

Evaluation of Strategic Optimization of Housing and Settlement Planning in Balikpapan with Integration EWM-DEA

Christopher Davito Prabandewa Hertadi^{1,2✉}, Firly Eryun Desita Safitri³,
Ahmad Jamil⁴, Putri Gesan Prabawa Anwar⁵, Healty Susantiningdyah⁶,
Windi Auliana⁷

^{1, 2, 3, 4, 6, 7} Industrial Engineering, Faculty of Engineering and Industrial Technology, Institut Teknologi Kalimantan, Indonesia

^{2, 5} Logistic Engineering, Faculty of Engineering and Industrial Technology, Institut Teknologi Kalimantan, Indonesia

✉ **Corresponding Author** : Christopher Davito P. Hertadi (e-mail: christopher.davito@lecturer.itk.ac.id)

Article Information	ABSTRACT
Article History Received : April 28, 2026 Revised : May 06, 2026 Published : July 02, 2026	Rapid population growth, limited developable land, and rising housing demand create increasing pressure on the urban settlement system in Balikpapan. This study aims to develop a comprehensive model to support sustainable housing planning by examining the interactions among social, economic, and environmental factors. The study gave strategic optimization in housing and settlement planing in Balikpapan with social, economic, and environmental consideration. A system dynamics model was constructed using causal loop and stock–flow structures to simulate system behavior from 2020 to 2050. Indicator performance was assessed using an entropy-based weighting method, while efficiency was evaluated through a data envelopment analysis approach. Three policy scenarios were tested: economic growth, development of public rental housing, and a combined strategy. The results of the study indicate that the environmental output variable (green open space) experienced a significant decline from 696,800 hectares to 390,599.6 hectares. The results also show that environmental indicators consistently achieved the highest performance, followed by social indicators, while economic indicators remained the weakest due to high development costs. Therefore, recommendations for improvements in the environmental sector can provide better output results. The scenario focused on vertical public housing provides the most balanced outcome, improving social welfare while reducing pressure on land resources. These findings emphasize the importance of integrated policy planning that aligns effectiveness and resource efficiency to support sustainable urban development.
Keywords: <i>Housing Planning;</i> <i>Sustainable;</i> <i>System dynamics;</i> <i>Urban Development;</i> <i>Vertical Public Housing.</i>	

INTRODUCTION

Urban housing systems in rapidly growing cities face increasing pressure due to population expansion, limited urban land, and environmental constraints. In Balikpapan, these challenges are intensified by economic development and the city's strategic role as a supporting region for the new national capital.

Without a comprehensive planning approach, the imbalance between housing demand, land capacity, and environmental resilience may lead to spatial inequality, informal settlements,

and declining urban quality of life. These conditions highlight the urgent need for planning frameworks that integrate social, economic, and environmental considerations in a single analytical system. A considerable number of studies has examined housing and settlement development using various analytical approaches. Conventional planning approaches mainly emphasize physical housing provision, infrastructure availability, and land allocation. Other studies employ statistical projections to estimate future housing needs, while more advanced works apply optimization models to allocate land and infrastructure more efficiently. Among these, system-oriented approaches have been increasingly recognized as more capable of capturing dynamic interactions between population, land, and environmental conditions. In particular, system dynamics models are considered superior because they allow simulation of policy alternatives and identification of long-term impacts that may not be visible under static analyses.

However, existing research still presents several notable limitations. Many system dynamics applications focus primarily on system behavior description and scenario comparison, but lack explicit and quantitative evaluation of performance outcomes across sustainability dimensions. Likewise, studies that evaluate sustainability using indicators often treat effectiveness and efficiency separately, without linking them to system behavior over time. As a result, decision makers still have limited tools to understand which policy scenario performs best, not only in terms of outcomes, but also in terms of resource use and operational efficiency. This study attempts to address these limitations by integrating system simulation with formal performance evaluation. The novelty of this paper lies in the development of an analytical framework that (i) models the dynamic relationships among social, economic, and environmental variables; (ii) assigns objective indicator weights using the Entropy Weight Method; and (iii) evaluates efficiency through the Data Envelopment Analysis–EBM approach across multiple policy scenarios. Through this integration, the framework enables simultaneous analysis of effectiveness, efficiency, and long-term system behavior, providing a more comprehensive decision-support tool for sustainable housing management. The objective of this research is to analyze the dynamic behavior of the housing and settlement system in Balikpapan and to identify policy strategies that optimize sustainability while maintaining efficient use of limited urban resources.

