Journal of Renewable Energy, Electrical, and Computer Engineering
Volume 4, Number 2, September 2024. 142-149
eISSN 2776-0049
Research Original Article
DOI: https://doi.org/10.29103/jreece.v4i2.16470

Economic Analysis for Using Solar Energy Implementation to Support the Development of Nusantara Capital

Muhammad Syamil Fadlillah[1], Erma Suryani✉[2], Rahmatika Jagad Pramundito[3]
[1] Department of Information System, Insitut Teknologi Sepuluh Nopember, Keputih Sukolilo, Surabaya, 60111, Indonesia, muhammadsyamil0924@gmail.com
[2] Department of Information System, Insitut Teknologi Sepuluh Nopember, Keputih Sukolilo, Surabaya, 60111, Indonesia, erma.suryani@gmail.com
[3] Department of Information System, Insitut Teknologi Sepuluh Nopember, Keputih Sukolilo, Surabaya, 60111, Indonesia
✉Corresponding Author: erma.suryani@gmail.com | Phone: +6285929020005

Received: June 03, 2024 **Revision: August 10, 2024** **Accepted: September 20, 2024**

Abstract
The dynamic simulation model for economic analysis of solar energy in the new Indonesia's capital named IKN is a computer system designed to evaluate the viability of solar energy as a power source in the new capital being developed in East Kalimantan. The model aims to assess the economic feasibility of solar energy implementation, addressing cost-effectiveness. Strategies include policy enforcement, land optimization, and population growth impacts. The model's validation showed an error rate ≤ 5% and error variance ≤ 30%, confirming its accuracy. Scenario simulations (most likely, pessimistic, and optimistic) forecasted varying returns on investment (ROI), indicating solar energy's profitability under different conditions. The optimistic scenario predicted the highest ROI of 42% by 2045, with a break-even point by 2026.
Keywords: Solar Energy; Nusantara Capital; Simulation Model; Dynamic System; Economic Analysis

Introduction
The development of Nusantara Capital so called IKN is the new Indonesia’s Capital. IKN which build in East Kalimantan is being undertaken as Indonesia's project to build a new capital (Hutasoit, 2019). The process of relocating the capital is expected to take place in 2024, based on the enactment of new laws related to the national capital itself (Thoriq & Hakim, 2024). This new capital is built to serve as a symbol of national identity, a sustainable city in the world, and as a driver of Indonesia's future economy (Silalahi, 2019). Therefore, in its development, IKN aims to ensure that it is a green and environmentally friendly city. Thus, the use of clean energy in the form of renewable energy is a necessity (Limas et al., 2021).

The development of IKN in East Kalimantan began in 2022 and will be carried out in stages until its completion in 2045 (Limas et al., 2021). The city is expected to be inhabited starting in late of 2024. As IKN is designed to be a green and sustainable city, the use of solar energy is deemed suitable and optimal due to several reasons. Solar energy is abundant and renewable, aligning with the region's geographical and climatic advantages (Gong et al., 2019). Additionally, it reduces reliance on fossil fuels, lowers carbon emissions, and supports Indonesia's commitment and IKN development goals as a capital to environmental sustainability and energy security (Zhang et al., 2022).

Therefore this research are keen to know the economic value and investment feasibility analysis of solar energy investment in Nusantara capital (IKN). The model is designed and develop to assess the viability of implementing solar energy as an electricity source in IKN, which is being developed in East Kalimantan. This new capital will encompass Kutai Kartanegara and Penajam Paser Utara, that also affecting nearby cities like Balikpapan and Samarinda (Daryono et al., 2023). However, there are diverse perceptions regarding the cost-effectiveness of solar energy. Some believe it to be prohibitively expensive, while others see it as a more affordable alternative (Hsu, 2012). To address these concerns, a simulation model was developed to provide stakeholders, including the IKN Authority and potential investors, with a comprehensive understanding of the feasibility and profitability of solar energy investment.

A dynamic system is used as the method because it can provide a holistic representation of a real-world system. This system can then be simulated to predict future outcomes, allowing for thorough analysis and the development of recommendations (Suryani et al., 2023). These recommendations help optimize the real-world system to achieve the best possible results, ensuring informed decision-making for stakeholders involved in the development of IKN.

