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Analyzing rice production and consumption using a system dynamics model in East Kalimantan

Analisis produksi dan konsumsi beras menggunakan model sistem dinamik di Kalimantan Timur

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Abstract

The decision to relocate the capital of Indonesia from Jakarta to Ibu Kota Nusantara (IKN), in East Kalimantan poses significant challenges to food security, particularly concerning maintaining a balance between rice production and consumption. This study aims to predict the balance between rice demand and supply in the IKN area until 2030. This study uses a dynamic systems approach to estimate the impact of the IKN relocation on the dynamics of rice consumption and supply. By analyzing projected population migration and economic factors, this study estimates an increase in rice demand due to the influx of people to East Kalimantan. The study suggests several strategies to address this increase in rice demand, including optimizing agricultural land use for rice farming, promoting household income increases, and implementing price stabilization policies. With appropriate measures as suggested in this analysis, East Kalimantan can substantially reduce its dependence on rice supply from other regions and improve sustainable food security. This study emphasizes the importance of collaborative efforts with other rice-producing regions on the island of Kalimantan and rice production centers in Indonesia to strengthen food security in East Kalimantan.

Keywords: *consumption, East Kalimantan, production, rice, system dynamics*

Abstrak

Keputusan untuk memindahkan ibu kota negara Indonesia dari Jakarta ke Ibu Kota Nusantara (IKN) di Kalimantan Timur menimbulkan tantangan signifikan terhadap ketahanan pangan, khususnya terkait dengan menjaga keseimbangan produksi dan konsumsi beras. Penelitian ini bertujuan memprediksi keseimbangan permintaan dan pasokan beras di IKN sampai 2030. Analisis dilakukan menggunakan pendekatan sistem dinamik untuk memperkirakan dampak pemindahan IKN terhadap dinamika konsumsi dan pasokan beras. Dengan menganalisis proyeksi migrasi penduduk dan faktor ekonomi, penelitian ini memperkirakan peningkatan permintaan beras akibat masuknya penduduk ke Kalimantan Timur. Hasil analisis menyarankan beberapa strategi untuk mengatasi kenaikan permintaan beras, antara lain dengan memanfaatkan lahan pertanian yang tidak digunakan untuk usaha tani padi, mendorong peningkatan pendapatan humah tangga, dan menerapkan kebijakan stabilisasi harga. Dengan langkah-langkah yang tepat seperti disarankan dalam analisis ini, Kalimantan Timur dapat secara substansial mengurangi ketergantungannya pada perdagangan beras dari daerah lain dan meningkatkan ketahanan pangan keberlanjutan. Selain itu, hasil penelitian ini merekomendasikan pentingnya upaya kolaboratif dengan daerah penghasil beras lainnya di Pulau Kalimantan dan wilayah sentra produksi beras di Indonesia untuk lebih memperkuat ketahanan pangan di Kalimantan Timur.

Kata kunci: beras, Kalimantan Timur, konsumsi, produksi, sistem dinamik

1. Introduction

The decision to relocate the capital of Indonesia from Jakarta to Ibu Kota Nusantara (IKN) in East Kalimantan presents significant challenges to food security, particularly regarding rice production and consumption. While the demand for rice continues to rise due to population growth, the supply side is constrained by factors such as land conversion, price fluctuations, and productivity issues. Additionally, the planned relocation of approximately 1.5 million residents to the new capital is expected to exacerbate the existing rice deficit in East Kalimantan (Otorita IKN 2022). Despite current policies aimed at boosting rice production, they may not be adequate to meet the growing demand. Furthermore, economic factors such as income and pricing significantly influence rice consumption, indicating a need for comprehensive strategies to address the supply and demand aspects of rice availability in East Kalimantan. Therefore, there is a pressing need to develop effective policies and interventions to ensure sustainable rice production and consumption in the context of the region's capital relocation and broader food security challenges (Cahyono and Tokuda 2024).

Indonesia remains heavily relies on rice as its primary staple food, with demand increasing at an annual rate of 1.16%. However, rice production has been expanding at an average rate of only 0.81% per year. This imbalance is compounded by land conversion, price fluctuations, and persistent productivity challenges, all of which undermine long-term food security (Kusnadi and Tinaprilla 2011; Sutardi et al. 2023). Moreover, the conversion of rice fields in Indonesia poses a significant threat to agricultural land at the local, provincial, and national levels, leading to a decline in rice production. This threat is particularly worrisome as rapid economic growth correlates with land use shifts (Suliman et al. 2023).

The government's decision to relocate the capital to East Kalimantan could have far-reaching effects on food security, particularly regarding the availability and demand for rice. Unfortunately, East Kalimantan already experiences an annual rice deficit. The relocation of a large number of residents, primarily government officials from Jakarta, with an average family size of four, over the next five to ten years will significantly increase rice demand and likely deepen this deficit. Given Indonesia's per capita rice consumption of nearly 100 kilograms annually, among the highest in Asia, reducing demand is particularly challenging (Arifin et al. 2019). Income and rice prices play a crucial role in shaping household food consumption patterns in East Kalimantan. The implementation of a government-imposed minimum retail price for rice has contributed to a decline in rice demand, particularly as a response to inflationary pressures (Bidarti et al. 2019). Rice is considered an inelastic product, meaning that a price increase will not lower demand but rather increase the percentage of household spending on rice. Conversely, an increase in household income will lead to a decrease in the percentage of household expenditure on rice, with an elasticity of −0.4. This implies that a 1% increase in income will result in only a 0.4% decrease in rice consumption (Cahyono and Tokuda 2023).

