a fourier quantile causality approach. *Frontiers in Environmental Science*, 9. <https://doi.org/10.3389/fenvs.2021.770152>

- Fearnehough, H., Skribbe, R., Hambrecht, L., NewClimate Institute, Vianda, F., & Maswan, P. (2024). Identifying finance needs for a just transformation of Indonesia's power sector. In *newclimate.org*. https://newclimate.org/sites/default/files/2024-02/indonesijetp_financeneeds_newclimate_iesr_fullreport_3.pdf
- Firman, R. S. (2022, June 9). IKN Nusantara electricity to use new renewable energy. *Antara News*. <https://en.antaranews.com/news/233369/ikn-nusantara-electricity-to-use-new-renewable-energy>
- Firmansyah, V., Adinarayana, M. K., Tetrisyanda, R., & Wibawa, G. (2023). Scenario of renewable energy transition from fossil energy resources towards net zero emission in Indonesia. *E3S Web of Conferences*, 467, 04005. <https://doi.org/10.1051/e3sconf/202346704005>
- Fragkos, P., Van Soest, H. L., Schaeffer, R., Reedman, L., Köberle, A. C., Macaluso, N., Evangelopoulou, S., De Vita, A., Sha, F., Qimin, C., Jiang, K., Mathur, R., Shekhar, S., Dewi, R. G., Diego, S. H., Oshiro, K., Fujimori, S., Park, C., Safonov, G., & Iyer, G. (2021). Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States. *Energy*, 216, 119385. <https://doi.org/10.1016/j.energy.2020.119385>
- Fripp, M., 2012. Switch: A Planning Tool for Power Systems with Large Shares of Intermittent Renewable Energy. *Environ. Sci. Technol.*, 46(11), p.6371–6378. DOI: 10.1021/es204645c
- Gatra, S. (2023, May 9). Pemanfaatan Energi Baru dan Terbarukan di IKN Nusantara Halaman all - Kompas.com. *KOMPAS.com*. <https://www.kompas.com/properti/read/2023/05/09/134403121/pemanfaatan-energi-baru-dan-terbarukan-di-ikn-nusantara?page=all>
- Ghimire, H. R. and Phuyal, S. (2022). Spatiotemporal analysis of hydropower projects with terrestrial environmentally sensitive areas of nepal. *Environmental Challenges*, 9, 100598. <https://doi.org/10.1016/j.envc.2022.100598>
- Gibbs, D., & Deutz, P. (2007). Reflections on implementing industrial ecology through eco-industrial park development. *Journal of Cleaner Production*, 15(17), 1683–1695. <https://doi.org/10.1016/j.jclepro.2007.02.003>
- Gokarn, K., Steingrube, A., & Sen, R. (2023). Local strategies towards 100% renewable energy cities and regions for west nusa tenggara, indonesia. *IOP Conference Series: Earth and Environmental Science*, 1199(1), 012009. <https://doi.org/10.1088/1755-1315/1199/1/012009>
- Gonzalez, J. M., Tomlinson, J. E., Ceseña, E. a. M., Basheer, M., Obuobie, E., Padi, P. T., Addo, S., Baisie, R., Etichia, M., Hurford, A., Bottacin-Busolin, A., Matthews, J., Dalton, J., Smith, D. M., Sheffield, J., Panteli, M., & Harou, J. J. (2023). Designing diversified renewable energy systems to balance multisector performance. *Nature Sustainability*, 6(4), 415–427. <https://doi.org/10.1038/s41893-022-01033-0>
- Govindasamy, V. and Suresh, K. (2017). Exploring approaches to drivers and barriers of corporate social responsibility implementation in academic literature. *SHS Web of Conferences*, 33, 00021. <https://doi.org/10.1051/shsconf/20173300021>
- Gubernur Kalimantan Timur. (2019). Rencana Umum Energi Daerah.
- Guild, J. (2019). Feed-in-tariffs and the politics of renewable energy in indonesia and the philippines. *Asia & The Pacific Policy Studies*, 6(3), 417-431. <https://doi.org/10.1002/app5.288>
- Hansen, K., Breyer, C., & Lund, H. (2019). Status and perspectives on 100% renewable energy systems. *Energy*, 175, 471–480
- Hasselbring, W., Carr, L., Hettrick, S., Packer, H. S., & Tiropanis, T. (2020). Open source research software. *Computer*, 53(8), 84-88. <https://doi.org/10.1109/mc.2020.2998235>
- Herrmann, N. (2011): Regional Energy 2050: A sustainability oriented strategic backcasting methodology for local utilities. 1. Edition, 2011. Rainer Hampp Verlag, München (D)
- Hoes, O., Meijer, L., Van Der Ent, R., & Van De Giesen, N. (2017). Systematic high-resolution assessment of global hydropower potential. *PLoS One*, 12(2), e0171844. <https://doi.org/10.1371/journal.pone.0171844>
- Hollmann, S., Regierer, B., Bechis, J., Tobin, L. T., & D'Elia, D. (2022). Ten simple rules on how to develop a stakeholder engagement plan. *PLoS Computational Biology*, 18(10), e1010520. <https://doi.org/10.1371/journal.pcbi.1010520>

- Howells, M. et al., 2011. OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. *Energy Policy*, 39(10), p.5850–5870. DOI: 10.1016/j.enpol.2011.06.033
- HuffPost, O. a. F. (2017, November 1). These 5 U.S. towns are powered entirely by renewable energy. HuffPost. https://www.huffpost.com/entry/american-cities-powered-by-renewable-energy_n_59ea2cbee4b0958c4681d32a#:~:text=Over%20the%20past%20decade%2C%20five,switch%20to%20100%20percent%20renewables.
- HUMAS EBTKE. (2022, November 4). *RUU EBT, wujud penguatan regulasi pengembangan energi baru terbarukan Tanah Air*. Retrieved September 3, 2024, from <https://ebtke.esdm.go.id/post/2022/11/04/3321/ruu.ebt.wujud.penguatan.regulasi.pengembangan.energi.baru.terbarukan.tanah.air>
- Humas OIKN. (2023, October 26). *Otorita IKN Pastikan Keberlangsungan Masyarakat Adat dan Kearifan Lokal*. IKN. <https://www.ikn.go.id/en/otorita-ikn-pastikan-keberlangsungan-masyarakat-adat-dan-kearifan-lokal>
- Hunter, K., Sreepathi, S. & DeCarolis, J.F., 2013. Modeling for insight using Tools for Energy Model Optimization and Analysis (Temoa). *Energy Economics*, 40, p.339–349. DOI: 10.1016/j.eneco.2013.07.014
- IESR (2023). *Indonesia Energy Transition Outlook 2024: Peaking Indonesia’s Energy Sector Emission by 2030: The Beginning or The End of Energy Transition Promise*. Jakarta: Institute for Essential Services Reform (IESR)
- IESR (2023). *Indonesia Energy Transition Outlook 2024: Peaking Indonesia’s Energy Sector Emission by 2030: The Beginning or The End of Energy Transition Promise*. Jakarta: Institute for Essential Services Reform (IESR)
- IESR. (2021). Beyond 443 GW: Indonesia’s infinite renewable energy potentials. In *Institute for Essential Services Reform*. <https://iesr.or.id/wp-content/uploads/2021/10/IESR-Beyond-443-GW-Indonesias-Infinite-Renewable-Energy-Potentials.pdf>
- IESR. (2024). *Indonesian Government’s Capacity for Just Energy Transition Planning*. Jakarta: Institute for Essential Services Reform (IESR)
- International Bank for Reconstruction and Development. (2023). *Management’s discussion & Analysis and financial Statements June 30, 2023*. <https://thedocs.worldbank.org/en/doc/66512cff3c06766d0bd85f5042d4101-0040012023/original/IBRD-Financial-Statements-June-2023.pdf>
- IRENA (2022), *Indonesia energy transition outlook*, International Renewable Energy Agency, Abu Dhabi. ISBN: 978-92-9260-476-9
- Irsyad, M. I. A., Halog, A., Nepal, R., & Koesrindartoto, D. P. (2017). Selecting tools for renewable energy analysis in developing countries: An expanded review. *Frontiers in Energy Research*, 5. <https://doi.org/10.3389/fenrg.2017.00034>
- Islam, F. R., & Mamun, K. A. (2017). Possibilities and Challenges of Implementing Renewable Energy in the Light of PESTLE & SWOT Analyses for Island Countries. In *Green energy and technology* (pp. 1–19). https://doi.org/10.1007/978-3-319-50197-0_1
- Islami, M. S., & Aditya, E. (2020). 100% Renewables Cities and Regions Roadmap. In <https://icleiseas.org/>. <https://icleiseas.org/index.php/2021/12/14/100-renewables-cities-and-regions-roadmap-project-launches-framework-and-case-studies/>
- JETP Indonesia. (2023). *Just Energy Transition Partnership Indonesia Comprehensive Investment and Policy Plan 2023*. In <https://jetp-id.org>. Retrieved February 18, 2024, from <https://jetp-id.org/cipp>
- JKALanger. (n.d.). *GitHub - JKALanger/calliope_indonesia*. GitHub. Retrieved April 4, 2024, from https://github.com/JKALanger/Calliope_Indonesia

- Jong, M. d., Joss, S., Schraven, D., Zhan, C., & Weijnen, M. (2015). Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *Journal of Cleaner Production*, 109, 25-38. <https://doi.org/10.1016/j.jclepro.2015.02.004>
- Juwita, R. D. (2024, June 27). Investors demand over 12 per cent return for Indonesia’s Nusantara projects. *The Star*. <https://www.thestar.com.my/aseanplus/aseanplus-news/2024/06/27/investors-demand-over-12-percent-return-for-indonesia039s-nusantara-projects>
- Kansongue, N., Njuguna, J., & Vertigans, S. (2023). A PESTEL and SWOT impact analysis on renewable energy development in Togo. *Frontiers in Sustainability (Lausanne)*, 3. <https://doi.org/10.3389/frsus.2022.990173>
- Kashfi, M. A. S. J. and Hanna, P. (2022). How could local communities regulate companies to assess the overlooked environmental and social impacts of industrial projects?. *Palgrave Studies in Energy Transitions*, 1-24. https://doi.org/10.1007/978-3-030-74725-1_12-1
- Kayupa, O. O. (2015). DAMPAK SEBELUM DAN SESUDAH PEMBANGUNAN PEMBANGKIT LISTRIK TENAGA AIR (PLTA) TERHADAP KONDISI SOSIAL DAN EKONOMI MASYARAKAT DI DESA SULEWANA KECAMATAN PAMONA UTARA KABUPATEN POSO. In *e-Jurnal Katalogis* (Vols. 3–11, pp. 217–227) [Journal-article]. <https://media.neliti.com/media/publications/149365-ID-dampak-sebelum-dan-sesudah-pembangunan-p.pdf>
- Kehbila, A. G., Masumbuko, R. K., Ogeya, M., & Osano, P. (2021). Assessing transition pathways to low-carbon electricity generation in kenya: a hybrid approach using backcasting, socio-technical scenarios and energy system modelling. *Renewable and Sustainable Energy Transition*, 1, 100004. <https://doi.org/10.1016/j.rset.2021.100004>
- Kementerian ESDM RI. (n.d.). Kementerian ESDM RI - Profil - Duties & Functions. [esdm.go.id](https://www.esdm.go.id/en/profile/duties-functions/kementerian-esdm). Retrieved March 7, 2024, from <https://www.esdm.go.id/en/profile/duties-functions/kementerian-esdm>
- Kencana, D. (2023, August 27). LTHE dan SKEM, Esensi Kunci Transisi dengan Efisiensi Energi. *IDN Times Jateng*. <https://jateng.idntimes.com/business/economy/dhana-kencana-1/lthe-dan-skem-esensi-kunci-transisi-dengan-efisiensi-energi?page=all>
- Khare, V., Nema, S., & Baredar, P. (2018). Reliability analysis of hybrid renewable energy system by fault tree analysis. *Energy & Environment*, 30(3), 542-555. <https://doi.org/10.1177/0958305x18802765>
- Kibler, K. M. and Tullós, D. (2013). Cumulative biophysical impact of small and large hydropower development in nu river, china. *Water Resources Research*, 49(6), 3104-3118. <https://doi.org/10.1002/wrcr.20243>
- KIC. (2022). *PERSEPSI MASYARAKAT TERHADAP ENERGI TERBARUKAN*. https://cdn1.katadata.co.id/media/files/2022/12/22/2022_12_22-14_58_37_6a6695039c4bd9122e5736eaf9e9ae51.pdf
- Kiesecker, J. M., Baruch-Mordo, S., Heiner, M., Negandhi, D., Oakleaf, J. R., Kennedy, C. M., ... & Chauhan, P. R. (2019). Renewable energy and land use in india: a vision to facilitate sustainable development. *Sustainability*, 12(1), 281. <https://doi.org/10.3390/su12010281>
- Kirby, B., & Hirst, E. (1998). Generator response to intrahour load fluctuations. *IEEE Transactions on Power Systems*, 13(4), 1373–1378. <https://doi.org/10.1109/59.736279>
- Kishita, Y., Höjer, M., & Quist, J. (2024). Consolidating backcasting: A design framework towards a users’ guide. *Technological Forecasting & Social Change*, 202, 123285. <https://doi.org/10.1016/j.techfore.2024.123285>
- Kumaran, V. V., Ridzuan, A. R., Khan, F. U., Abdullah, H., & Mohamad, Z. Z. (2020). An empirical analysis of factors affecting renewable energy consumption in association of southeast asian nations-4 countries. *International Journal of Energy Economics and Policy*, 10(2), 48-56. <https://doi.org/10.32479/ijeep.8142>
- Kumparanbisnis. (2019, September 2). *Kesiapan pasokan listrik di calon ibu kota baru*. Kumparan. Retrieved March 5, 2024, from <https://kumparan.com/kumparanbisnis/kesiapan-pasokan-listrik-di-calon-ibu-kota-baru-1rmfHQObQXL/full>
- Kusdiana, D. (2023, September 12). *Kebutuhan infrastruktur ketenagalistrikan di IKN*. Webinar Listrik Bersih Lingkungan Untuk Ibu Kota Nusantara Kalimantan Timur, Indonesia. <https://www.bapeten.go.id/berita/webinar-listrik-bersih-lingkungan-untuk-ibu-kota-nusantara-kalimantan-timur-122832#>