The model integrates several strategic approaches to ensure the successful implementation of solar energy. These strategies include policy enforcement to promote solar energy use, optimizing available land for strategic solar panel installation, and managing population growth through planned migration. The increasing population in IKN is anticipated to drive up electricity demand, making efficient and sustainable energy solutions crucial (Patriamurti et al., 2021). However, uncontrolled population growth could also pose economic challenges, underscoring the need for careful planning and policy implementation (Hsiao et al., 2018).

The simulation model develop in this research is divided into five sub-models which cover the electricity need, population within the capital cities and arounds it, and economic analysis for solar. These sub-models collectively provide a detailed analysis of solar energy's economic viability. By evaluating the potential outcomes, the model aims to ensure that solar energy can effectively meet the region's growing electricity needs while providing economic benefits over time.

Materials & Methods

The method use in this research is system dynamic. System dynamics is a robust approach for understanding the behavior of complex systems over time. By utilizing this method, we can model, simulate, and analyze the interactions and feedback loops within the system under study. This methodology allows us to capture the dynamic interrelationships and temporal changes that occur within the system, providing valuable insights into its structure and behavior. The following sections will detail the specific steps and processes undertaken in applying system dynamics to our research, including model construction, validation, and simulation.

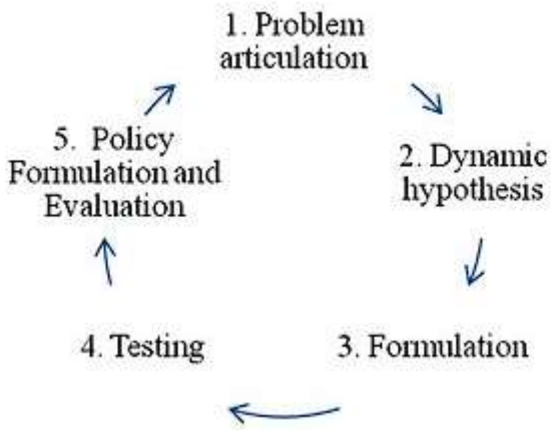


Figure 1. System Dynamic Methodology

Problem Articulation

This initial stage involves clearly defining and articulating the problem to be addressed. It includes identifying the key issues, setting the boundaries of the system, and determining the main variables and stakeholders involved. The goal is to establish a clear understanding of the problem context and objectives.

Dynamic Hypothesis

In this stage, a dynamic hypothesis is formulated to explain the causes of the problem behavior. This hypothesis is based on the understanding of the system's structure and feedback loops. It involves identifying the relationships between variables and hypothesizing how these relationships drive the behavior of the system over time. This stage is where the causal loop diagram (CLD) start to develop, CLD is a mapping form aimed at understanding cause-and-effect relationships between variables (Sterman, 2000).

Table 1. Causal Loop Diagram Symbols

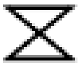
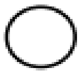
Variable	Symbol	Description
Positive Links	A —(+)→ B	There is a positive/causal relationship from variable A to variable B.
Negative Links	C —(-)→ D	There is a negative/causal relationship from variable C to variable D.
Delay Links	E —‖→ F	There is a time delay in the interaction between variable E and variable F.
Positive Loop	↺ +	The effect of a positive/increasing influence among variables where its loop is named reinforcing. This loop occurs when the relationships among variables are the same (both + positive or both - negative).
Negative Loop	↺ -	The effect of a negative/decreasing influence among variables where its loop is named balancing. This loop occurs when the relationships among variables are balancing (There is an odd number of variables with a - negative relationship).

After we find all the variables, define the characteristics of each variable in the model. Next, all the variables are modelled into a causal-loop diagram (CLD). The CLD model that has been developed can determine the cause and effect relationship between each variable in the system (Arishinta & Suryani, 2021).

Formulation

During formulation, the dynamic hypothesis is translated into a formal model. This involves constructing stock-and-flow diagrams, defining equations, and specifying parameters. The model should capture the essential features of the system and allow for simulation and analysis. In this step is where the stock and flow diagram (SFD) being develop. In an SFD, stocks represent accumulations that can increase or decrease, while flows represent the processes that cause these changes in stocks (Suryani et al., 2022). This structured classification enhances clarity and facilitates the creation of the stock and flow diagram. Following this, each variable is intricately linked based on their intrinsic relationships, ensuring that the final diagram provides a thorough and detailed depiction of the system's behavior over time (Chi et al., 2022).