RESEARCH METHODS

Data Resource

The research was conducted in Balikpapan, where rapid population growth and limited land availability generate increasing pressure on housing development. The study uses secondary data obtained from the Central Bureau of Statistics, the Housing and Settlement Office, the Environmental Agency, and relevant policy documents for the period 2020–2023. These data include demographic indicators, economic indicators, housing characteristics, and environmental variables required to evaluate sustainability performance (BPS, 2023; PUPR, 2022).

The indicators were grouped into social, economic, and environmental dimensions. Each indicator was selected based on relevance to sustainable housing and data availability. The indicators also serve as inputs for the modeling process and subsequent effectiveness and efficiency evaluation.

System Dynamics Model Development

System Dynamics was applied to represent the interactions among population, housing demand, land availability, and environmental capacity. The modeling process began with problem identification, followed by construction of Causal Loop Diagrams (CLD) to conceptualize feedback relationships within the system.

These diagrams were then translated into Stock and Flow Diagrams (SFD) to describe the quantitative structure of the model. Model calibration and validation were conducted by comparing simulated results with historical data trends. The simulation period extends from 2020 to 2050 to capture long-term dynamics and policy impacts, consistent with system modeling approaches used in urban planning (Sterman, 2000).

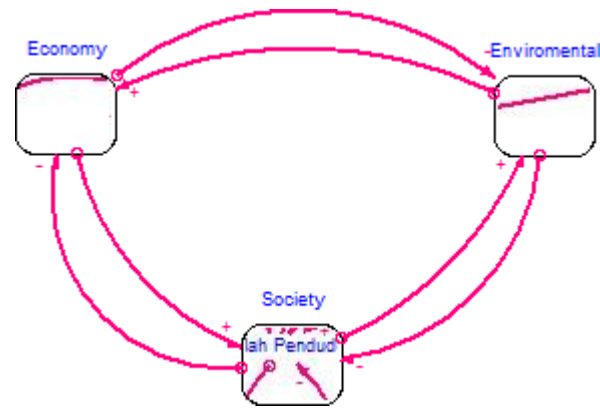


Figure 1. Module of Model

Validation Model

Model validation was performed using the t-test method, comparing the average value of the simulation results with the average value of the actual data. This process aims to determine the level of agreement between the model's behavior and real-world conditions. The variables tested included population, green space area, and mortgage demand. The test was conducted using the criterion that the model is valid if the calculated t-value is less than the t-table at a significance level of 0.05. Calculations were performed using Microsoft Excel software to obtain the calculated t-value for each variable.

Effectiveness Evaluation Using Entropy Weight Method

The Entropy Weight Method (EWM) was employed to calculate indicator weights objectively. The method assumes that indicators with higher variability contain more informational value and therefore should receive larger weights (Qu et al., 2022).

First, the data were normalized. The normalized value X' for indicator j in scenario i was obtained using Equation (1):

$$X'_{ij} = \begin{cases} 0.9 \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} + 0.1 \text{ Positive Indicator} \\ 0.9 \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} + 0.1 \text{ Negative Indicator} \end{cases} \quad (1)$$

The entropy value of each indicator was calculated as:

$$e_j = -k \sum_{i=1}^M (Y_{ij} \times \ln Y_{ij}) \quad (2)$$

Where Y_{ij} is the proportional contribution of indicator j in scenario i , and $k = 1/\ln(m)$. Redundancy values were then computed and converted into final weights. The weighted scores were used to determine scenario effectiveness. This approach reduces subjective bias in weighting while ensuring transparency in indicator evaluation (Zhu et al., 2020).

Efficiency Evaluation Using DEA-EBM

Efficiency was assessed using Data Envelopment Analysis with the Epsilon-Based Measure (DEA-EBM). DEA compares units known as decision-making units (DMUs) based on the ratio of outputs produced to inputs consumed (Sabrina et al., 2024). The EBM model integrates both radial and non-radial components, providing a more realistic representation of excess inputs and insufficient outputs (Rusli et al., 2022).

In this study, each scenario-year combination was treated as a DMU. Inputs consisted of land use and resource variables, while outputs represented housing provision, social benefits, and environmental improvements. The efficiency value ranges from 0 to 1, where a value of 1 indicates full efficiency.

RESULTS AND DISCUSSION

The results present an integrated assessment of sustainable housing and settlement management in Balikpapan based on dynamic interactions among social, economic, and environmental variables over the simulation period 2020–2050. The analysis is structured around key variables that represent urban growth pressures, housing provision mechanisms, land utilization, and environmental capacity.