In light of the decision to relocate the capital, some steps have been taken to improve food security, particularly in production. These measures include bolstering agricultural infrastructure, providing access to cutting-edge technology and support, expanding planting and harvesting areas, and reducing losses due to crop damage. Crucially, reducing per capita rice consumption is a key priority, given that Indonesia's current rate exceeds recommended healthy standards. One approach to achieving this is to focus on economic factors such as prices and income. This can be modeled in a rice production-consumption simulation that factors in scenarios for increased income and stabilized rice prices. Additionally, improving the productivity of rice fields in East Kalimantan is a top priority to minimize rice shortfalls and increase overall production. Finally, the move to a new capital provides an opportunity to allocate new agricultural land.

Under Presidential Decree No. 63 of 2022, the new capital, Ibu Kota Nusantara (IKN), is being developed with a focus on sustainable agricultural clusters. Approximately 10% of the city's land area (around 25,600 hectares) is designated for food production, including paddy cultivation, oil palm, and aquaculture. The Minister of Agriculture's Decree No. 472 of 2018 on the Location of National Agricultural Areas has identified Paser, Kutai Kartanegara, and North Penajam Paser as the ideal regions for rice cultivation in East Kalimantan. However, rice farming in these areas faces high production costs and limited potential for further expansion, posing constraints to achieving self-sufficiency at both regency and provincial levels (Handani et al. 2021).

Previous studies have investigated the supply and demand of rice in East Kalimantan by analyzing factors such as population growth, production, and nutritional needs (Deshaliman and Gantina 2019; Adi et al. 2021). However, these studies have also considered economic factors, such as price and income, which can impact the demand for rice at the household level (Burggraf et al. 2015; Sari 2016). Most dynamic system studies related to food security in East Kalimantan have primarily explained production and consumption aspects, relying on population size and nutritional requirements. Nevertheless, economic variables like income and rice prices have not yet been incorporated into these models, even though they significantly impact rice consumption behavior. This study addresses that gap by incorporating income and rice prices into a dynamic system framework for more robust projections of rice availability.

The system dynamics was the simulation approach used in a recent analysis of inclusive wealth capital movements. Shimamura and Mizunoya (2020) found that more than the current investment plan is needed to ensure sustainable results for inclusive wealth due to the income gap between Jakarta and the new capital area. The study suggests that increasing income is necessary to address this issue. The dynamic system approach has been widely used in the agricultural and food sectors. For example, Giedelmann-L et al. (2022) simulated food inventory policies in the humanitarian supply chain, while Somantri et al. (2020) and Fristovana et al. (2020) evaluated the rice self-sufficiency program in Indonesia. Furthermore, Adi et al. (2021) analyzed rice availability in East Kalimantan. The rice value chain is an interconnected system from production to consumption or marketing, which can be described with the concept of a dynamic systems approach (Chung 2018). With a dynamic system, the rice value chain's development potential can be calculated to promote sustainable intensification for food security (Tey et al. 2020).

Accordingly, this study constructs a dynamic system model that integrates economic factors, specifically income and rice prices, into projections of rice supply and demand in East Kalimantan in the context of Indonesia's capital relocation. Through the application of a system dynamics approach, the study provides deeper insights into the overall rice production-consumption framework and explores strategies to enhance the sustainability of East Kalimantan's food system. A rice production–consumption model was developed to simulate both short- and long-term dynamics in the relationships among its components. Understanding the behavior of farming stakeholders entails developing a conceptual model, such as a causal loop diagram, to describe the relationships between interrelated variables from the perspective of current system dynamics. This model can effectively characterize the situation and guide future research aimed at developing model scenarios (Mutisari et al. 2024).

2. Methodology

This study employs a system dynamics modeling approach to investigate and simulate the interactions between rice production and consumption in East Kalimantan, specifically in response to the projected population increase resulting from Indonesia's capital city relocation. The system dynamics method offers a comprehensive framework for understanding complex and non-linear systems through feedback loops and time-based simulations. By integrating various interrelated components, such as land use, population growth, income levels, and consumption behavior, this methodology enables the identification of potential policy interventions and their long-term impacts. The overall modeling process involves the formulation of a conceptual framework, construction of causal and stock-flow diagrams, model validation, and scenario simulations to project rice production and consumption trends up to the year 2030.

2.1. Research framework

The system dynamics methodology employs a holistic approach to problem-solving, wherein the entire system is considered, and the interconnections between its various components are carefully analyzed. This method is especially effective when dealing with intricate and non-linear systems that involve feedback interactions. Developed by Forrester (1997), this approach employs dynamic system simulations to capture the cause-and-effect relationships, feedback loops, and delays between the system components, comprehensively characterizing complex non-linear systems.