Table 2. Stock and Flows Diagram Symbols

Variable	Symbol	Description
Stock (Level)		A variable that accumulates value over time based on rate changes.
Flow (rate)		A variable that influences the change in value of a stock.
Auxiliary		A variable that is influenced by other variables and contains calculation formulas.

Subsequently, dynamic systems utilize simulation processes to construct models that reflect real-world conditions. These models are rigorously tested to gain insights into the system's behavior (Shannon, 1998). Following testing, evaluations are performed to formulate operational strategies for the system. Simulations are invaluable for decision-making and designing solutions for intricate system issues, ultimately resulting in a framework that is free from assumptions (Chaharbaghi, 1990).

Testing

The model is tested to ensure its validity and reliability. This involves comparing the model's behavior with real-world data, checking for consistency and plausibility, and performing sensitivity analysis. Testing helps to refine the model and improve its accuracy in representing the actual system. In this research testing are held in 2 ways, first is verification which to ensure the model do not have bug and error within (Hendrawan et al., 2019). Secondly there is validation which to to ensure that the model's behavior outputs accurately represent current conditions. If the model does not function correctly or the results do not represent the current conditions, then the model is considered invalid (Barlas, 1996). In validation we use: mean comparison (E1) which is comparing the average of real-historical data and simulation results from the model, error varriance (E2) which is the same but comparing the standart deviation.

$$E1 = \left(\frac{S-A}{A}\right) \quad (1)$$

Where,
S = Average of simulation results
A = Average of real-historical data
The result will be considered valid if E1 < 5%.

$$E2 = \left(\frac{Ss-Sa}{Sa}\right) \quad (2)$$

Where,
Ss = Standart Deviation of simulation results
As = Standart Deviation of real-historical data
The result will be considered valid if E2 < 30%.

Policy Formulation and Evaluation

In this final stage, the validated model is used to design and evaluate potential policies or interventions. The goal is to identify strategies that can effectively address the problem and achieve desired outcomes. Different scenarios and policy options are simulated to assess their impacts and to support decision-making. The scenarios are seperated into Most likely, Optimistic, and Pessimistic. The scenarios implemented will use strategy:

1. The implementation of policies to meet electricity needs using solar energy, thereby increasing the number of installed solar panels.
2. Optimizing the amount of available or existing land through the strategic installation of solar panels, thus increasing the number of installed solar panels.

3. Increasing the population in the IKN area through planned migration. This population increase will have potential positive and negative impacts. The positive impact is an increased demand for electricity, which drives the fulfillment of electricity needs in the community. The negative impact is that uncontrolled population growth can lead to economic disparity and slow down economic development.

Data Collection

The data used in this study were meticulously gathered from a variety of sources to ensure comprehensive coverage and reliability. This section outlines the data collection methodologies employed, including the types of data collected, the sources from which the data were obtained, and the procedures followed to ensure data accuracy and integrity. By systematically collecting and analyzing relevant data, we aim to create a robust model that accurately represents the system under study and supports effective policy formulation and evaluation. The data used were obtained from reports by the Central Statistics Agency and PLN statistical reports.

Results and Discussion

In this chapter, we present the findings of our study and provide a comprehensive discussion on their implications. The results are derived from the analysis and simulations conducted using the system dynamics model outlined in the methodology section. Each key result is discussed in detail, highlighting how it contributes to our understanding of the system under study. We examine the behavior of various system variables, the impact of different policy scenarios, and the overall performance of the model in representing real-world conditions. Additionally, we interpret the significance of these findings in the context of existing literature and the practical implications for stakeholders. This discussion aims to provide a nuanced understanding of the complex dynamics at play and offer insights into potential strategies for effective system management.