The social dimension is represented by population size, population growth rate, housing demand, housing availability ratio, and social welfare indicators. The economic dimension includes gross regional domestic product (GRDP), infrastructure investment, housing development cost, and economic growth rate. The environmental dimension consists of land availability, land consumption rate, green open space proportion, environmental carrying capacity, and environmental pressure index. Within the system dynamics framework, population, housing stock, land consumption, and environmental capacity are modeled as stock variables, while population growth, housing construction, land conversion, and environmental degradation are treated as flow variables.

The causal structure governing interactions among these variables is illustrated using a Causal Loop Diagram (CLD)

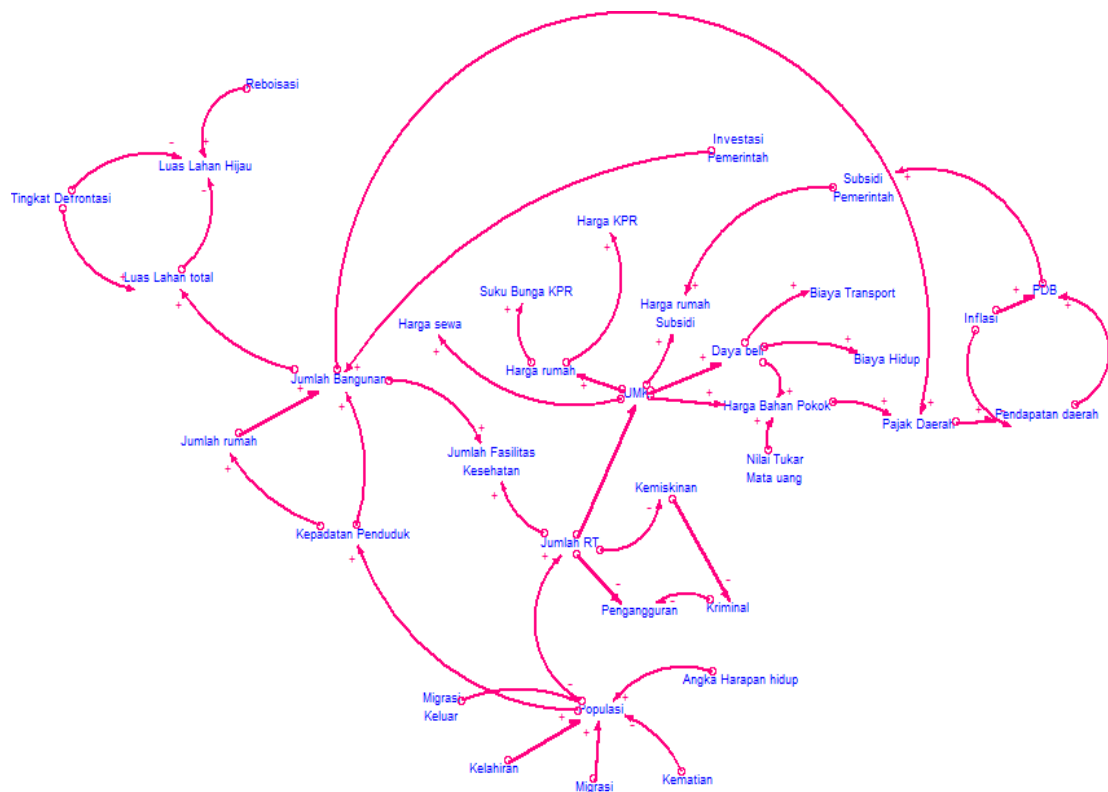


Figure 2. Causal Loop Diagram

Figure 2 illustrates a reinforcing feedback loop in which population growth increases housing demand, leading to intensified housing development and accelerated land consumption. Rising land consumption reduces environmental carrying capacity and increases environmental pressure, reinforcing unsustainable development trends. Policy interventions, particularly vertical housing development, introduce balancing feedback loops by increasing housing supply without proportional land expansion, thereby reducing environmental stress.

The causal relationships are translated into a Stock and Flow Diagram (SFD) to enable quantitative simulation of long-term system behavior.