- Kutlu, Ç., Li, J., Su, Y., Wang, Y., Pei, G., & Riffat, S. (2020). Investigation of an innovative pv/t-orc system using amorphous silicon cells and evacuated flat plate solar collectors. *Energy*, 203, 117873. <https://doi.org/10.1016/j.energy.2020.117873>
- Langer, J., Quist, J., & Blok, K. (2021). Review of renewable energy potentials in Indonesia and their contribution to a 100% renewable electricity system. *Energies*, 14(21), 7033. <https://doi.org/10.3390/en14217033>
- Langer, J., Zaaijer, M. B., Quist, J., & Blok, K. (2023). Introducing site selection flexibility to technical and economic onshore wind potential assessments: New method with application to Indonesia. *Renewable Energy*, 202, 320–335. <https://doi.org/10.1016/j.renene.2022.11.084>
- Langer, Jannis & Lombardi, Francesco & Pfenninger, Stefan & Rahayu, Harkunti & al Irsyad, Muhammad & Blok, Kornelis. (2024). Full decarbonisation scenarios for Indonesia's power sector. 10.13140/RG.2.2.26796.85120.
- Laoli, N. (2024, February 6). *Penjualan REC Naik, PLN dinilai sukses penuhi kebutuhan listrik hijau untuk industri*. kontan.co.id. Retrieved May 22, 2024, from <https://industri.kontan.co.id/news/penjualan-rec-naik-pln-dinilai-sukses-penuhi-kebutuhan-listrik-hijau-untuk-industri>
- Liu, H., Andresen, G. B., Brown, T., & Greiner, M. (2019). A high-resolution hydro power time-series model for energy systems analysis: Validated with Chinese hydro reservoirs. *MethodsX*, 6, 1370–1378. <https://doi.org/10.1016/j.mex.2019.05.024>
- Lombardi, F., Pickering, B., Colombo, E., & Pfenninger, S. (2020). Policy Decision Support for Renewables Deployment through Spatially Explicit Practically Optimal Alternatives. *Joule*, 4(10), 2185–2207. <https://doi.org/10.1016/j.joule.2020.08.002>
- Lombardi, F., Pickering, B., Colombo, E., & Pfenninger, S. (2020). Policy Decision Support for Renewables Deployment through Spatially Explicit Practically Optimal Alternatives. *Joule*, 4(10), 2185–2207. <https://doi.org/10.1016/j.joule.2020.08.002>
- Lombardi, F., Pickering, B., Colombo, E., & Pfenninger, S. (2020b). Policy Decision Support for Renewables Deployment through Spatially Explicit Practically Optimal Alternatives. *Joule*, 4(10), 2185–2207. <https://doi.org/10.1016/j.joule.2020.08.002>
- Madsen, D. Ø. and Grønseth, B. O. (2022). Pestel analysis. *Encyclopedia of Tourism Management and Marketing*, 473-475. <https://doi.org/10.4337/9781800377486.pestel.analysis>
- Mander, S., Bows, A., Anderson, K., Shackley, S., Agnolucci, P., & Ekins, P. (2008). The Tyndall decarbonisation scenarios—Part I: Development of a backcasting methodology with stakeholder participation. *Energy Policy*, 36(10), 3754–3763. <https://doi.org/10.1016/j.enpol.2008.06.003>
- Mander, S., Bows, A., Anderson, K., Shackley, S., Agnolucci, P., & Ekins, P. (2007). Uncertainty and the Tyndall decarbonisation scenarios. *Global Environmental Change*, 17(1), 25–36. <https://doi.org/10.1016/j.gloenvcha.2006.11.004>
- Matrosov, E. S., Woods, A., & Harou, J. J. (2013). Robust Decision Making and Info-Gap Decision Theory for water resource system planning. *Journal of Hydrology*, 494, 43–58. <https://doi.org/10.1016/j.jhydrol.2013.03.006>
- Mauritzen, J. (2013). Dead battery? wind power, the spot market, and hydropower interaction in the nordic electricity market. *The Energy Journal*, 34(1), 103-124. <https://doi.org/10.5547/01956574.34.1.5>
- Misna, A. F. (2023). Indonesia's Financing and Technology Needs for Reaching NZE in 2060 or sooner. In *ASEAN Sustainable Finance for Clean Energy Workshop*. https://iea.blob.core.windows.net/assets/f4875516-8106-4413-997b-2433106bf7e2/2023.10.16_DEA-ASEANSustainableFinanceforCleanEnergyWorkshopRev3.pdf
- Muharam, A. (2021, December 9). Gubernur Kaltim Pastikan Tak Ada Tanah Adat yang Digunakan dalam Pembangunan IKN: Saya Jamin - Halaman 2. [www.Pikiran-Rakyat.com. https://www.pikiran-rakyat.com/nasional/pr-013190649/gubernur-kaltim-pastikan-tak-ada-tanah-adat-yang-digunakan-dalam-pembangunan-ikn-saya-jamin?page=2](https://www.pikiran-rakyat.com/nasional/pr-013190649/gubernur-kaltim-pastikan-tak-ada-tanah-adat-yang-digunakan-dalam-pembangunan-ikn-saya-jamin?page=2)
- National Energy Council. (2021). Technology Data for the Indonesian Power Sector -Catalogue for Generation and Storage of Electricity. https://ens.dk/sites/ens.dk/files/Globalcooperation/technology_data_for_the_indonesian_power_sector_-_final.pdf
- Negara, D. J. K. (n.d.). Membangun peradaban melalui IKN. [https://www.djkn.kemenkeu.go.id/artikel/baca/15875/Membangun-Peradaban-Melalui-IKN.html#:~:text=IKN%20akan%20dibangun%20dengan%20mengimplementasikan,%2C%20\(7\)%20kenyamanan%20dan%20efisiensi](https://www.djkn.kemenkeu.go.id/artikel/baca/15875/Membangun-Peradaban-Melalui-IKN.html#:~:text=IKN%20akan%20dibangun%20dengan%20mengimplementasikan,%2C%20(7)%20kenyamanan%20dan%20efisiensi)

- Negev, M. (2015). Interagency aspects of environmental policy: the case of environmental health. *Environmental Policy and Governance*, 26(3), 205-219. <https://doi.org/10.1002/eet.1700>
- Nic Aoidh, A., Hülsken, C., Good, C., Ó Neachtain, E., Elfgren, E., Ó hOgáin, F., Centria.fi, Risberg, M., Nic Suibhne, O., Leonard, P., Etelamaki, P., Fischer, R., Kajimura, R., Herrmann, S., Müller, U., & Mehl, W. (n.d.). *PESTLE ANALYSIS of Barriers to community Energy development*. https://www.jokkmokk.se/globalassets/kommun--samhalle/miljo-o-energi/filer/leco/pestle_analysis_leco_a4_180927-singlepages-final.pdf
- Noradika Maharani, Y., Ikhsan, & Wibowo, T. (2024). Renewable energy transition in facing climate change in indonesia. *IOP Conference Series: Earth and Environmental Science*, 1339(1), 012036. <https://doi.org/10.1088/1755-1315/1339/1/012036>
- Nugraheni, D. T., Purwana, R., & Hamzah, U. S. (2023). Environmental impact assessment of co-firing implementation at x steam power plant, west java. *Jurnal Presipitasi : Media Komunikasi Dan Pengembangan Teknik Lingkungan*, 20(2), 334-344. <https://doi.org/10.14710/presipitasi.v20i2.334-344>
- Nurfitra, A. C. T. (2023, November 27). IKN solar power plant to become operational in February 2024. *Antara News*. <https://en.antaranews.com/news/299562/ikn-solar-power-plant-to-become-operational-in-february-2024>
- OECD. (2021). *Clean Energy Finance and Investment Policy Review of Indonesia*. www.oecd-ilibrary.org. <https://www.oecd-ilibrary.org/sites/d877bde1-en/index.html?itemId=/content/component/d877bde1-en>
- Ordóñez, J. a. F., Fritz, M., & Eckstein, J. (2022). Coal vs. renewables: Least-cost optimization of the Indonesian power sector. *Energy for Sustainable Development*, 68, 350–363. <https://doi.org/10.1016/j.esd.2022.04.017>
- Osman, A. I., Chen, L., Yang, M., Msigwa, G., Farghali, M., Fawzy, S., Rooney, D. W., & Yap, P. (2022). Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. *Environmental Chemistry Letters*, 21(2), 741–764. <https://doi.org/10.1007/s10311-022-01532-8>
- Ozawa, A., Furusato, R., & Yoshida, Y. (2017). Tailor-Made feedback to reduce residential electricity consumption: The effect of information on household lifestyle in Japan. *Sustainability*, 9(4), 528. <https://doi.org/10.3390/su9040528>
- Paiboonsin, P., Oluleye, G., Howells, M., Yeganyan, R., Cannone, C., & Patterson, S. (2023). Pathways to Clean Energy Transition in Indonesia's Electricity Sector with Open-Source Energy Modelling System Modelling (OSEMOSYS). *Energies*, 17(1), 75. <https://doi.org/10.3390/en17010075>
[Pemerintah Indonesia. 2022.](https://www.pemerintah.go.id)
- Perdana, A. A., Wijaya, M. E., & Ichsan, I. (2022). Accelerating renewable energy development toward energy security. *Jurnal Kebijakan Publik*, 13(4), 404. <https://doi.org/10.31258/jkp.v13i4.8149>
- Perea-Moreno, M., Hernández-Escobedo, Q., & Perea-Moreno, A. (2018). Renewable energy in urban areas: worldwide research trends. *Energies*, 11(3), 577. <https://doi.org/10.3390/en11030577>
- Perkumpulan PRAKARSA. (2022). *Melacak Kemajuan Sektor Perbankan dalam Pembiayaan Transisi Energi Indonesia untuk Mempercepat Net Zero Emission*. Perkumpulan PRAKARSA: Jakarta
- Petrauskienė, K., Dvarionienė, J., Kaveckis, G., Kliaugaitė, D., Chenadec, J., Hehn, L., ... & Erman, M. (2020). Situation analysis of policies for electric mobility development: experience from five european regions. *Sustainability*, 12(7), 2935. <https://doi.org/10.3390/su12072935>
- Pfenninger, S., & Pickering, B. (2018). Calliope: a multi-scale energy systems modelling framework. *Journal of Open Source Software*, 3(29), 825. <https://doi.org/10.21105/joss.00825>
- Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. *Renewable & Sustainable Energy Reviews*, 33, 74–86. <https://doi.org/10.1016/j.rser.2014.02.003>
- Phillips, D., Eiser, D., & Bell, D. (2021). Options for reforming the devolved fiscal frameworks post-pandemic.. <https://doi.org/10.1920/re.ifs.2021.0207>
- Pickering, B., Lombardi, F., & Pfenninger, S. (2022). Diversity of options to eliminate fossil fuels and reach carbon neutrality across the entire european energy system. *Joule*, 6(6), 1253-1276. <https://doi.org/10.1016/j.joule.2022.05.009>