The system dynamics methodology is an invaluable tool for gaining insights into complex systems. By analyzing the various components, relationships, dependencies, and interactions within a system, , it enables a deep understanding of system behavior and supports optimization through intervention scenarios designed to manage feedback and achieve optimal outcomes (Bala et al. 2017). Furthermore, the methodology facilitates the prediction of future system performance over time, whether under intervention or a maintained status quo, through simulation. Systems dynamics is particularly useful in examining complex food systems and the repercussions of current policies and practices (Jagustović et al. 2021). This modeling approach has found widespread application in sustainability research, and it involves a dynamic cycle of creating a simulation process and analyzing the resulting model to gain a more comprehensive understanding of the system's behavior (de Haan et al. 2019).

When utilizing system dynamics, there are several key factors to consider. These include defining the issue, analyzing the system's structure, constructing a model, and verifying accuracy. Initially, it is necessary to establish a conceptual framework based on the current system description and compare it to the anticipated performance. Following that, a system model can be developed by constructing a causal loop diagram (CLD) that displays the variables, cause-and-effect connections, and loop behavior. Next, a stock flow diagram (SFD) should be created to enter data, serving as the foundation for simulation validation. Once the model has been validated, it can be simulated to evaluate potential future interventions as well as business-as-usual scenarios.

This study focuses on analyzing the production and consumption of rice in East Kalimantan by using a dynamic model. The study involves four major steps: data collection, analysis of current conditions, identification of significant variables, model design, and creation of a basic model in the form of a stock-flow diagram. The simulations are conducted using Powersim software, while exploratory studies analyze complex food systems and assess the impact of existing policies and practices. The model comprises two subsystems - the production and consumption of rice. The analysis of the rice production subsystem is based on the potential of paddy fields for rice production. The dynamic system model follows a cause-and-effect arrangement to explain the interaction between variables in the production and consumption of rice in East Kalimantan. The simulation policy aims to achieve multiple objectives, including encouraging agricultural expansion, reducing land conversion, and decreasing rice consumption. This policy scenario addresses concerns such as managing rice price inflation and improving household income and expenditure. Moreover, the simulation considers the increase in demand for rice due to population growth resulting from the relocation of the national capital. To better understand the research framework, refer to Figure 1 in the dynamic system model.

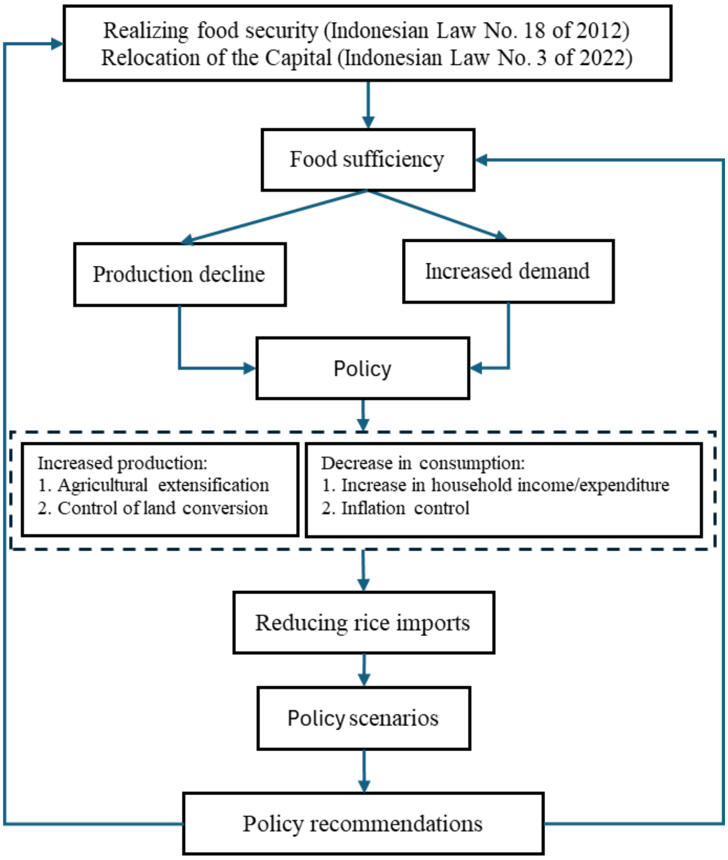


Figure 1. The system dynamic model framework

2.2. Scope of discussion

The scope of this study includes an analysis of the dynamics of rice production and consumption in East Kalimantan Province. The main focus is directed at two subsystems: (1) The rice production subsystem, which includes production potential, land conversion, harvest index, productivity, and post-harvest yield losses. (2) The rice consumption subsystem, which includes household consumption, price and income elasticity, population growth, and the impact of the relocation of the nation's capital. The study also includes policy scenarios to respond to the challenges of food security, price stability, and changes in public consumption.

2.3. Location and time of study

The study was conducted in East Kalimantan Province, Indonesia. This location was chosen because it is a strategic area with high population growth projections due to the planned relocation of Indonesia's capital from Jakarta to the new capital city, Ibu Kota Nusantara (IKN), in East Kalimantan. The study period began with data collection in 2021, and a projection simulation was carried out until 2030.