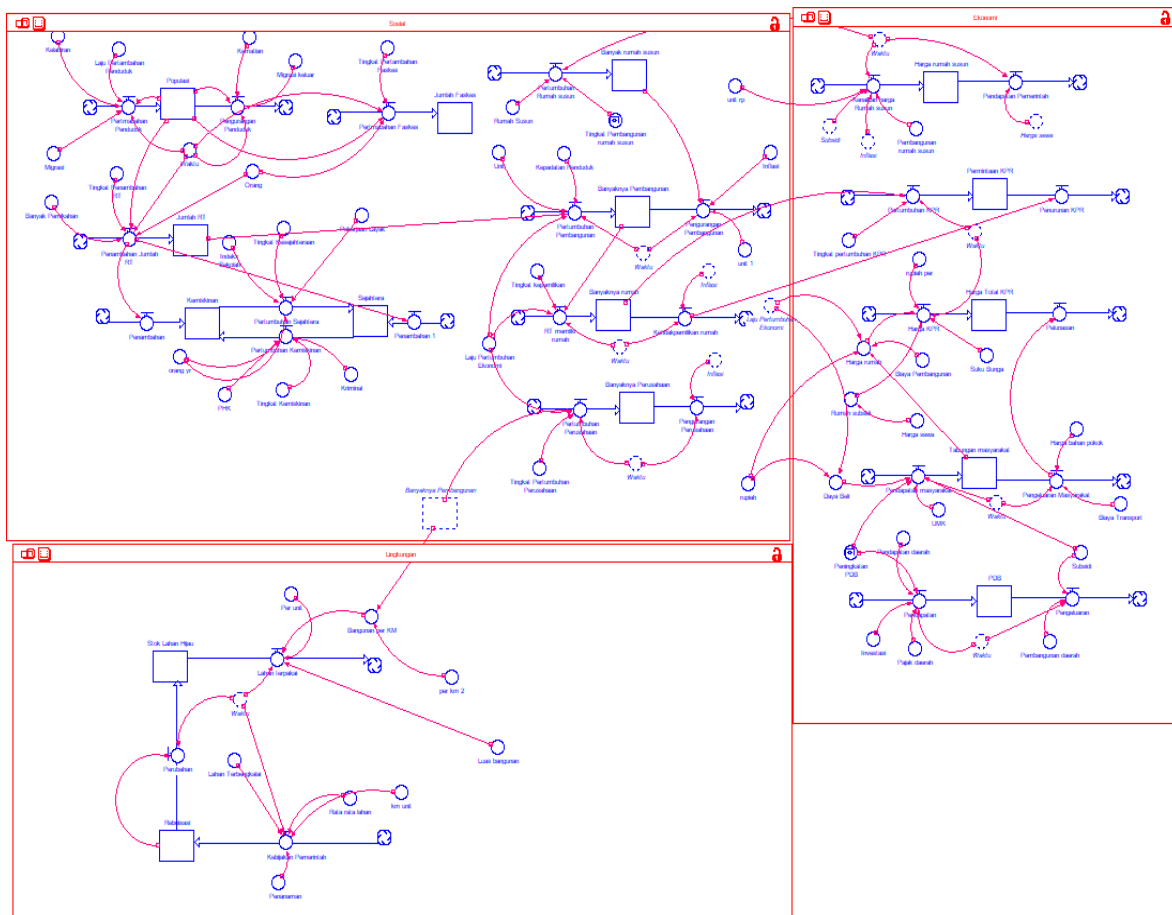


Figure 3. Stock and Flow Diagram

Figure 3 shows how stock variables accumulate and evolve over time through regulated flow processes influenced by policy decisions. This structure allows simulation of alternative housing development scenarios and their cumulative impacts on land use and environmental sustainability. The model is then simulated under existing conditions, scenario 1 GDP as a representation of economic growth, scenario 2 increased apartment capacity as a strategy to meet housing needs and control land use, and scenario 3 when scenarios 1 and 2 are implemented simultaneously.

The existing model results indicate a decrease in green open land area, from 696,800 hectares in 2020 to 390,599.6 hectares in 2050, representing a 44% increase in deforestation. Furthermore, comparisons between sectors show that the environmental sector has high effectiveness and efficiency, suggesting that scenarios in this sector could have a greater impact on the overall model results.

Effectiveness evaluation was conducted using the Entropy Weight Method (EWM) to measure sustainability performance across social, economic, and environmental indicators, including population density, housing availability ratio, land-use efficiency, green open space proportion, and environmental load index. Indicator weights were determined objectively based on data variability.