- PLN. (2021). *Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero): 2021-2030*
- PLN. (2023). *Statistik PLN 2022*. <https://web.pln.co.id/statics/uploads/2023/05/Statistik-PLN-2022-Final-2.pdf>
- Pln. (2023, November 3). Groundbreaking PLTS, PLN Hadirkan 100 Persen Energi Bersih di IKN. *Ekonomi*. <https://www.cnnindonesia.com/ekonomi/20231103152019-625-1019673/groundbreaking->
- Post, J. (2023, November 2). *PLN explains hydropower development strategy to Jokowi - Front Row - The Jakarta Post*. The Jakarta Post. <https://www.thejakartapost.com/front-row/2023/11/02/pln-explains-hydropower-development-strategy-to-jokowi.html>
- Pradnyawati, I. G. A. K. I., Ayu Putri Kartika, I. G., & Gde Subha Karma Resen, M. (2023). Konsekuensi pengaturan Kepala Otorita Ibu Kota Nusantara dalam Undang-Undang Nomor 3 Tahun 2022 tentang Ibu Kota Negara terhadap prinsip Check and Balances. *Jurnal Legislasi Indonesia*, 20(2). <https://e-jurnal.peraturan.go.id/index.php/jli/article/download/118/pdf>
- Pragt, F. (2021). Assessment of the technical and economic potential of utility-scale solar PV in Indonesia and the effects of policy interventions [Master's thesis, Delft University of Technology]. TU Delft Repository. <https://repository.tudelft.nl/>
- Pramono, A. (2023, February 3). *Pengujian Standar Kinerja Energi Minimum (SKEM) dan Label Tanda Hemat Energi (LTHE) Peralatan Pemanfaatan Energi*. <https://www.b4t.go.id/pengujian-standar-kinerja-energi-minimum-skem-dan-label-tanda-hemat-energi-lthe-peralatan-pemanfaat-energi/>
- Presidential Regulation. (2022). *Peraturan Presiden Nomor 63 Tahun 2022 Tentang Perincian Rencana Induk Ibu Kota Nusantara (Number 63 of 2022 concerning New Capital City Master Plan)*. Retrieved from <https://ikn.go.id/tentang-ikn>
- Pribadi, A. (2023, September 12). *Sekjen ESDM Tegaskan Listrik IKN harus efisien dan bersih*. www.esdm.go.id. Retrieved May 2, 2024, from <https://www.esdm.go.id/id/media-center/arsip-berita/sekjen-esdm-tegaskan-listrik-ikn-harus-efisien-dan-bersih-#:~:text=Pada%20kesempatan%20itu%2C%20Dadan%20juga,kapasitas%20ditargetkan%20sebesar%201.051%20MW.>
- PricewaterhouseCoopers. (2023, November 4). *Masdar City: The Eco-Oasis Blueprint for Sustainable Cities*. PwC. <https://www.pwc.com/gx/en/issues/esg/the-energy-transition/sustainable-energy-infrastructure/the-eco-oasis-blueprint-for-sustainable-cities.html>
- PT PLN (Persero). (n.d.). *Company profile*. web.pln.co.id. Retrieved March 11, 2024, from <https://web.pln.co.id/en/about-us/company-profile#:~:text=Our%20Business,in%20generation%2C%20transmission%20and%20distribution.>
- Purnama, I. D. (2022, February 2). Otorita IKN Nusantara Beda dengan Batam, Setara Provinsi tapi Pakai APBN. <https://economy.okezone.com/>. <https://economy.okezone.com/read/2022/02/02/470/2541497/otorita-ikn-nusantara-beda-dengan-batam-setara-provinsi-tapi-pakai-apbn?page=2>
- Purnomo, D., Budiastuti, M. T. S., & Setyaningrum, D. (2022). The role of soybean agroforestry in mitigating climate change in indonesia. *IOP Conference Series: Earth and Environmental Science*, 1016(1), 012024. <https://doi.org/10.1088/1755-1315/1016/1/012024>
- Purnomo, S. D., Wani, N., Suharno, S., Arintoko, A., Sambodo, H., & Badriah, L. S. (2023). The effect of energy consumption and renewable energy on economic growth in indonesia. *International Journal of Energy Economics and Policy*, 13(1), 22-30. <https://doi.org/10.32479/ijeep.13684>
- Putra, H. D. (2021). Energy transition in the Kalimantan Power System: Combining spatiotemporal power system modelling with Energy Justice analysis [Master Thesis, TU DELFT]. <https://repository.tudelft.nl/islandora/object/uuid:0b3063dd-dae3-4df0-a5a5-7e1521fdcc7c?collection=education>
- PwC Indonesia. (2023). *Power in Indonesia: Investment and Taxation Guide* (7th ed.) [Guide]. <https://www.pwc.com/id/en/energy-utilities-mining/assets/power/power-guide-2023.pdf>
- Quist, J. and Vergragt, P. J. (2006). Past and future of backcasting: the shift to stakeholder participation and a proposal for a methodological framework. *Futures*, 38(9), 1027-1045. <https://doi.org/10.1016/j.futures.2006.02.010>

- Rahayuv, A. C. (2023, October 25). PLN Nusantara Power akui hadapi sejumlah tantangan bangun PLTS di IKN. <https://industri.kontan.co.id/>. Retrieved February 19, 2024, from <https://industri.kontan.co.id/news/pln-nusantara-power-akui-hadapi-sejumlah-tantangan-bangun-plts-di-ikn>
- Rai, N. and Khawas, V. (2021). Climate change and hydropower development in the eastern himalaya: emerging conflicts in the upper tista catchment of sikkim, india.. <https://doi.org/10.21203/rs.3.rs-393218/v1>
- Ranalli, J. and Alhamwi, A. (2020). Configurations of renewable power generation in cities using open source approaches: with philadelphia case study. *Applied Energy*, 269, 115027. <https://doi.org/10.1016/j.apenergy.2020.115027>
- Redondo, P. D., & Van Vliet, O. (2015). Modelling the Energy Future of Switzerland after the Phase Out of Nuclear Power Plants. *Energy Procedia*, 76, 49–58. <https://doi.org/10.1016/j.egypro.2015.07.843>
- Reyseliani, N., & Purwanto, W. W. (2021). Pathway towards 100% renewable energy in Indonesia power system by 2050. *Renewable Energy*, 176, 305–321. <https://doi.org/10.1016/j.renene.2021.05.118>
- Rino, M. (2023b). Scenario Planning for Renewable Energy Development towards Net Zero Emission in Indonesia's New Capital City "Nusantara." *European Journal of Business Management and Research*, 8(6), 77–86. <https://doi.org/10.24018/ejbmr.2023.8.6.2171>
- Rohmah, K. (2023, November 14). Tahun Ini, 71 Desa di Kaltim akan Teraliri Listrik PLN. Diskominfo Prov. Kaltim. Retrieved March 5, 2024, from [https://diskominfo.kaltimprov.go.id/pembangunan/tahun-ini-71-desa-di-kaltim-akan-teraliri-listrik-pln#:~:text=Sementara%2C%20untuk%20Rasio%20Elektrifikasi%20\(RE,total%20mencapai%2099%2C99%20per](https://diskominfo.kaltimprov.go.id/pembangunan/tahun-ini-71-desa-di-kaltim-akan-teraliri-listrik-pln#:~:text=Sementara%2C%20untuk%20Rasio%20Elektrifikasi%20(RE,total%20mencapai%2099%2C99%20per)sen.
- Rotmans, J., Kemp, R., & Asselt, M. v. (2001). More evolution than revolution: transition management in public policy. *Foresight*, 3(1), 15-31. <https://doi.org/10.1108/14636680110803003>
- Sani, L., Khatiwada, D., Harahap, F., & Silveira, S. (2021). Decarbonization pathways for the power sector in Sumatra, Indonesia. *Renewable & Sustainable Energy Reviews*, 150, 111507. <https://doi.org/10.1016/j.rser.2021.111507>
- Santika, W. G., Urmeel, T., Simsek, Y., Bahri, P. A., & Anisuzzaman, M. (2020). An assessment of energy policy impacts on achieving Sustainable Development Goal 7 in Indonesia. *Energy for Sustainable Development*, 59, 33–48. <https://doi.org/10.1016/j.esd.2020.08.011>
- Sarjiya, S., Putranto, L. M., Tumiran, Budi, R. F. S., Novitasari, D., & Deendarlianto. (2023). Generation expansion planning with a renewable energy target and interconnection option: A case study of the Sulawesi region, Indonesia. *Renewable & Sustainable Energy Reviews*, 183, 113489. <https://doi.org/10.1016/j.rser.2023.113489>
- Schetinger, A. M., Dias, D. H. N., Borba, B. S. M. C., & Silva, G. D. P. d. (2020). techno-economic feasibility study on electric vehicle and renewable energy integration: a case study. *Energy Storage*, 2(6). <https://doi.org/10.1002/est2.197>
- Segreto, M., Principe, L., Desormeaux, A., Torre, M., Tomassetti, L., Tratzi, P., Paolini, V., & Petracchini, F. (2020). Trends in Social Acceptance of Renewable Energy across Europe—A Literature review. *International Journal of Environmental Research and Public Health/International Journal of Environmental Research and Public Health*, 17(24), 9161. <https://doi.org/10.3390/ijerph17249161>
- Setiawan, Agus & Arifin, Zainal & Sudiarto, Budi & Garniwa, Iwa. (2021). Electricity Tariff Simulation on The Largest Electric Power System in Indonesia Using The Time Of Use and Critical Peak Pricing Schemes Based on Revenue Neutrality. 93-98. 10.1109/ICPEA52760.2021.9639304.
- Setiawan, E. A., Thalib, H., & Maarif, S. (2021). Techno-economic analysis of solar photovoltaic system for fishery cold storage based on ownership models and regulatory boundaries in indonesia. *Processes*, 9(11), 1973. <https://doi.org/10.3390/pr9111973>
- Setiyono, J., Nabela, N., Syafiqurrohman, & NafiAlrasyid (2023). Renewable energy regulatory urgency in global energy security. *IOP Conference Series: Earth and Environmental Science*, 1270(1), 012021. <https://doi.org/10.1088/1755-1315/1270/1/012021>