2.4. Types and methods of data collection

The type of data used in this study is secondary data obtained from East Kalimantan Central Statistics Agency (BPS), the Ministry of Agriculture, and other relevant official publication sources. The data collected includes the area of irrigated and non-irrigated rice fields, land conversion rate, harvest index, productivity and yield loss, population and population growth, household expenditure and proportion of expenditure on food, rice prices, government rice stocks, and price and income elasticity. The period of the data used is 2018 to 2022, which is detailed in Table 1.

Table 1. Data input rice supply-demand in East Kalimantan, 2021

Parameters	Value (2021)	Unit
Irrigated field	9,939	ha
Non-irrigated field	39,504	ha
Land conversion	400	ha/year
Crop index	1.3	harvested area (rice field)
Productivity	3.6	ton/ha
Post-harvest losses	9	%
Rice yield	63	%
Population	3,793,152	people
Population growth (2020: 3,721,389 people)	2	%
Total household consumption expenditure	115,053.4	billion Rupiah
Household consumption expenditure growth (2019: IDR 109,767.66 billion; 2020: IDR 110,821.28 billion)	2.5	%
Food expenditure proportion	43	%
Rice price	13,500	IDR/kg
Price elasticity	−0.4	% quantity demanded/% price change
Income elasticity	−0.4	% quantity demanded/% income change
Government rice stock	500	ton
Seed	0.025	ton/ha

Source: BPS Kaltim (2022a, 2022b, 2023a) and the Ministry of Agriculture (2022)

For an accurate analysis, a comprehensive five-year dataset encompassing rice production, population, and household spending is required, as detailed in Table 2. Explicit income data for the population are unavailable; therefore, household expenditure data are employed as an estimate. Nevertheless, the available information provides valuable insights and supports the derivation of significant conclusions.

Table 2. Population, rice production, and household expenditure in East Kalimantan, 2018−2022

Year	Population (people)	Rice production (ton)	Household expenditure (billion rupiah)
2018	3,648,835	152,059	464,694
2019	3,721,389	146,878	486,523
2020	3,793,152	151,863	472,393
2021	3,708,936	142,321	484,438
2022	3,752,605	139,266	484,438

Source: Ministry of Agriculture (2022) and BPS Kaltim (2023a)

2.5. Data analysis

The analysis was conducted through a system dynamics modeling approach using Powersim software. The analysis steps are as follows:

First, develop a Causal Loop Diagram (CLD) to map the causal relationships between variables in the system. To gain a deeper understanding of the rice supply and demand system in East Kalimantan, a Causal Loop Diagram (CLD) can be utilized. This complex system consists of two subsystems: the rice production subsystem and the rice consumption subsystem, each comprised of various variables that possess unique characteristics and interact. These variables are dynamic and change over time. Figure 2 effectively depicts the interplay between the rice supply and demand subsystems, as well as the individual components that comprise the rice production and consumption system.