Problem Articulation

By establishing these variables, we lay the groundwork for the subsequent development of our system dynamics model, ensuring a comprehensive understanding of the intricate relationships and feedback loops that drive the system's behavior. This foundational step is crucial for accurately modeling the system and deriving meaningful insights into its operation and potential interventions. It is found that all the variables are categorized as below:

Table 3. Endogenous Variables

Variables Name	
Population	PV Absorption Power
Job Availability	PV Cost Production
Industry	Capacity Charge
GDP	Total Dam
Total PV Investment	Land Availability
Return On Investment	Installation Area
Possible PV Installation	Full Time Jobs
Total PV Production Revenue	Desired Number Employment
New Electricity Budget Investment	Trainees
O&M Jobs	Governmental Subsidies
PV Installation Jobs	Technology Innovation
Total Electricity Produced	PV Conversion Loss
Electricity Demand	PV Absorption Power

Table 4. Exogenous Variables

Variables Name	
Death Rate	Projected Demand
Immigration	Work Transferred
Emigration	Local
Government Agency	

Dynamic Hypothesis

Having categorized the key variables influencing our system into endogenous and exogenous types, we now proceed to develop the Causal Loop Diagram (CLD). This step is critical as the CLD visually represents the complex interrelationships and feedback loops among the variables. The CLD will help elucidate how these variables interact over time, highlighting the reinforcing and balancing loops that drive system behavior. By constructing the CLD, we aim to capture the essence of the system's structure, providing a clear and detailed map of the causal relationships that will inform subsequent modeling and analysis stages.

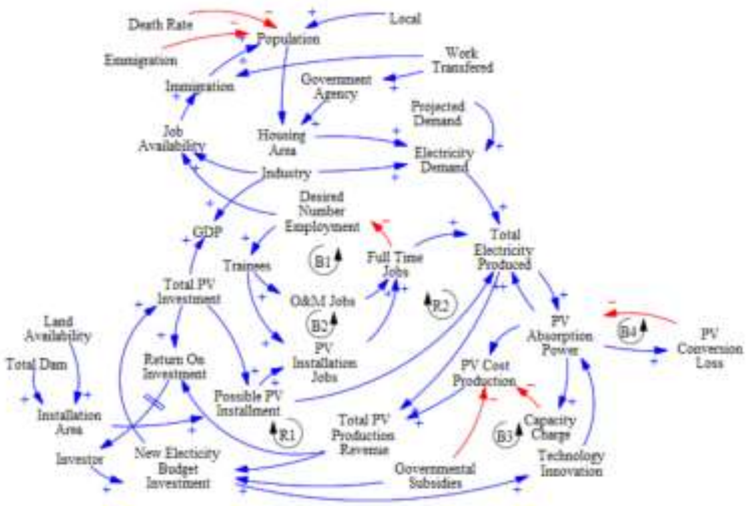


Figure 2. Causal Loop Diagram

Formulation

The model is divided into five sub-models, each with its respective name: Sub-model Electricity, Sub-model PPU & KK Population, Sub-model Samarinda Population, Sub-model Balikpapan Population, and Sub-model Solar ROI. From the Causal Loop Diagram (CLD) shown in Figure 1 of the CLD Model for Solar Energy Investment Feasibility Analysis, a Stock and Flow Diagram (SFD) will be developed. The purpose of creating the SFD is to observe the relationships and interactions between variables, providing new information about the system's state. This knowledge will offer insights into the system and influence final decision-making. The developed SFD can be used for scenario testing simulations. Before conducting scenario testing, the model will undergo validation and verification.