- Setiyono, J., Nabela, N., Syafiqurrohman, & NafiAlrasyid (2023). Renewable energy regulatory urgency in global energy security. *IOP Conference Series: Earth and Environmental Science*, 1270(1), 012021. <https://doi.org/10.1088/1755-1315/1270/1/012021>
- Setyadi, D. S., Rowa, H., & Utomo, A. B. (2023). Permit simplification for upstream oil and gas operation in Indonesia: the development administration and good governance perspectives. *Eduvest - Journal of Universal Studies*, 3(4), 793-807. <https://doi.org/10.59188/eduvest.v3i4.789>
- Setyowati, A. B., & Quist, J. (2022). Contested transition? Exploring the politics and process of regional energy planning in Indonesia. *Energy Policy*, 165, 112980. <https://doi.org/10.1016/j.enpol.2022.112980>
- Silalahi, D. F., Blakers, A., & Cheng, C. (2023b). 100% renewable electricity in Indonesia. *Energies*, 17(1), 3. <https://doi.org/10.3390/en17010003>
- Silva, G. D. P. d. and Branco, D. A. C. (2018). Is floating photovoltaic better than conventional photovoltaic? assessing environmental impacts. *Impact Assessment and Project Appraisal*, 36(5), 390-400. <https://doi.org/10.1080/14615517.2018.1477498>
- Silva, K. d., Yapa, P., & Vesty, G. (2020). The impact of accountability mechanisms on public sector environmental sustainability performance: a case study of Sri Lanka. *Australasian Accounting, Business and Finance Journal*, 14(3), 38-55. <https://doi.org/10.14453/aabfj.v14i3.4>
- Simanjuntak, J. S. (2021). Techno-economic and institutional assessment of wind energy in Indonesia: A spatial evaluation of wind energy potential and its pertinent institution [Master's thesis, Delft University of Technology]. TU Delft Repository. <https://repository.tudelft.nl/>
- Sinha, S. and Chandel, S. (2014). Review of software tools for hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, 32, 192-205. <https://doi.org/10.1016/j.rser.2014.01.035>
- Sitanggang, E., Wihardjo, E., Mursyidah, I. L., & Jannah, W. (2024). The impact of the relocation of the state capital to East Kalimantan on the local and regional economy. *ResearchGate*. https://www.researchgate.net/publication/381515958_The_Impact_of_the_Relocation_of_the_State_Capital_to_East_Kalimantan_on_the_Local_and_Regional_Economy
- Skill, A., Author, et al. (2021). Running on renewables: Building local support for 100% net-renewable electricity resolutions at the municipal scale in the United States. *Energy Research & Social Science*. <https://doi.org/10.1016/j.erss.2021.101995>
- Skill, E. E., Stafford, E. R., & McCann, R. (2020). Community engagement strategies to achieve 100 percent net-renewable electricity resolutions. *Sustainability*, 13(5), 225-241. <https://doi.org/10.1089/sus.2020.0045>
- Song, Y., Hu, W., Xu, X., Huang, Q., Chen, G., Han, X., ... & Chen, Z. (2019). Optimal investment strategies for solar energy based systems. *Energies*, 12(14), 2826. <https://doi.org/10.3390/en12142826>
- Stocks, M., Stocks, R., Lü, B., Cheng, C., & Blakers, A. (2021). Global Atlas of Closed-Loop Pumped Hydro Energy Storage. *Joule*, 5(1), 270-284. <https://doi.org/10.1016/j.joule.2020.11.015>
- Sudarmaji, E., Achsan, N. A., Arkeman, Y., & Fahmi, I. (2022). Does rebound effect influence the factors of carbon emission in Indonesia? Kaya index and LMDI decomposition. *IOP Conference Series: Earth and Environmental Science*, 1041(1), 012086. <https://doi.org/10.1088/1755-1315/1041/1/012086>
- Sugiawan, Y., & Managi, S. (2016). The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy. *Energy Policy*, 98, 187-198. <https://doi.org/10.1016/j.enpol.2016.08.029>
- Sugiyono, A., Febijanto, I., Hilmawan, E., & Adiarso. (2022). Potential of biomass and coal co-firing power plants in Indonesia: a PESTEL analysis. *IOP Conference Series: Earth and Environmental Science (Online)*, 963(1), 012007. <https://doi.org/10.1088/1755-1315/963/1/012007>
- Suharsono, A., International Institute for Sustainable Development, & Global Subsidies Initiative. (2020). Achieving Low Solar Energy Price in Indonesia: Lessons learned from the Gulf Cooperation Council region and India. In *International Institute for Sustainable Development* [Report]. <https://www.iisd.org/system/files/publications/low-solar-energy-price-indonesia.pdf>

- Sukadri, D. (2021, May 31). Tantangan Indonesia Menuju Netral Karbon 2070 - Mongabay.co.id. Mongabay.co.id. Retrieved February 16, 2024, from <https://www.mongabay.co.id/2021/05/31/tantangan-indonesia-menuju-netral-karbon-2070/>
- Sulich, A., & Soľoducho-Pelc, L. (2021). Renewable energy producers' strategies in the Visegrád Group countries. *Energies (Basel)*, 14(11), 3048. <https://doi.org/10.3390/en14113048>
- Sunarharum, Dr. (2022, November 19). Perencanaan Pembangunan Ibu Kota Nusantara (IKN). Webinar Nasional "Aspek Penting Mitigasi Bencana Dalam Perencanaan Ibu Kota Nusantara," Jakarta, DKI Jakarta, Indonesia. https://www.its.ac.id/tgeofisika/wp-content/uploads/sites/33/2022/11/Materi-Dr-Tri-Mulyani-Sunarharum_2.pdf
- Suroso, Djoko & Prilandita, Niken & Anindito, Dhimas & Setiawan, Budhi & Nathania, Arliza & Fitriyanto, Muhammad & Pradono, Pradono & Hilman, Dadang. (2021). SNAPFI NATIONAL STUDY Indonesia - Towards Climate Governance Model for the Indonesian Energy Sector: Mapping on Actor Interaction. 10.13140/RG.2.2.24432.99841.
- Suryani, A., Bezama, A., Mair-Bauernfeind, C., Makenzi, M., & Thrän, D. (2022). Drivers and barriers to substituting firewood with biomass briquettes in the kenyan tea industry. *Sustainability*, 14(9), 5611. <https://doi.org/10.3390/su14095611>
- Tsangas, M., Jeguirim, M., Limousy, L., & Zorpas, A. A. (2019). The application of analytical hierarchy process in combination with pestel-swot analysis to assess the hydrocarbons sector in cyprus. *Energies*, 12(5), 791. <https://doi.org/10.3390/en12050791>
- Tumiran, N., Putranto, L. M., Sarjiya, N., & Pramono, E. Y. (2021). Maximum penetration determination of variable renewable energy generation: A case in Java–Bali power systems. *Renewable Energy*, 163, 561–570. <https://doi.org/10.1016/j.renene.2020.08.048>
- U.S. Energy Information Administration, Utah state energy profile, 2019
- Udin, U. (2020). Renewable energy and human resource development: challenges and opportunities in indonesia. *International Journal of Energy Economics and Policy*, 10(2), 233-237. <https://doi.org/10.32479/ijeep.8782>
- Undang-Undang Nomor 3 Tahun 2022 tentang Ibu Kota Negara. (n.d.). JDIH Kementerian Koordinator Maritim & Investasi. <https://jdih.maritim.go.id/id/undang-undang-nomor-3-tahun-2022-tentang-ibu-kota-negara>
- Untoro, A. A., & Siagian, H. N. (2021). Quo vadis steam power plant in Indonesia? Implementation of GE-McKinsey matrix analysis on creating the strategy for steam power plant business entity. *IOP Conference Series. Earth and Environmental Science (Online)*, 753(1), 012025. <https://doi.org/10.1088/1755-1315/753/1/012025>
- Vergragt, P. J., & Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue. *Technological Forecasting & Social Change/Technological Forecasting and Social Change*, 78(5), 747–755. <https://doi.org/10.1016/j.techfore.2011.03.010>
- WALHI. (2022, March 1). *Presiden Jokowi meresmikan PLTA Poso di tengah derita berkepanjangan warga - WALHI*. <https://www.walhi.or.id/presiden-jokowi-meresmikan-plta-poso-di-tengah-derita-berkepanjangan-warga>
- Widiaryanto, Pungky & Landon, Nigel & Sari, Pratama & Handayani, Wiwandari & Bassi, Andrea & Jessup, Timothy & Muslich, Anisa & Field, Simon & Yusuf, Sidqy & Purboyo, Suyuti & Ladda, Brijgopal & Ilavarasan, Rajkumar & Vong, John & Morton, Tessa & Anggraeni, Mega & Pradonawati, Niken & Contributors, Alicia. (2023). Indonesia New Capital City (IKN) Nusantara Net Zero Strategy 2045.
- World Bank Group. (2021, September 27). *What you need to know about concessional finance for climate action*. World Bank. <https://www.worldbank.org/en/news/feature/2021/09/16/what-you-need-to-know-about-concessional-finance-for-climate-action>
- Xia, Z., Li, Y., Zhang, W., Guo, S., Zheng, L., Jia, N., ... & Du, P. (2023). Quantitatively distinguishing the impact of solar photovoltaics programs on vegetation in dryland using satellite imagery. *Land Degradation & Development*, 34(14), 4373-4385. <https://doi.org/10.1002/ldr.4783>
- Yasin, T. R., Anna, Z., & Utama, G. L. (2024). Unpacking Indonesia's energy transition through a PESTEL analysis, for achieving Sustainable Development Goals. *E3S Web of Conferences*, 495, 01007. <https://doi.org/10.1051/e3sconf/202449501007>

- Yudha, S. W. and Tjahjono, B. (2019). Stakeholder mapping and analysis of the renewable energy industry in indonesia. *Energies*, 12(4), 602. <https://doi.org/10.3390/en12040602>
- Yudha, S. W. and Tjahjono, B. (2022). Unearthing the dynamics of indonesia's geothermal energy development. *Energies*, 15(14), 5009. <https://doi.org/10.3390/en15145009>
- Yudha, S. W., Tjahjono, B., & Longhurst, P. J. (2021). Stakeholders' recount on the dynamics of Indonesia's renewable energy sector. *Energies (Basel)*, 14(10), 2762. <https://doi.org/10.3390/en14102762>
- Yustika, M. (2024). Pathways to Financial Sustainability for PLN through renewable energy development. In *ieefa.org*. IEEFA. <https://ieefa.org/sites/default/files/2024-05/20240513%20-%20Pathways%20to%20Financial%20Sustainability%20for%20PLN%20through%20Renewable%20Energy%20Development.pdf>
- Zakaria, I. (2024, January 29). Potensi 7,8 Juta Ton Biomassa di Kaltim - Prokal. *Potensi 7,8 Juta Ton Biomassa Di Kaltim - Prokal*. <https://www.prokal.co/bisnis/1774047715/potensi-78-juta-ton-biomassa-di-kaltim>
- Zakaria, I. (2024b, April 8). Tanah ulayat teridentifikasi 16,34 persen dari luas Kaltim, paling luas dari 16 provinsi di Indonesia - Prokal. *Portal Berita Kalimantan*. <https://www.prokal.co/kalimantan-timur/1774527780/tanah-ulyayat-teridentifikasi-1634-persen-dari-luas-kaltim-paling-luas-dari-16-provinsi-di-indonesia>
- Zhang, H. (2019). Prioritizing access of renewable energy to the grid in china: regulatory mechanisms and challenges for implementation. *Chinese Journal of Environmental Law*, 3(2), 167-202. <https://doi.org/10.1163/24686042-12340041>

APPENDIX

Appendix A

The cities or regions aiming to achieve 100 percent renewable electricity

United States

Refer to (Engel-Cox & Geocaris, 2023) the City of Los Angeles has conducted a detailed study, known as the LA100 study, to examine the feasibility of achieving 100% renewable power by 2045. When technically feasible, especially with ongoing technology advancements, the challenge for 100 percent renewable power can now be perceived as largely economic—specifically to maintain a balance of supply and demand at a similar cost to the current system throughout seasonal variability. The author suggests that the Ideal technology solution to help maintain reliable power during extreme weather and when load drop needs to be built. Potentially viable options that have been proposed by the authors are:

- a) Develop Renewable energy technologies with less variability such as geothermal, waterpower, and biomass, could overcome the seasonal mismatch problem.
- b) Longer-duration advanced storage technologies may prove to be valuable tools in mitigating the seasonal mismatch in high renewable energy power systems.
- c) Carbon capture and storage combined with bioenergy (BECCS) can produce clean, renewable energy while emitting no emissions.
- d) Dynamic two-way distributed energy resources (DERs) in creative distributed grid architectures can stabilize the grid by offering adaptable capacity.