Table 1. Effectiveness Summary (EWM)

Scenario	Aspect	Average Effectiveness	Effectiveness (%)
Existing	Environmental	0.7248	46.60
	Social	0.4452	28.62
	Economic	0.3855	24.78
	Total	1.5555	100.00
1	Environmental	0.7248	46.60
	Social	0.4452	28.62
	Economic	0.3855	24.78
	Total	1.5555	100.00
2	Environmental	0.7248	47.05
	Social	0.4339	28.16
	Economic	0.3819	24.79
	Total	1.5406	100.00
3	Environmental	0.7377	47.50
	Social	0.4201	27.90
	Economic	0.3821	24.60
	Total	1.5399	100.00

Table 1 indicates that environmental effectiveness consistently achieves the highest scores across all policy scenarios, reflecting the dominant role of land and environmental management in sustainable housing development. Social effectiveness follows, indicating improvements in housing accessibility and welfare outcomes. Economic effectiveness remains comparatively low, suggesting that economic gains do not scale proportionally with development inputs.

Efficiency analysis was performed using the Data Envelopment Analysis–Epsilon Based Measure (DEA- EBM), in which each scenario–year combination is treated as a decision-making unit. Input variables include land consumption and infrastructure investment, while output variables consist of housing provision, social welfare indicators, and environmental quality indices.

Table 2. Efficiency Summary (DEA-EBM)

Scenario	Aspect	Average Effectiveness	Effectiveness (%)
Existing	Environmental	0.7248	40.33
	Economic	0.5500	30.60
	Social	0.5226	29.08
	Total	1.7974	100.00
1	Environmental	0.7248	40.33
	Economic	0.5500	30.60
	Social	0.5226	29.08
	Total	1.7974	100.00
2	Environmental	0.7248	40.32
	Economic	0.5500	30.60
	Social	0.5227	29.08
	Total	1.7975	100.00
3	Environmental	0.7377	40.34
	Economic	0.5500	30.08
	Social	0.5410	29.59
	Total	1.8287	100.00

Table 2 demonstrates that environmental efficiency dominates across all scenarios, with efficiency scores approaching unity under the vertical housing policy. Social efficiency improves

due to increased housing provision relative to land use, whereas economic efficiency remains the weakest dimension due to higher capital and infrastructure costs.

An integrated comparison of effectiveness and efficiency across policy scenarios provides a comprehensive assessment of sustainability performance. The comparison between the actual condition and the three scenarios shows that policy interventions do not change the basic structure of system performance, but they affect the level of effectiveness and efficiency of each aspect. Among all scenarios, Scenario 2, which focuses on vertical housing development, shows the best overall performance. In terms of effectiveness (EWM), Scenario 2 produces the highest environmental contribution, indicating that vertical housing can reduce land pressure and support environmental sustainability. Social and economic effectiveness values remain relatively stable across scenarios. In terms of efficiency (DEA-EBM), Scenario 2 maintains efficiency levels similar to the actual condition, meaning that the intervention does not reduce system efficiency. Overall, these results indicate that vertical housing development is the most appropriate option because it improves environmental performance while maintaining system stability in housing and settlement management in Balikpapan.

CONCLUSION

This study was conducted to develop an integrated analytical framework for supporting sustainable housing and settlement planning in Balikpapan by capturing the dynamic interactions among social, economic, and environmental aspects. The system dynamics model constructed using Causal Loop Diagrams (CLD) and Stock–Flow Diagrams (SFD) successfully represents the long-term behavior of the housing system, particularly the interactions between population growth, housing demand, land availability, economic capacity, and environmental pressure. The simulation results confirm that housing and settlement systems in rapidly growing cities exhibit complex feedback structures that require long-term and integrated policy assessment.

The integration of the Entropy Weight Method (EWM) and Data Envelopment Analysis–Epsilon Based Measure (DEA–EBM) provides a comprehensive evaluation of system performance by jointly assessing effectiveness and efficiency. The findings indicate that environmental aspects consistently play a dominant role in determining sustainability performance, followed by social aspects, while economic aspects show relatively weaker contributions. Among the evaluated policy scenarios, the vertical housing development scenario demonstrates the most balanced performance by improving environmental effectiveness without reducing efficiency. These results suggest that compact housing strategies can optimize land use while maintaining system stability. The proposed modeling framework offers practical value for urban planners and policymakers as a decision-support tool for evaluating housing development strategies. Future studies may extend this framework by incorporating spatial analysis, institutional factors, and broader socio-economic indicators to enhance policy relevance and robustness.

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