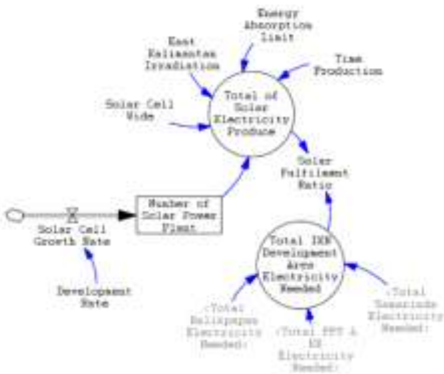


Figure 3. SFD Sub-model Electricity Production

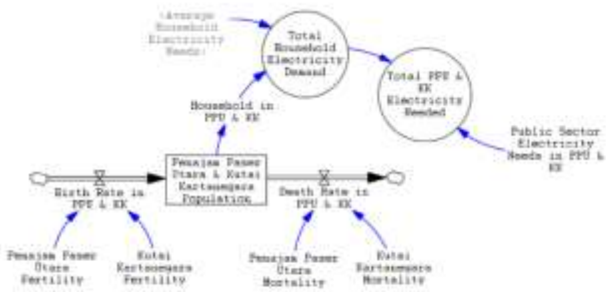


Figure 4. SFD Sub-model Capital Area Eletricity Needs

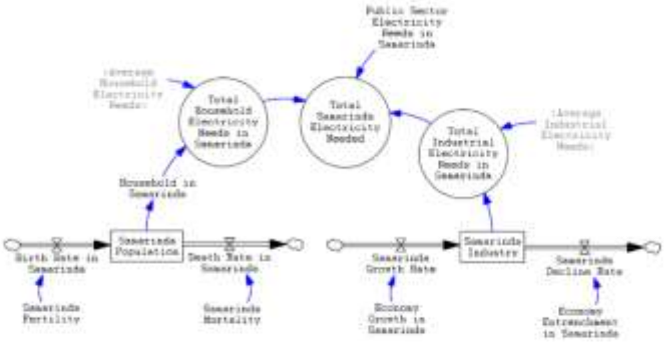


Figure 5. SFD Sub-model Samarinda Eletricity Needs

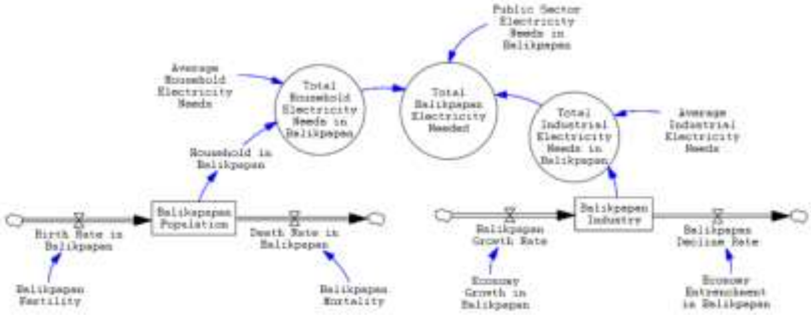


Figure 6. SFD Sub-model Balikpapan Eletricity Needs

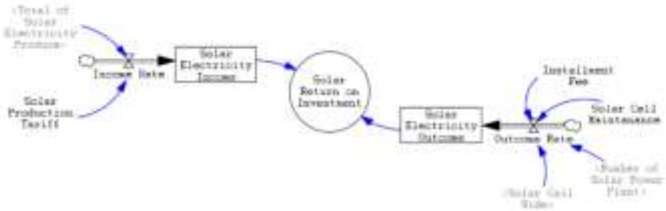


Figure 7. SFD Sub-model Solar Economic Analysis

Testing

Model validation is conducted by comparing the average error rate and error variance stated as in 2.4 before. A model is considered valid if the error rate is ≤ 5% and the error variance is ≤ 30%. The results for the validation as shown below:

Table 5. Exogenous Variables

Variables	Type of Validation	Results
Total of Solar Power Plant	Mean Comparison (E1)	2 %
	Error Variance (E2)	28 %
Population in Kutai and Penajam Paser	Mean Comparison (E1)	1 %
	Error Variance (E2)	13 %
Population in Balikpapan	Mean Comparison (E1)	1 %
	Error Variance (E2)	9 %
Population in Samarinda	Mean Comparison (E1)	1 %
	Error Variance (E2)	29 %
Industrial Population	Mean Comparison (E1)	1 %
	Error Variance (E2)	14 %

Policy Formulation and Evaluation

In the dynamic system simulation model for the feasibility analysis of solar energy investment in the Nusantara Capital, scenarios were also implemented to understand the potential outcomes for the system. Three types of scenarios were applied:

1. Most Likely Scenario: A scenario where the system or model operates under normal conditions without any additional factors altering the system.
2. Pessimistic Scenario: A scenario where the system or model operates under poor to very poor conditions.
3. Optimistic Scenario: A scenario where the system or model operates well under fairly good to excellent conditions.