Other cities have also taken a role in forming energy policy. For example, the City of Philadelphia has adopted a plan to reduce carbon pollution by 80% and to transition to 100% carbon-free electricity by 2050 (Ranalli & Alhamwi, 2020). The energy optimization study for Philadelphia has been conducted by using FlexiGIS (Flexibilization in Geographic Information Systems). FlexiGIS is an open-source GIS-based platform for the optimization of flexibility options in urban areas and has previously been applied and showcased in literature in a primarily European context.

A comparison has been made between Oldenburg City, Germany, and Philadelphia in the United States. As a result, Philadelphia had a stronger demand for energy balance due to renewable energy contribution levels being higher than in Oldenburg. However, Philadelphia had a well-balanced ideal combination of solar and wind power to minimize the cost function, whereas Oldenburg strongly supported wind generation for this combination. This was approximately in line with estimations made based on the yearly variance in load, wind, and solar generation seen within the monthly aggregate time series.

Moreover, Salt Lake City, Park City, and Moab were the first cities in Utah to adopt resolutions to transition their cities to 100% net-renewable electricity (Skill et al., 2020). Over the last 20 years, Salt Lake City has been actively working to mitigate climate change and improve its local air quality, which at times ranks among the worst cities for air quality in the world (HuffPost, 2017). Some of these efforts include installing EV charging stations, adopting an idle free ordinance, adding solar energy to city buildings, implementing a residential solar installation program, adopting zoning

changes to develop more walkable and bike-able streets, increasing the number of bike lanes, and built net-zero buildings.

On the other hand, Park City has action to create green energy by installing solar arrays in public buildings. Moab City also takes action to achieve green electricity by powering 4% of the City's electricity with wind energy through a program the regional utility offered, adopting a resolution to continue to purchase wind power and encourage local businesses to do the same, and promote energy-efficient technologies. All this action needs community support to make it successful.

The research conducted by (Skill et al., 2020) provides a five-step framework to help communities across the United States country to adopt 100% net-renewable electricity resolutions which are: (1) using trigger events for inspiration; (2) envisioning change; (3) identifying challenges and potential solutions; (4) building support; and (5) taking it to a vote.

Denmark

Refer to (Theluffsen & Lund, 2016) cities and municipalities in Denmark are increasingly looking into climate and renewable energy targets. For example, Copenhagen has a target of CO₂ neutrality by 2025, Sønderborg which has target of CO₂ neutrality by 2029, and Aalborg with a vision of a local 100% renewable energy system by 2050. The goal of all of these programs is to meet local targets. Nevertheless, the methods which cities or municipalities propose may conflict with national renewable energy plans. Therefore, the right local development plan is crucial to national renewable energy systems, as stated in (Theluffsen & Lund, 2016).¹⁶ which studied the connection between the local and national system by investigating how well the systems integrate. The study divided the excess electricity into (1) integrable excess electricity and (2) nonintegrable excess electricity. Integrable excess electricity is the excess electricity that can be handled between the local and national system, while non-integrable excess electricity is the remaining excess production that has to be handled in a different manner.

An urban area in Copenhagen and a smaller city in a rural area in Sønderborg, both connect to a national Danish system has been chosen to implement the study. The Copenhagen example shows a situation with little integration between the local plan and the national plan, whereas the Sønderborg example shows a plan much more suited to integrate with the surrounding Danish energy system. In both examples the tool enables utilization of the critical excess electricity from each individual system, thus by integration enabling better performance of energy systems. In conclusion, the methodology can potentially be applied in designing energy plans that can utilize the benefits of local action and national coordination.

Abu Dhabi

Masdar City in Abu Dhabi is one of the world's most eco-friendly communities. It aims to meet all its energy needs through renewable sources. Although it still draws some power from the national grid, a significant amount is generated by 11 MW of solar panels on building roofs and an on-site solar photovoltaic plant. Currently, Masdar City is home to over 4,000 residents, with plans to eventually accommodate up to 50,000 people. The community relies partly on renewable energy produced on-

site and is built using sustainable materials. Its environmentally friendly buildings are designed to cut energy and water use by at least 40% (PricewaterhouseCoopers, 2023).

To further enhance energy efficiency, Masdar City employs various strategies. These include insulation techniques, low-energy lighting, optimizing natural light, using smart appliances and meters, and implementing building management systems that connect to the city's smart grid (PricewaterhouseCoopers, 2023).

Indonesia

The Province of West Nusa Tenggara (NTB) in Indonesia has set a target to achieve 100% renewable energy use in its territory by 2050 as part of the 100% Renewables Cities and Regions Roadmap project Gokarn (2023). The energy system model used in the case of West Nusa Tenggara is KomMod, developed by Fraunhofer ISE. KomMod is an optimization model that finds the lowest cost option for a mix of supply technologies, to meet given energy demand under defined boundary conditions. It optimizes the whole energy system, including electricity, heating/cooling, and transportation, in an hourly time frame across a whole year.

Energy systems modeling has demonstrated the feasibility of achieving 100 percent renewable energy utilization at a local level in West Nusa Tenggara. This modeling has identified the combination of technologies capable of meeting energy demands, along with an optimal operational plan. Leveraging these technical insights, several recommendations can be made, particularly concerning the strategic placement of specific technologies to manage costs effectively. Additionally, recommendations can be offered for the optimal deployment of renewable energy sources and their supporting infrastructure. However, realizing this vision necessitates collaboration across various government levels, integrating both top-down and bottom-up approaches.

Nevertheless, implementing this vision faces various challenges and barriers to renewable energy development in Indonesia. These hurdles include the requirement for well-defined policy frameworks, effective financing mechanisms, and market incentives to promote the adoption of renewable energy.

Appendix B

List of Reviewed Research

No	Research Title and Author	Research Objective	Area of Study	Use Energy Modelling
1	100% Renewable Electricity in Indonesia Author: Silalahi et al. (2023) Journal name : Energies	examines a step in Indonesia's energy decarbonization process, primarily utilizing solar photovoltaics	National	Yes
2	Pathway towards 100% renewable energy in Indonesia power system by 2050 Author: (Reyseliani & Purwanto, 2021b) Journal Name: Renewable Energy	This research evaluates the transition path of Indonesia's power system to achieve 100% renewable energy by 2050.	National	Yes
3	Energy system transitions and low-carbon pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States Author: Fragkos et al., 2021 Journal name: Energy	comprehensive assessment models that incorporate detailed depictions of the energy, transport, and land systems, offering insights into emissions, energy systems, and the economic impacts of low-emission pathways up to 2050.	National	Yes
4	An assessment of energy policy impacts on achieving Sustainable Development Goal 7 in Indonesia Author: Santika et al., 2020 journal Name: Energy for Sustainable Development	evaluates the effectiveness of Indonesia's energy policy in advancing universal energy access, significantly increasing renewable energy deployment, and enhancing energy efficiency.	National	No
5	Coal vs. renewables: Least-cost optimization of the Indonesian power sector Author: Ordóñez et al. (2022) Journal name: Energy for Sustainable Development	Create a cost-optimization model for the power sector to evaluate capacity expansion, electricity generation, CO ₂ emissions, and overall system costs through 2040.	National	Yes
6	Accelerating a clean energy transition in Southeast Asia: Role of governments and public policy Author: Aleluia et al. (2022) Journal Name: Renewable & Sustainable Energy Reviews	analyses energy sector trends in Southeast Asia, emphasizing electricity supply and demand in relation to global decarbonization efforts.	National	No

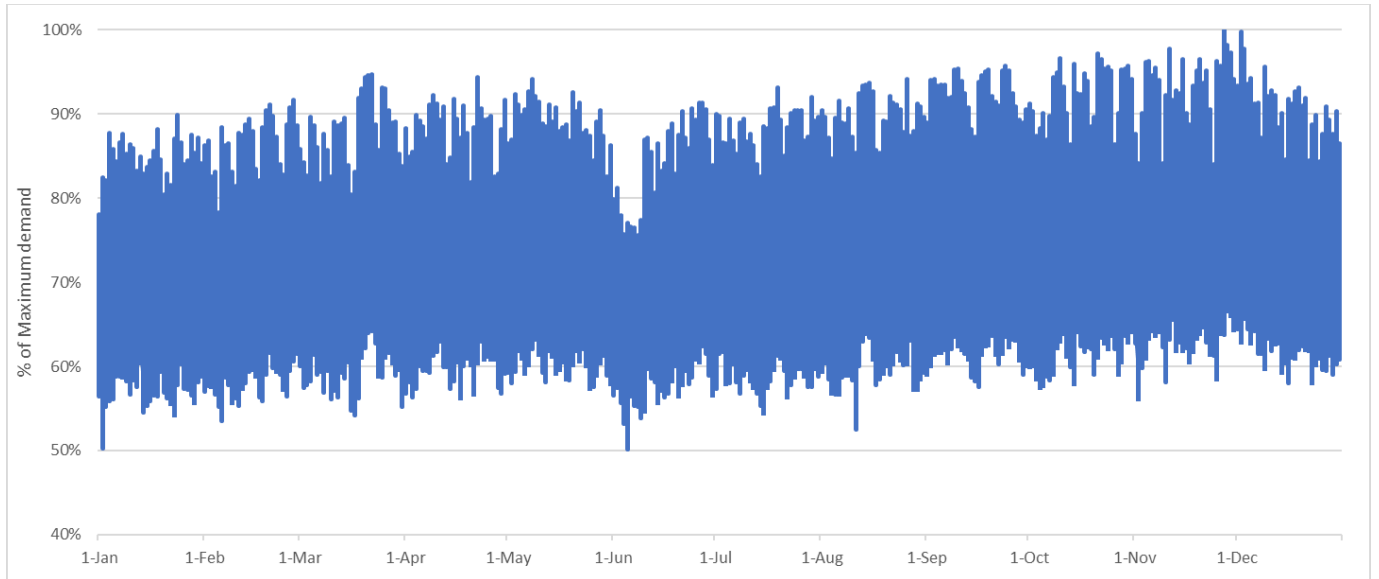
7	<p>Pathways to Clean Energy Transition in Indonesia's Electricity Sector with Open-Source Energy Modelling System Modelling (OSeMOSYS)</p> <p>Author: Paiboonsin et al. (2023)</p> <p>Journal Name: Energies</p>	<p>This project seeks to explore Indonesia's opportunities and potential for achieving low-carbon goals in the energy sector, while also identifying alternative pathways for the country's energy transition. The study utilizes the open-source energy modeling system (OSeMOSYS)</p>	National	Yes
8	<p>Scenario of renewable energy transition from fossil energy resources towards net zero emission in Indonesia</p> <p>Author: Firmansyah et al. (2023)</p> <p>Journal Name: E3S Web of Conferences</p>	<p>Examine scenarios for both energy consumption and utilization to attain net-zero emissions (NZE) by 2060.</p>	National	Yes
9	<p>Generation expansion planning with a renewable energy target and interconnection option: A case study of the Sulawesi region, Indonesia</p> <p>Author: Sarjiya et al., (2023)</p> <p>Journal name: Renewable & Sustainable Energy Reviews</p>	<p>Create an interconnection model for the Sulawesi region and determine the most effective electricity development strategy by taking into account renewable energy integration and cost optimization.</p>	Regional	Yes
10	<p>Decarbonization pathways for the power sector in Sumatra, Indonesia</p> <p>Author: (Sani et al., 2021b)</p> <p>Journal Name: Renewable & Sustainable Energy Reviews</p>	<p>Explore cost-effective pathways for advancing the power sector in alignment with climate goals using the Low Emissions Analysis Platform (LEAP) software.</p>	Regional	Yes
11	<p>Contested transition? Exploring the politics and process of regional energy planning in Indonesia</p> <p>Author: (Setyowati & Quist, 2022)</p> <p>Journal Name: Energy Policy</p>	<p>analyzes how various actors at both national and provincial levels interact during the energy planning process and identifies specific contextual factors that influence the outcomes.</p>	Regional	No
12	<p>Equitable, affordable, and deep decarbonization pathways for low-latitude developing cities by rooftop photovoltaics integrated with electric vehicles</p> <p>Author :Dewi et al., (2023)</p> <p>Journal Name: Applied Energy</p>	<p>Investigate the potential of combining rooftop photovoltaics with electric vehicles for urban decarbonization in Jakarta, Indonesia, through a techno-economic analysis.</p>	Regional	Yes
13	<p>Local strategies towards 100% renewable energy cities and regions for West Nusa Tenggara, Indonesia</p> <p>Author: Gokarn et al. (2023)</p> <p>Journal Name: Earth and</p>	<p>Reviews the findings from the energy systems modeling performed in NTB, outlining the path to achieving net-zero emissions by 2050.</p>	Regional	Yes