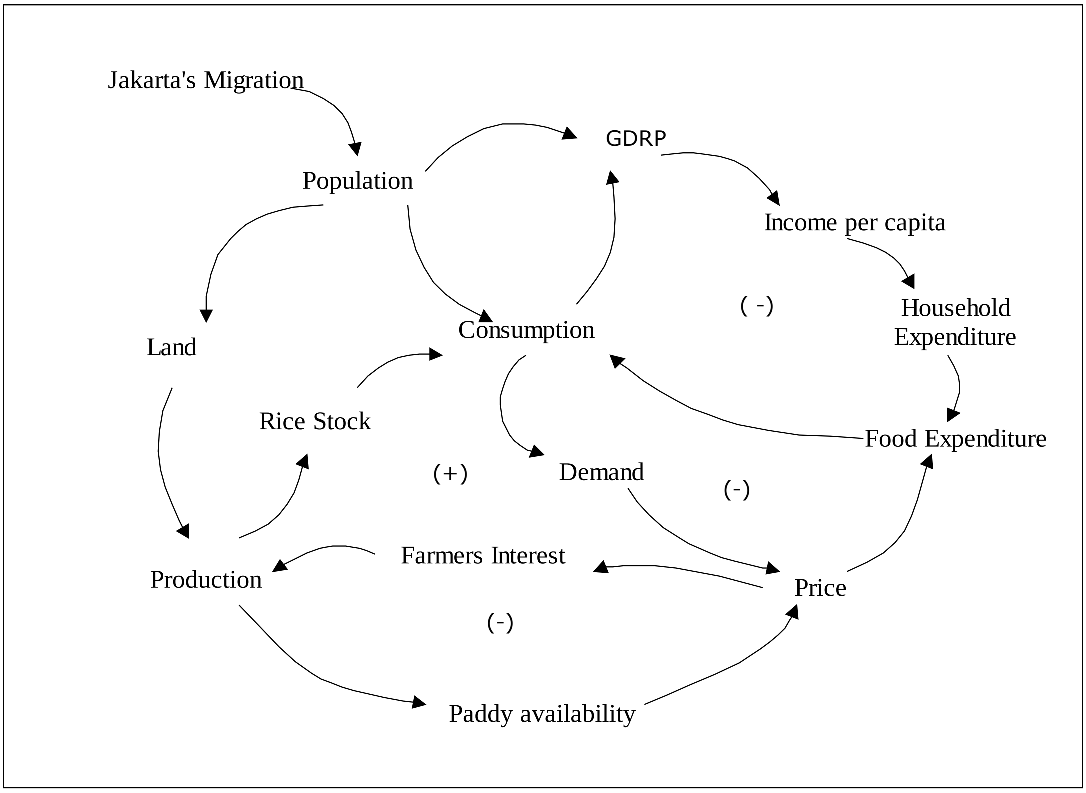


Figure 2. Causal loop of rice supply-demand diagram

This study introduces a dynamic model that showcases the interplay between rice production and consumption, as depicted in Figure 2. The diagram features various variables that constitute the system, interconnected by arrows. The base of each arrow denotes the cause, while the tip corresponds to the effect. Additionally, the relationships between variables are denoted with a positive (+) or negative (-) sign. Figure 2 exhibits four closed loops. For instance, an uptick in household expenditure leads to a rise in household food expenditure, but this results in a decrease in the share of spending on rice, culminating in a decline in rice purchases. Consequently, both rice consumption and the GDP generated from rice consumption dwindled.

In a negative cycle, a decline in consumption triggers a drop in demand, which can cause prices to plummet, ultimately leading to a possible reduction in rice production. However, a surge in rice prices can motivate farmers to replant and increase crop yields, thereby boosting production and rice availability. Consequently, this brings about a fall in prices. With population growth, it is estimated that rice consumption will also increase. It is necessary to increase the rice stock in anticipation of the growing population and food needs. This increase in stock aims to create a stable food supply. With sufficient stocks, food shortages can be minimized, and food needs can be met without significant fluctuations. However, with the increasing population, the demand for rice is likely to increase. An increase in demand for rice from a region can affect the price of rice in the market. Therefore, if rice stocks are limited and demand is high, this can create a situation where the supply is insufficient to meet demand, and rice prices tend to rise.

Land conversion significantly negatively impacts agricultural land as it reduces the available land area for farming. To ensure the preservation of rice fields, fostering collaboration between the government, the private sector, and farmers is crucial. By focusing on reducing land conversion and expanding agricultural land through agricultural extensification, there can be an increase in planting and harvest area, leading to higher production yields. A model can be developed to better understand the extent of conversion and extensification, including the additional paddy field fraction and paddy conversion rate. As household income or expenditure increases, rice consumption is anticipated to decrease. By considering income and price elasticity, it is possible to determine the percentage reduction in rice consumption.

In recent years, households have been expanding their food choices, leading to a decline in rice consumption. This shift in consumption patterns is characterized by an increase in animal protein, fruits, and vegetables, and a decrease in reliance on rice. Promoting sustainable agricultural practices is essential to preserve natural resources and maintain the capacity to feed a growing population. Ensuring a sufficient stock of high-quality rice to meet the needs of the entire population depends on the balance between production and consumption. Rice production is influenced by factors such as land productivity, harvested area, and output from agricultural land (Somantri et al. 2020). The population of East Kalimantan Province includes all individuals who reside in the geographic area, including an estimated 1.5 million people relocating from DKI Jakarta over the next five to ten years (Otorita IKN 2022). The Gross Regional Domestic Product indicates the effect of per capita income on rice consumption.

Second, the preparation of a Stock and Flow Diagram (SFD) based on the identified variables, including the creation of a mathematical model of the rice production and consumption system. The model comprises two interconnected sub-models: one for rice production and the other for rice consumption. These sub-models have a cause-and-effect relationship that influences each other. The production sub-model, illustrated in Figure 3, outlines the domestic rice production capabilities. It incorporates variables from prior studies and considers productive rice field activities, encompassing both irrigated and non-irrigated production, which are affected by land clearing and conversion rates. Furthermore, productivity levels and crop indices play a role in determining the overall production quantity.

Figure 3 displays the variables represented by yellow, which are utilized as policy interventions or scenarios in this study. These interventions will be carefully chosen to formulate policies and conduct simulations. While past studies in East Kalimantan has concentrated on enhancing land productivity through technological advancements to boost rice production, this study incorporates initiatives to expand land use and decrease land conversion. Data from the regional government indicates a substantial opportunity to expand and enhance rice fields, as outlined in Table 3, serving as a basis for the extensification scenario.