The results from the scenarios are as be seen below:

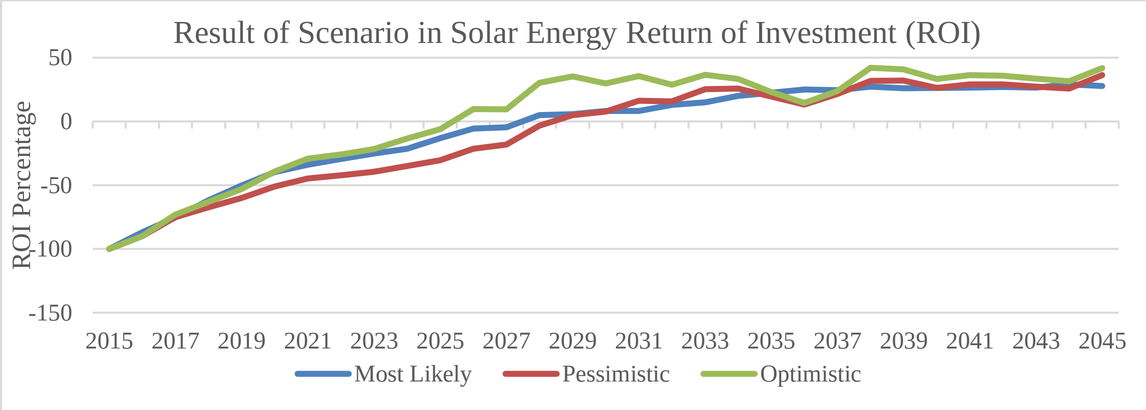


Figure 8. Scenarios Results for Solar Economic Analysis

The results of the dynamic system simulation model for the feasibility analysis of solar energy investment in the Nusantara Capital, with simulations spanning from 2015 to 2045, are presented. Each scenario strategy is applied starting from 2023 and continues for 22 years. Based on the simulation results shown in Figure 12, "Return on Investment of Solar Energy in Each Scenario," the following conclusions were drawn:

1. The application of the optimistic scenario yields the highest ROI at 42% in 2045, while the most likely scenario provides the lowest ROI at only 28%.
2. The optimistic scenario achieves a break-even ROI or profitability by 2026, which is 4 years after the policy implementation. In contrast, the pessimistic scenario becomes profitable in 2029, which is 7 years after the policy implementation, and the most likely scenario differs by 1 year from the pessimistic scenario, becoming profitable in 2028.
3. Essentially, the adoption of solar energy is already profitable, albeit time-consuming. Therefore, it is necessary to make changes to the system so that the implementation of solar energy can yield faster profits compared to the normal timeframe, thereby further legitimizing the solar energy industry.

Conclusions

The dynamic system simulation model for the economic analysis of solar energy investment in the Nusantara Capital City (IKN) demonstrates that solar energy is a viable and profitable energy source for the new capital. The model, validated with an average error rate of ≤ 5% and an error variance of ≤ 30%, accurately represents the system's behavior under different scenarios. The optimistic scenario yields the highest return on investment (ROI) at 42% by 2045, with a break-even point in 2026. Even under the pessimistic scenario, solar energy becomes profitable by 2029. These results underscore the economic benefits of adopting solar energy in IKN and highlight the importance of strategic policy implementation and land optimization to enhance profitability. Overall, the study confirms that solar energy investment is a sustainable and economically sound decision for supporting the development of IKN.

Future research should focus on expanding the model to include other renewable energy sources such as wind and hydroelectric power to provide a more comprehensive analysis of sustainable energy options for IKN. Additionally, further studies could investigate the socio-economic impacts of large-scale solar energy implementation, including effects on local communities and job creation. Exploring advanced technologies in solar energy and their potential integration into the existing energy grid would also be valuable. Finally, long-term environmental impact assessments should be conducted to ensure that the adoption of solar energy aligns with the sustainability goals of IKN.

Acknowledgments

The authors would like to express their gratitude to the Institut Teknologi Sepuluh Nopember for their support and resources in conducting this research. We also thank the Central Statistics Agency and PLN for providing the necessary data. Special thanks to Prof. Erma Suryani who guides and help on this research, and to our families for their continuous encouragement and support.

References

Arishinta, A., & Suryani, E. (2021). Dynamic System Modeling Of Renewable Energy Diversification At Its Surabaya As A Sustainable University Management Effort. *Iptek Journal Of Proceedings Series*, *6*, 195–202.

Barlas, Y. (1996). Formal Aspects Of Model Validity And Validation In System Dynamics. *System Dynamics Review: The Journal Of The System Dynamics Society*, *12*(3), 183–210.