	Environmental Science			
14	Energy future for the new Indonesia's capital city: An energy modelling approach Author: Toontje (2022)	This research focuses on analyzing energy model scenarios for the power sector in East Borneo, where Indonesia's new capital city is situated, through to 2050.	IKN	Yes
15	Geospatial approaches to model renewable energy requirements of the new capital city of Indonesia Author: De Vries and Schrey (2022) Journal Name: Frontiers in Sustainable Cities	This article explores spatial expansion, forest encroachment, and the needs for sustainable energy infrastructure in Indonesia's new capital city	IKN	No
16	Scenario Planning for Renewable Energy Development towards Net Zero Emission in Indonesia's New Capital City "Nusantara." Author: Rino M., (2022) Journal Name: European Journal of Business Management and Research	Analyzes a net-zero emissions scenario, along with reference and renewable policy scenarios, to identify the additional actions required beyond the current path to achieve net-zero emissions.	IKN	Yes
17	Indonesia New Capital City (IKN) Nusantara Net Zero Strategy 2045 Author: Widiaryanto et al. (2023)	Formulate the Net Zero strategy for IKN by undertaking thorough preparatory stages, which involve ongoing consultations with experts, academics, relevant ministries and government bodies, local and national NGOs, associations, and community groups via workshops, focus groups, panel discussions, and public consultations.	IKN	No

Appendix C

Dataset Hourly Profile used in this study

1. Demand Profile

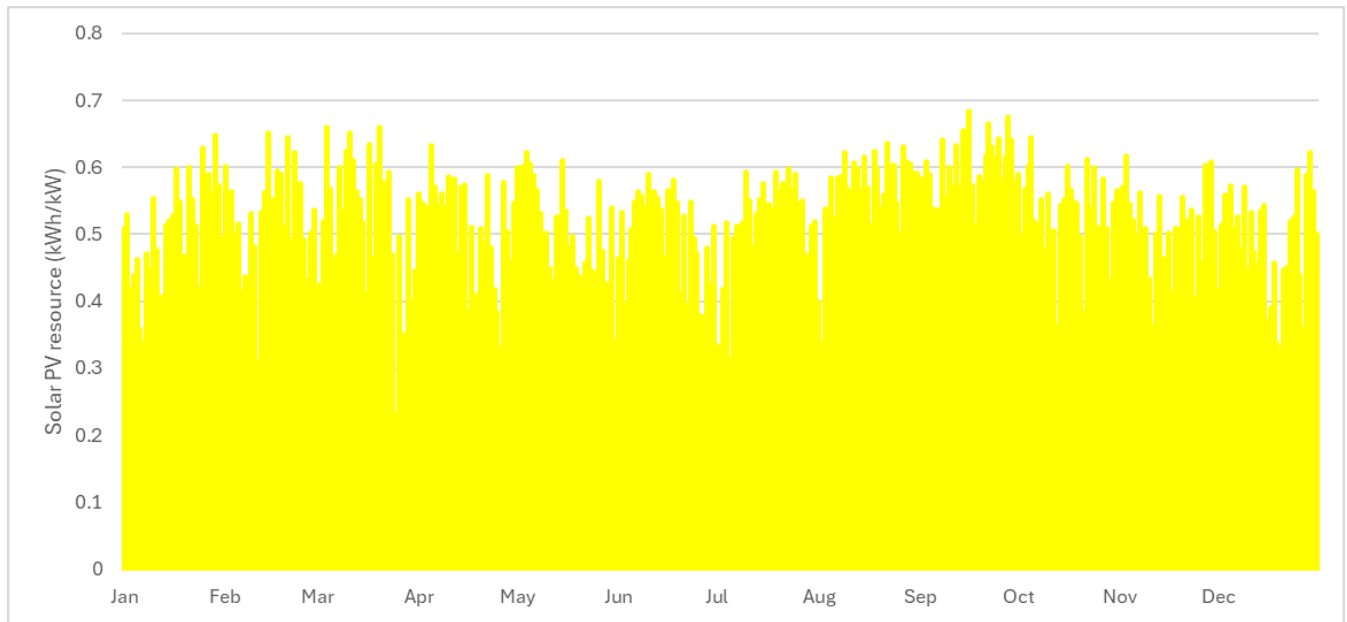


2. The Derivation Method of Solar PV Profile Dataset

The Solar energy dataset utilized in this study is derived from the publicly available Calliope Indonesia model developed by Langer et al. (2024). This dataset is generated using Geographic Information System (GIS) software, the Global Solar Atlas (GSA), and ERA5 reanalysis. Unsuitable areas such as nature conservation zones and water bodies are identified and removed using GIS. The average annual power production data is obtained from GSA.

While resource maps like GSA offer valuable insights into average annual power production, they lack temporal resolution, making them inadequate for capturing intraday and seasonal fluctuations necessary for modeling variable Renewable Energy Technologies (RET). Conversely, meteorological datasets such as ERA5 provide hourly data spanning decades, albeit with lower spatial resolution and insufficient local topographical detail (Langer et al., 2024).

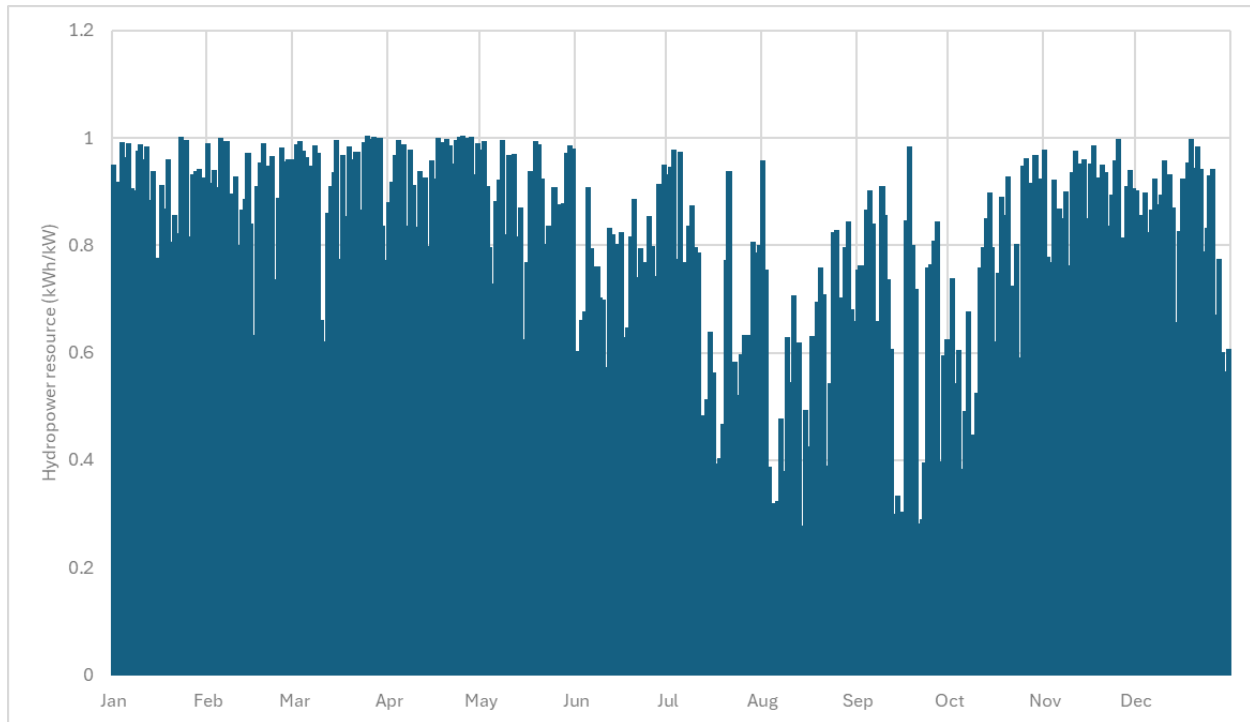
The integration of GSA and ERA5 data through bias correction methods enables high-resolution modeling of renewable power production. This process involves aligning GSA power production data with ERA5 data points, deriving site-specific scaling factors to adjust ERA5 power production profiles, and ensuring consistency with GSA values on an annual basis. This coupling enhances the accuracy of modeling renewable energy generation across both spatial and temporal scales (Langer et al., 2024).



The hourly profile of solar energy in East Kalimantan which is used in the model.

3. The Derivation Method of Hydropower Profile Dataset

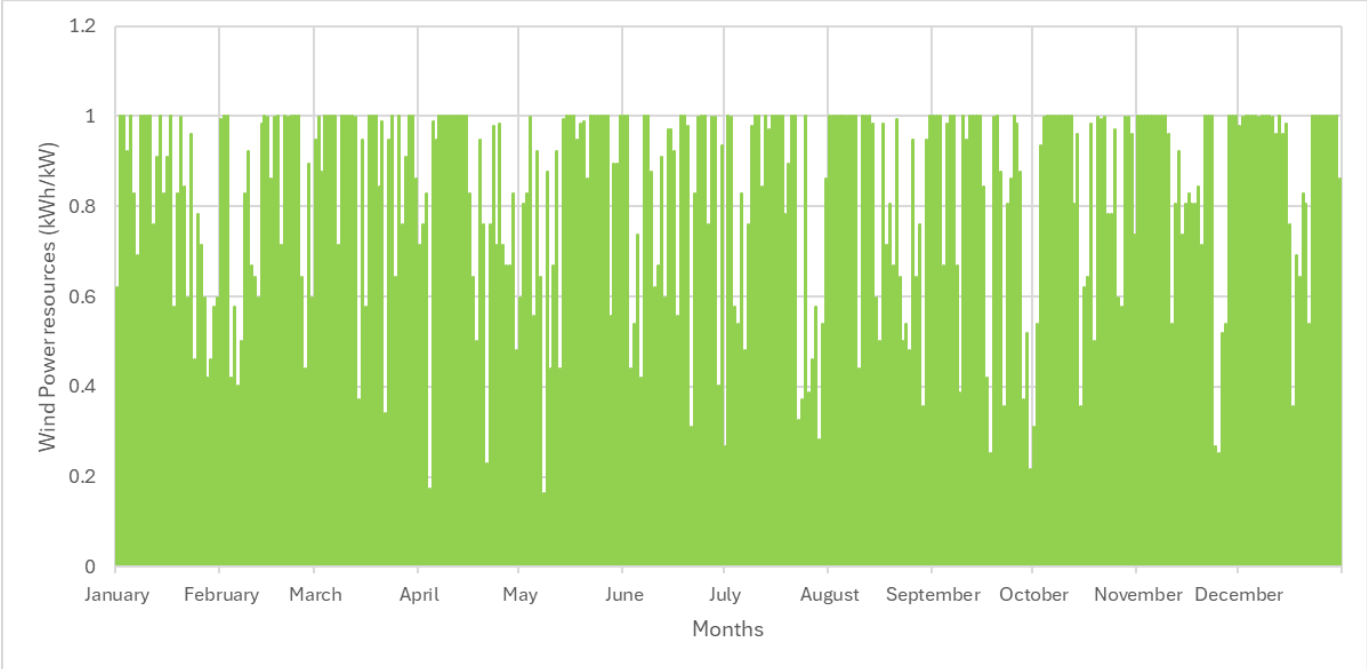
The hydropower dataset utilized in this study is derived from the publicly available Calliope Indonesia model developed by Langer et al. (2024). To ensure compatibility with Calliope, this dataset is constructed based on research by Hoes et al. (2017) and Liu et al. (2019). Specific information regarding hydropower plant locations, mean river discharge, and hydraulic head is obtained from Hoes et al. (2017). Meanwhile, the conversion of river discharge into hourly time series is accomplished using ERA5 runoff data and the methodologies outlined by Liu et al. (2019).