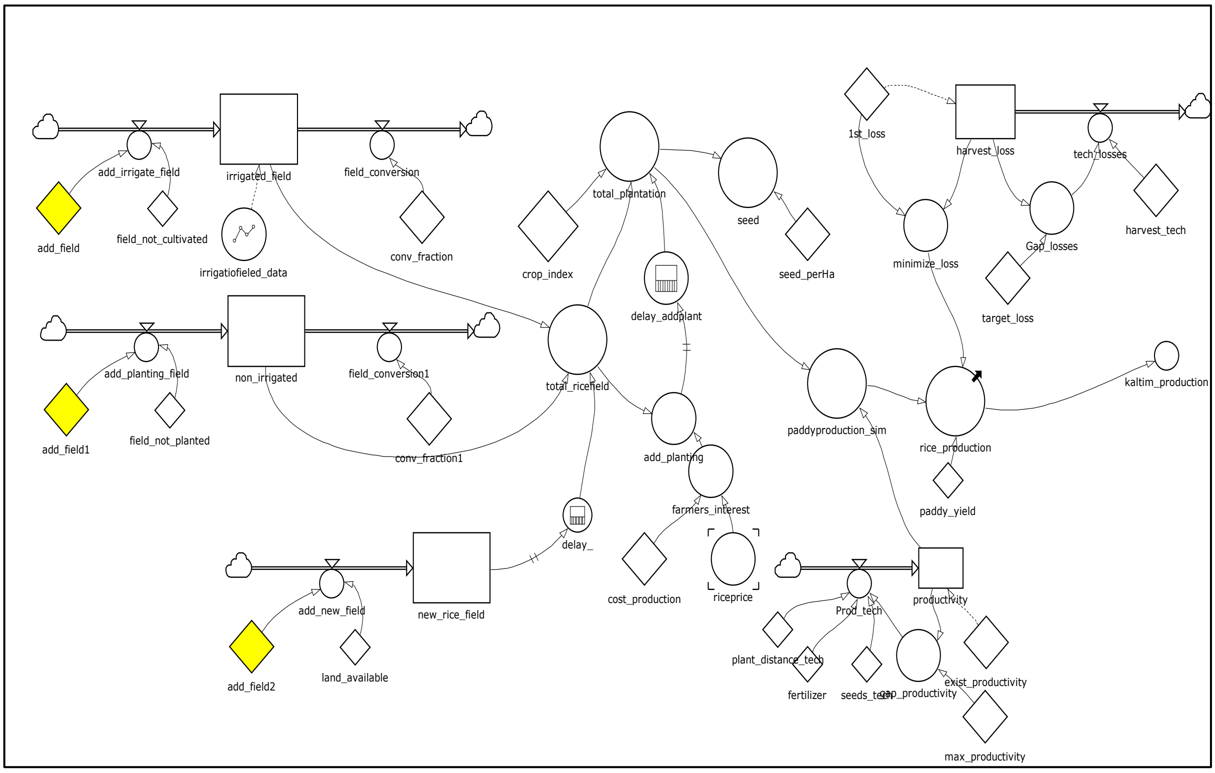


Figure 3. Stock and flow diagram of rice production

Table 3. Land area by type in East Kalimantan

Land type (ha)	2016	2017	2018	2019	2020
Irrigated rice fields	13,225	11,874	11,874	9,939	9,939
Temporarily not cultivated (irrigated)	4,060	25,696	25,696	1,800	1,800
Non-irrigated rice fields	39,519	47,550	47,550	39,504	39,504
Non-irrigated rice fields (temporarily not cultivated)	41,312	24,370	24,370	20,502	20,502

Source: BPS Kaltim (2022b)

Table 4 highlights a series of interconnected variables within a model through a stock and flow diagram. This diagram facilitates the sharing of data and mathematical functions among the various components and can be utilized for simulation to replicate the system's operations accurately.

Table 4. Parameters and formulas of the production sub-system

No.	Parameter	Formula	Unit
1.	Rice production	paddy production x paddy yield	ton
2.	Paddy production	(Planted area of irrigated land x productivity) + (Planted area of non-irrigated land x productivity of non-irrigated land)	ton
3.	Planting area	total rice field + additional plants field	ha
4.	Irrigation field	Irrigation field 2020 + additional annual irrigation land – irrigation land conversion	ha
5.	Non-irrigation field	non-irrigation land 2020 + additional annual land – (non-irrigation land conversion)	ha
6.	New rice field	available land x % target extensification	ha
7.	Crop Index	Harvest area: land area	

The presence of rice in East Kalimantan is influenced by multiple factors that impact rice consumption in the sub-model. Illustrated in Figure 4, this sub-model is limited by household, industrial, and feed rice consumption variables. The main factors in this sub-model are population size and household rice consumption.