Chaharbaghi, K. (1990). Using Simulation To Solve Design And Operational Problems. *International Journal Of Operations \& Production Management*, *10*(9), 89–105.

Chi, Y., Zhao, H., Hu, Y., Yuan, Y., & Pang, Y. (2022). The Impact Of Allocation Methods On Carbon Emission Trading Under Electricity Marketization Reform In China: A System Dynamics Analysis. *Energy*, *259*, 125034.

Daryono, B. S., Sarosa, W., Ubaidillah, R., Widyatmoko, D., Purnomo, D. W., Djohan, T. S., Hadisusanto, S., Aipassa, M.

I., & Setyawati, T. (2023). *Pembangunan Berkelanjutan Di Ibu Kota Negara Nusantara Perspektif Biologi*. Ugm Press.

Gong, J., Li, C., & Wasielewski, M. R. (2019). Advances In Solar Energy Conversion. *Chemical Society Reviews*, *48*(7), 1862–1864.

Hendrawan, R. A., Aristio, A. P., Buliali, J. L., Yuniarto, M. N., & Others. (2019). Testing Methods On System Dynamics: A Model Of Reliability, Average Reliability, And Demand Of Service. *Procedia Computer Science*, *161*, 968–975.

Hsiao, C.-T., Liu, C.-S., Chang, D.-S., & Chen, C.-C. (2018). Dynamic Modeling Of The Policy Effect And Development Of Electric Power Systems: A Case In Taiwan. *Energy Policy*, *122*, 377–387.

Hsu, C.-W. (2012). Using A System Dynamics Model To Assess The Effects Of Capital Subsidies And Feed-In Tariffs On Solar Pv Installations. *Applied Energy*, *100*, 205–217.

Hutasoit, W. L. (2019). Analisa Pemindahan Ibukota Negara. *Dedikasi: Jurnal Ilmiah Sosial, Hukum, Budaya*, *39*(2), 108–128.

Limas, C., Setyaningsih, O., Fauzi, I., & Others. (2021). Konsep Smart Port Di Ibu Kota Negara (Ikn) Indonesia. *Jurnal Penelitian Transportasi Laut*, *23*(2), 77–94.

Patriamurti, R., Sasana, H., Prakoso, J. A., & Others. (2021). Analisis Pertumbuhan Ekonomi, Pertumbuhan Industri, Pertumbuhan Penduduk, Pengeluaran Konsumsi, Dan Investasi Asing Terhadap Konsumsi Listrik Di Indonesia Tahun 1971-2019. *Dinamic: Directory Journal Of Economic*, *3*(4), 852–871.

Shannon, R. E. (1998). Introduction To The Art And Science Of Simulation. *1998 Winter Simulation Conference. Proceedings (Cat. No. 98ch36274)*, *1*, 7–14.

Silalahi, S. A. F. (2019). Dampak Ekonomi Dan Risiko Pemindahan Ibu Kota Negara. *Info Singkat*, *11*(16), 19–24.

Sterman, J. (2000). *Instructor's Manual To Accompany Business Dyanmics: Systems Thinking And Modeling For A Complex World*. Mcgraw-Hill.

Suryani, E., Hendrawan, R. A., Adipraja, P. F. E., Widodo, B., Zahra, A. A., & Chou, S.-Y. (2023). A Model To Improve Workability Of Transport Systems. *Environment, Development And Sustainability*, 1–33.

Suryani, E., Hendrawan, R. A., Muhandhis, I., & Indraswari, R. (2022). A Simulation Model To Improve The Value Of Rice Supply Chain (A Case Study In East Java--Indonesia). *Journal Of Simulation*, *16*(4), 392–414.

Thoriq, A. R., & Hakim, M. A. T. (2024). Legal Review Of The Position Of The Regulation Of The Head Of The Capital City Authority Of Nusantara As Local Legal Product: Tinjauan Yuridis Terhadap Kedudukan Peraturan Kepala Otorita Ibu Kota Nusantara Sebagai Produk Hukum Daerah. *Journal Social Sciences And Humanioran Review*, *1*(03), 122–131.

Zhang, L., Du, Q., Zhou, D., & Zhou, P. (2022). How Does The Photovoltaic Industry Contribute To China's Carbon Neutrality Goal? Analysis Of A System Dynamics Simulation. *Science Of The Total Environment*, *808*, 151868.