4. The Derivation method of Dataset of Wind Power Profile within East Kalimantan Province

In this study, various constraints are imposed on the onshore wind dataset. The hourly profile of wind energy used in the model is shown in Appendix D. These constraints include ensuring that the areas selected are outside of water bodies, built-up infrastructure, protected areas, and regions prone to natural catastrophes. Additionally, areas with slopes greater than 30 degrees and altitudes exceeding 2000 meters are excluded (Langer et al., 2024).

A minimum wind speed of 4 m/s at a hub height of 100 meters is chosen as a threshold, as it is deemed reasonable for achieving a competitive Levelized Cost of Electricity (LCOE), as suggested by Langer et al. (2024). Based on the selected hub height and wind speed criteria, wind turbines with a rated capacity of 2.5 MW and a diameter of 116 meters are chosen as the standard specification. Furthermore, the spacing between turbines within the wind farm is set by 5D x 10D rule. It means that the distance between each turbine is set to be 5 times the diameter (D) of the rotor, while the distance between rows of turbines (typically in the direction of prevailing winds) is set to be 10 times the rotor diameter.



Appendix D

The reduction of Fossil Fuel Capacity used in the model from 2022 to 2050

Province	2022				2030				2035				2040				2045				2050			
	Capacity (MW)				Capacity (MW)				Capacity (MW)				Capacity (MW)				Capacity (MW)				Capacity (MW)			
	Coal	OCGT	CCGT	Diesel	Coal	OCGT	CCGT	Diesel	Coal	OCGT	CCGT	Diesel	Coal	OCGT	CCGT	Diesel	Coal	OCGT	CCGT	Diesel	Coal	OCGT	CCGT	Diesel
West Kalimantan	436	100	0	229	349	80	0	183	262	60	0	138	174	40	0	92	87	20	0	46	0	0	0	0
Central Kalimantan	433	313	0	182	346	250	0	145	260	188	0	109	173	125	0	73	87	63	0	36	0	0	0	0
South Kalimantan	571	21	0	118	457	17	0	95	343	13	0	71	228	8	0	47	114	4	0	24	0	0	0	0
East Kalimantan	987	367	90	237	790	294	72	190	592	220	54	142	395	147	36	95	197	73	18	47	0	0	0	0
Noth Kalimantan	22	158	9	164	18	126	7	131	13	95	5	98	9	63	4	65	4	32	2	33	0	0	0	0

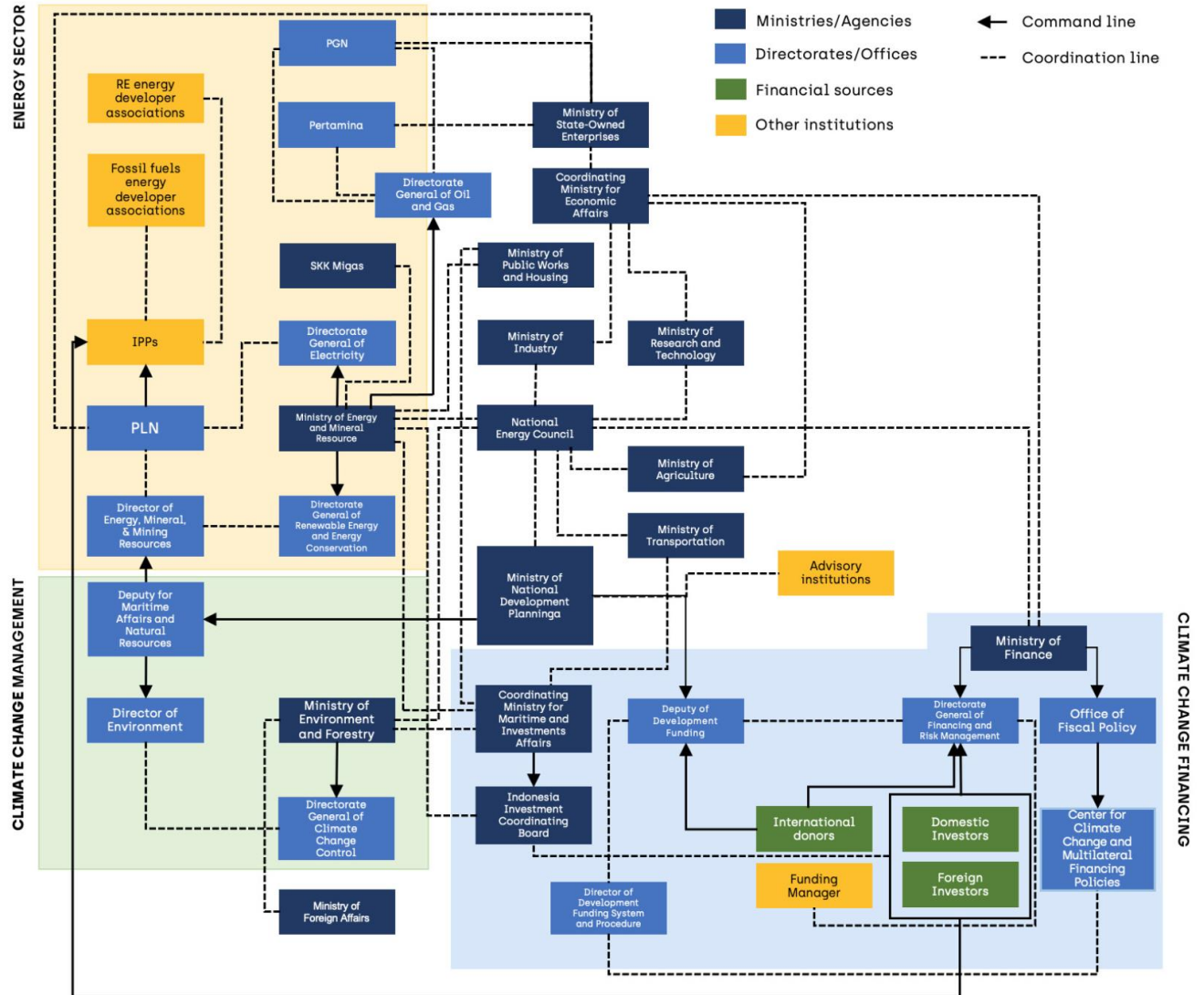
Appendix E

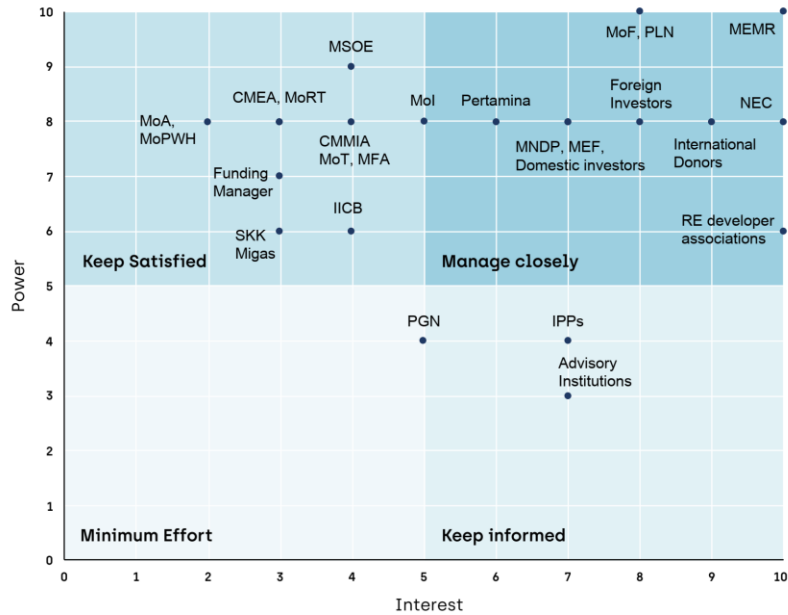
Technical and Economic Assumptions for Power generation and storage uses in this study (Langer et al., 2024)

Technology (Unit)	Coal	Diesel	CCGT	OCGT	Large Hydro (Reservoir)	Biomass	Small Hydro	Solar PV (Ground-mounted, Utility Scale)	Solar PV (Floating)	Onshore-wind	Battery	Pumped Hydro
Efficiency (%)	40%	48%	61%	405%	80%	32%	80%	X	X	X	-	-
Lifetime (years)	30	25	25	25	50	25	50	40	25	30	30	50
Minimum Load (%)	20	6	15	15	0	30	0	0	0	0	-	-
CAPEX (US\$/kWgen or US\$/MWhstor)												
2030	1442	847	958	986	1963	1923	2410	519	848	1116	298125	1116
2035	1430	842	939.5	970	1928	1822	2365.5	482.5	660.5	1058	275540	1116
2040	1418	837	921	954	1893	1721	2321	446	473	1000	252955	1116
2045	-	-	-	-	1858.5	1707	2277	409	439	942	230369.5	1116
2050	-	-	-	-	1824	1693	2233	372	405	884	207784	1116
Fixed OPEX (US\$/kWgen/year or (US\$/MWh stor/year))												
2030	42	8.5	24	24	38	46	54	5.3	16.96	33	2442	17
2035	42	8.45	24	24	37.5	44.5	53	5.15	13.21	32	2259	17
2040	42	8.4	24	24	37	43	52	5	9.46	31	2076	17
2045	-	-	-	-	36	41.5	51.1	4.85	8.78	29.5	1893	17
2050	-	-	-	-	35	40	50.2	4.7	8.1	28	1710	17
Variable OPEX (US\$/kWgen/year or (US\$/MWh stor/year))												
2030	1.3	6.4	2.3	3.3	0.7	2.9	0.5	0	0	0	1.7	0.9
2035	1.25	6.35	2.3	3.3	0.65	2.8	0.5	0	0	0	1.65	0.9
2040	1.2	6.3	2.3	3.3	0.6	2.7	0.5	0	0	0	1.6	0.9
2045	-	-	-	-	0.6	2.6	0.5	0	0	0	1.55	0.9
2050	-	-	-	-	0.6	2.5	0.5	0	0	0	1.5	0.9
Fuel Cost (US\$/MWh thermal)	12.1	38.7	23.3	23.3	0	9	0	0		0	0	0

Appendix F

stakeholder map of current Energy Sector in Indonesia (Suroso, et al. 2021)





- MoEMR : Ministry of Energy and Mineral Resources (*Kementerian Energi dan Sumber Daya Mineral/KESDM*)
- MoF : Ministry of Finance (*Kementerian Keuangan/Kemenkeu*)
- PLN : *Perusahaan Listrik Negara* (National Electricity Company)
- MoNDP : Ministry of National Development Planning (*Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional – Kementerian PPN/Bappenas*)
- MoEF : Ministry of Environment and Forestry (*Kementerian Lingkungan Hidup dan Kehutanan/KLHK*)
- MoSOE : Ministry of State-Owned Enterprises (*Kementerian Badan Usaha Milik Negara/ Kementerian BUMN*)
- Mol : Ministry of Industry (*Kementerian Perindustrian/Kemenperin*)
- CMMIA : Coordinating Ministry for Maritime and Investment Affairs (*Kementerian Koordinator Bidang Maritim dan Investasi/Kemenkomarves*)
- MoT : Ministry of Trade (*Kementrian Perdagangan*)
- MoFA : Ministry of Foreign Affair (*Kementrian Luar Negeri*)
- MoRT : Ministry of Research and Technology (*Kementerian Riset dan Teknologi/Kemenristek*)
- CMEA : Coordinating Ministry of Economic Affairs
- MoA : Ministry of Agriculture (*Kementrian Pertanian*)
- MoPWH : Ministry of Public Works and Housing (*Kementerian Pekerjaan Umum dan Perumahan Rakyat/Kementerian PUPR*)
- IICB : Indonesia Investment Coordinating Board (*Indonesian: Badan Koordinasi Penanaman Modal, BKPM*)

SKK Migas, PGN, Pertamina is excluded in this research, since it is related to the Oil and Gas infrastructure development in Indonesia.