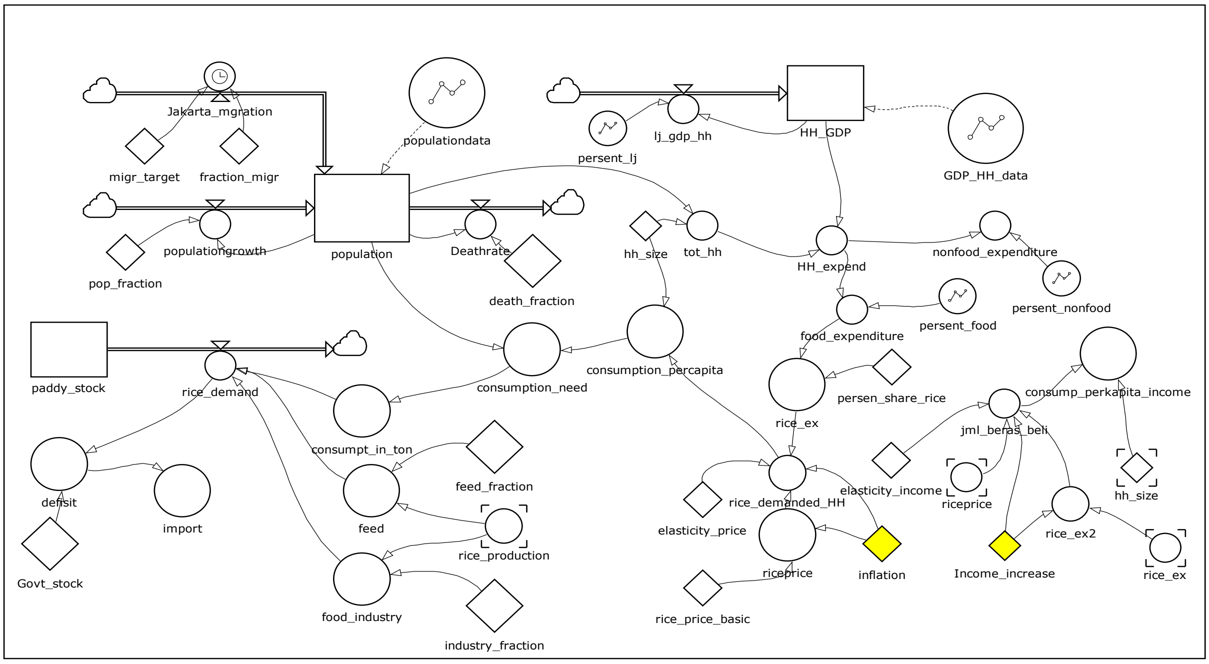


Figure 4. Stock and flow diagram of rice consumption

In Figure 4, the yellow color indicates the variables involved in policy scenarios, including changes in income and prices affecting rice demand. Studies have demonstrated that higher household income leads to lower rice consumption, and higher rice prices also result in reduced household consumption. This model uses the scenario of increasing income and price changes as a benchmark for reducing rice consumption.

Table 5. Parameters and formulas of the consumption sub-system

No.	Parameter	Formula	Unit
1.	Population	population 2020 + birth population + migration – death population	people
2.	Total HH expenditure	Total HH expenditure 2020 + growth rate of HH expenditure	Rupiah
3.	HH expenditure	Total HH expenditure/total household	Rupiah
4.	Food expenditure	% HH food expenditure x HH expenditure	Rupiah
5.	HH rice expenditure	% HH rice expenditure x Food expenditure	Rupiah
6.	HH rice demanded	HH rice expenditure/rice price	kg
7.	Rice demand	HH consumption + food industry + feed + govt. stock	ton

Note: HH refers to a household

Table 5 includes the variables and formulas for the rice consumption subsystem depicted in Figure 4. This subsystem is influenced by factors such as household rice consumption, industry, feed, and government rice reserves. A 1% increase in the cost of rice results in a 0.4% decrease in the quantity of rice purchased. To assess the impact on household rice consumption, the quantity of rice purchased is calculated as the household's expenditure on rice divided by the rice price minus 0.4% of the total amount of rice purchased. Up to 0.17% of rice production is utilized for feed purposes, and for industrial materials, 0.66% of rice production is used. Figure 4 depicts the stock and flow diagram of rice consumption in East Kalimantan concerning population migration during the capital relocation.

Third, policy scenario simulation, including an extensification scenario: conversion of 10% of idle land per year into productive land and reduction of agricultural land conversion to 0%, and a consumption reduction scenario: an increase in household income leading to a decrease in rice consumption (with an elasticity of -0.4).

Fourth, refer to Figure 2 to generate a stock and flow diagram, accompanied by a mathematical representation that models the data. Furthermore, kindly calculate the mean absolute percentage error (MAPE) using the provided formula to assess the precision of the simulated data, enabling a comparison to be made with the actual data.

$$MAPE = \frac{1}{N}\sum\frac{|X_m - X_d|}{X_d}x100\% \quad (1)$$

The study presents two scenarios for government policy: increasing productivity through extensification or reducing consumption by boosting household income and price stability. Equation (1) calculates the MAPE value using simulated data (*Xm*) and actual data (*Xd*), with *N* representing the amount of data. The simulation commences in 2020 and continues until 2030.

3. Results and discussion

According to this study, the population of East Kalimantan in 2020 was 3,793,152, growing at a rate of 2.0% per year. The Indonesian government plans to relocate the capital from DKI Jakarta to East Kalimantan in 2024, with a target of 1.5 million residents moving to the new capital (Otorita IKN 2022). Based on this target, the government estimates an influx of 325 thousand new residents every five years. This migration plan is expected to increase the population by an average of 65 thousand people annually, in addition to the natural population growth. Unlike previous studies (Deshaliman and Gantina 2019; Adi et al. 2021) that used total population calculations, this study aims to precisely calculate the additional population migration according to government targets on an annual basis.

Model validation was conducted to ensure the accuracy and consistency of the model, a critical step in determining whether it accurately reflects the system it was designed to simulate. The validation process involved comparing rice production simulations with historical data. The first data set comes from actual historical records, while the second set comes from simulation results. Table 6 displays the simulation results, historical data on rice production, and the results of statistical tests. A back-casting simulation was performed for the MAPE test using the available actual series data. The MAPE validation test value of 2.94% (less than 5%) indicates that the difference between the simulation output and the actual output is negligible, demonstrating that the model successfully captures actual conditions.