Appendix G

Main Energy and Electricity Policies in Indonesia (Islami & Aditya, 2020)

Policy	Content
Energy Law No. 30/2007	The law emphasizes several priorities in the energy sector including energy independence, national energy availability, sustainable energy management, energy efficiency, and energy accessibility, especially for those residing in isolated islands/areas and having financial difficulties
Government Regulation (PP) No. 79/2014 on the National Energy Policy (KEN).	The KEN is an energy roadmap of Indonesia 2010-2050 which provides general energy directions. The KEN shows that Indonesia has an optimal energy mix of (1) Renewable Energy of at least 23%, oil of less than 25%, coal of at least 30% and natural gas of at least 22% by 2025; (2) NRE of at least 31%, oil of less than 20%, coal of at least 25% and natural gas of at least 24% by 2050
PP No. 22/2017 on the National Energy Plan (RUEN)	Energy Plan (RUEN) Issued by the president, to achieve the KEN target. The RUEN is a general energy management direction in Indonesia that depicts the energy vision and status, GHG emission impact reduction, energy availability for national needs, energy development priority, energy utilization, and energy reservation
Electricity law No. 30/2009	Passed to strengthen the 2007 Energy Law. The law emphasizes the role of PLN in the electricity supply business and promotes a greater role for private enterprises, cooperatives, and self-reliant community institutions to participate in the business
PP No. 14/2012 (as amended by No. 23/2014) on Electricity Business Provision	Passed to support the 2009 Electricity Law. The law states that the MEMR can determine the National Electricity Plan (RUKN) after consultation with DPR
National Electricity Plan (RUKN) 2015-2034	The development of RUKN is based on KEN and RUEN as a reference. The RUKN sets out a projection of electricity demand and supply for 20 years. It acts as a guideline in electricity generation, distribution, and transmission. It also states the electrification ratio target, which must reach 100% by 2024, the electricity status per province and consumption growth, the electricity demand, and electricity investment needs
PLN's Electricity Provision Plan (RUPTL)	A 10-year electricity development plan in the operating areas of PLN. RUPTL is an important document for investors in the Indonesian electricity sector because it contains demand and supply forecast, future expansion plans, and procurement's route for IPP.
MoEMR Regulation No. 50/2017 (as amended by No. 4/2020) on Utilization of Renewable Energy Sources for Power Supply.	This regulation regulates the tariff regimes, project financing, and procurement model for renewable electricity generation

Appendix H

SIMULATION RESULT OF THE SCENARIOS

1. Scenario-1: Impact of Local Content Requirement on LCOE

	Renewable electricity Mix in 2045	Impact of Local Content Requirement (LCR) Implementation
Capacity (MW)		
Hydropower	791	791
Solar PV	870	870
LCOE (cent \$/kWh)		
Hydropower	4.75	4.75
Solar PV	3.51	4.23
Total System	4.57	4.73

2. Scenario-2: Impact of Land Incentive Policy

	Renewable Electricity Mix in 2045 (Base Case)	Implementation of Land Incentive
Capacity (MW)		
Hydropower	791	789
Solar PV	870	898
Power from Transmissions Line	0	2.71
LCOE (cent \$/kWh)		
Hydropower	4.75	4.52
Solar PV	3.51	2.74
Total System	4.57	4.22

3. Scenario-3: Various of Project Discount Rate

	Renewable electricity Mix in 2045 with a Project Discount rate of			
	5%	7%	10%	15%
Capacity (MW)				
Hydropower	783	783	791	791
Solar PV	961	954	870	870
Transmission Line	9	8	0	0
LCOE (cent \$/kWh)				
Hydropower	2.95	3.64	4.75	6.67
Solar PV	2.18	2.69	3.51	4.99
Total System	2.97	3.60	5.49	6.26

Annual Investment Cost (Million \$)				
Hydropower	107.9	133.7	176.9	249.4
Solar PV	38.7	33.9	40.6	57.8

4. Scenario-4: using High Efficiency Solar PV Module

	Renewable Electricity Mix in 2045 (Bases Case)	Using high-efficiency Solar PV Module
Capacity (MW)		
Hydropower	791	791
Solar PV	870	829
LCOE (cent \$/kWh)		
Hydropower	4.75	4.75
Solar PV	3.51	3.35
Total System	4.57	4.53
Annual Investment Cost (Mil \$)		
Hydropower	176.9	176.9
Solar PV	40.6	38.7

5. Implementation Delay of Hydropower Plants

	Renewable electricity Mix in 2030 (Base Case)	No Installation of Hydropower in 2030
Capacity (MW)		
Hydropower	143	-
Solar PV	-	389
Power from the transmission line (East Kalimantan)	112	199
Battery	-	54
LCOE (cent \$/kWh)		
Kalimantan System	4.22	6.73
Investment Cost (Million \$)		
Hydropower	33.7	22.7
Solar PV	-	-
Battery	-	7

6. Scenario-6: Electricity Consumption Reduction

	Renewable electricity Mix in 2045 (Base Case)	Impact of Reducing the electricity consumption	
		5%	10%
Capacity (MW)			
Hydropower	791	752	712
Solar PV	870	827	784

Peak Power Demand	792	752	712
LCOE (cent \$/kWh)			
Hydropower	4.75	4.75	4.75
Solar PV	3.51	3.51	3.51
Annual Investment Cost (Million \$)			
Hydropower	176.9	168	159.2
Solar PV	40.6	38.6	36.6

7. Scenario-7: Impact of shifting electricity use from Peak to off-peak

	Renewable electricity Mix in 2045 (Base Case)	shifting electricity consumption from peak time (18:00-21:00) to off-peak time (14:00 – 16:00)	
		5%	10%
Capacity (MW)			
Hydropower	791	752	727
Solar PV	870	815	1138
Peak Demand Power	792	752	779
LCOE (cent \$/kWh)			
Hydropower	4.75	4.75	4.75
Solar PV	3.51	3.51	3.56
System	4.57	4.58	4.51
Investment Cost (Million \$)			
Hydropower	176.9	168	162.3
Solar PV	40.6	38	53.1

APPENDIX I

BACKCASTING METHOD

Quist & Vergragt (2006) discusses the evolution of backcasting as a strategic planning method and emphasizes the shift towards stakeholder participation in the backcasting process. The paper proposes a methodological framework for backcasting, highlighting the importance of engaging diverse stakeholders in the development of future scenarios and pathways. The authors emphasize the need for participatory approaches and the inclusion of stakeholder perspectives in shaping future visions and policy goals. The paper provides insights into the application of backcasting as a method for developing pathways for sustainable transitions, with a focus on stakeholder engagement and participatory decision-making.

Refer to Quist & Vergragt (2006), it has been possible to generalize and translate most backcasting approach found in several literature into a methodological framework for participatory backcasting consisting of five stages which are:

1. Strategic problem orientation;
This step includes setting normative assumptions and targets, which can also be done through stakeholder participation. This step aims at exploring the problem from a systemic viewpoint, possible problem definitions, main unsustainability, opportunities, and possible solutions, identifying and involving relevant stakeholders. In addition, it should be analyzed how the problem is perceived by different stakeholders, how it relates to need and function fulfillment on an appropriate level – which is often a societal level or the level of socio-technical systems, how other stakeholders evaluate and judge the different problem formulations according to their own mind set, values, and interests, and how supply chain and demand side are interdependent and influence each other (Quist, 2013).
2. Construction of sustainable future visions or scenarios.
The future vision in the context of backcasting refers to the desired future state that is envisioned as part of the backcasting process. It represents a normative scenario or a preferred future that serves as a guiding vision for the planning and decision-making process. The future vision is a key component of the backcasting method, as it provides a clear and aspirational target towards which the planning and action pathways are directed. It serves as a reference point for identifying the necessary steps, policies, and strategies required to achieve the desired future state. The future vision can be developed through stakeholder engagement, participatory processes, and consensus-building, and it forms the basis for developing the backcasting scenarios and pathways. It represents an idealized future that reflects the values, goals, and aspirations of the stakeholders and society, and it guides the development of strategies and actions to realize that future state.
3. Backcasting Analysis;
The backcasting analysis, which looks backward from the desired future situation, evolves around the question “WHAT changes are needed to bring about the vision?” “HOW can the changes be brought about?” and “WHO could or should contribute to realizing the vision and what activities should they do?” The WHO question can be extended by asking “who would

oppose the required changes and how can this opposition be dealt with?" It is also possible to add a question on drivers and barriers for the proposed changes (Quist, 2013)

4. Elaboration, analysis, and defining follow-up and (action) agenda.

After the analysis, a pathway was elaborated that described a possible trajectory in which the future vision would be realized. Elaboration can take many forms and depends strongly on capacity, budget, and time available. Assessments, analyses, and feasibility studies are important in the first part of this step, while defining follow-up activities and agendas that enable implementation and realization on the longer term are important in the second part of this step. (Quist, 2013)

5. Embedding of results and generating follow-up and implementation.

Although stakeholder communication and consultation took place throughout the backcasting activities, it was extended in the last phase and shortly after the project. This led to a range of research and development proposals and other initiatives (Quist, 2013)

Backcasting has emerged as a widely adopted approach for addressing sustainability challenges, such as climate change, energy supply and consumption, transportation, urban planning, and land use. Since the 1970s, numerous scholars have proposed various backcasting methodologies, offering guidance on understanding, learning, and implementing backcasting (Kishita et al., 2024). As described before, a backcasting methodology typically comprises several steps, with the target users encompassing a diverse range of stakeholders, including researchers, policymakers, corporate strategists, public interest groups, and consultants. It is important to note that each methodology should be customized to address the specific problems and issues relevant to a particular project

Vergragt and Quist (2011) have outlined the diversity of backcasting in the following manner:

- Level of participation, ranging from non-participatory to involving a broad spectrum of stakeholders or citizens, with varying degrees of influence granted to participants.
- Scale, extending from local to global considerations.
- Domain, which involves adopting an integral perspective.
- Choice between developing a single vision or multiple visions.
- Utilization of the term "backcasting," ranging from being part of an overall approach to a specific step within other methodologies.
- Explicit consideration of impact or implementation efforts.

Differences in the overarching methodologies of various backcasting approaches can be attributed in part to their intended applications. For instance, frameworks like the Natural Step and Herrmann's approach were primarily designed for organizational and energy sector contexts (Herrmann, 2011). These frameworks emphasize the formulation of strategic plans customized to specific stakeholder groups. Anderson's methodology, on the other hand, focuses specifically on the electricity industry. In contrast, the Tyndall and Robinson methodologies utilize a comprehensive system analysis approach. Furthermore, the temporal evolution and refinement of these methodologies are significant, as seen in the iterative development of Robinson's approach (Robinson, 1982; 1990).

Robinson	Anderson	The Natural Step	Tyndall	Herrmann
1. Determine objectives	1. Specify the strategic objectives	1. Awareness	1. Specify the strategic objective	1. Definition of future landing place
2. Specify goals constraints and targets	2. Describe present generation and consumption	2. Baseline	2. Describe the present energy system	2. Description of future vision
3. Describe the present system	3. Choose end-point year	3. Visioning	3. Characterize energy demand	3. Analysis of the status quo
4. Specify exogenous variables	4. End-use analysis	4. Setting and managing priorities	4. Define an energy supply system	4. Derivation of external crossroads and internal milestones
5. Undertake scenario analysis	5. Supply analysis		5. Step back in time from the defined endpoint (describe the transition)	5. Identification of a strategic pathway
6. Undertake impact analysis	6. Policy development		6. Explore implications	
	7. Review procedure			