Table 6. The MAPE test for rice production, 2018−2022

Year	Rice production (ton)	
	Actual*	Simulation
2018	152,060	151,483
2019	146,878	150,317
2020	151,863	149,423
2021	142,321	148,528
2022	139,266	147,633
MAPE	2.94%	

Source: BPS Kaltim (2023b)

Figure 5 in the initial simulation depicts the behavior of the status quo, or business as usual (BAU), system without any policy intervention or new scenarios. In this scenario, agricultural development persists with the policies put in place the previous year. The status quo assumption is grounded in input data (refer to Table 1), which indicates an annual land conversion of 100 hectares for irrigated rice fields and 300 hectares for non-irrigated rice fields. Additionally, the incorporation of new land totaling 700 hectares annually is derived from the East Kalimantan Regional Medium Term Development Plan document.

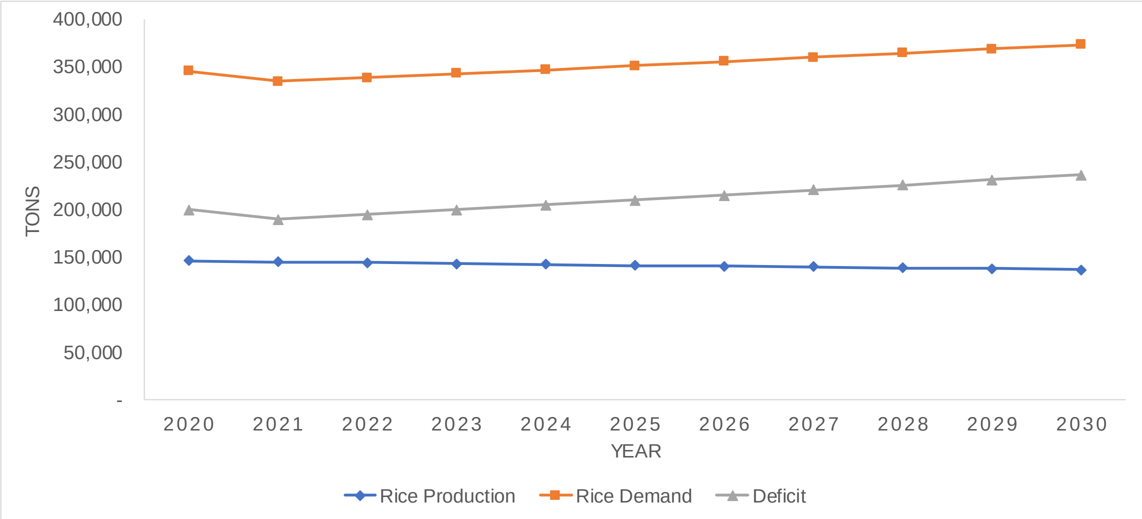


Figure 5. Rice production and rice demand in East Kalimantan (business as usual), 2020−2030

The data presented in Figure 5 illustrates a consistent increase in the demand for rice in East Kalimantan, which aligns with the region's population growth. The COVID-19 outbreak temporarily decreased rice demand during 2020−2021, but the demand has since rebounded. In contrast, rice production has been steadily declining. Based on the simulation results, it is projected that by 2024, there will be a deficit of 216,879 tons, and this deficit is expected to grow to 249,694 tons by 2030. The average annual decline in rice production is estimated to be 0.65%.

3.1. Scenario I: extensification and reduction of land conversion

The first scenario involves a policy to increase productivity and reduce land conversion. According to data from the East Kalimantan provincial government, 1,800 hectares of irrigated rice fields need to be cultivated, with an annual conversion of 100 hectares of rice fields. Additionally, 20,502 hectares of non-irrigated rice fields are not being grown, with a yearly land conversion of approximately 300 hectares. To address this issue, the extensification policy scenario proposes to make 10% of the uncultivated rice fields productive again each year and to reduce the conversion of irrigated rice fields to zero while also reducing the conversion of non-irrigated rice fields from 300 to 100 hectares per year. The results of the simulation of the extensification and reduced land conversion scenarios are presented in Table 7.

Table 7. Comparison of rice production between business as usual (BAU) and extensification and reduction of land conversion, 2023−2030

Year	Rice production (ton)		Gap (ton)
	BAU	Scenario I (Extensification & reduction of land conversion)	
2023	145,778	145,778	-
2024	144,611	152,072	7,461
2025	143,716	158,639	14,923
2026	142,821	165,207	22,386
2027	141,926	171,776	29,851
2028	141,030	178,347	37,317
2029	140,134	184,918	44,784
2030	139,238	191,491	52,253

Expanding rice production can be achieved by utilizing uncultivated rice fields and increasing annual yield. With a high population and growth rate, the availability of unused land presents an opportunity to implement an extensification program through agrarian reform. Beginning in 2024, the extensification policy aims to optimize available rice fields by 10% per year and eliminate the conversion of rice fields. The simulation results in Table 7 demonstrate a significant increase in rice production with the extensification program compared to the standard approach. Indonesian Law No. 41 of 2009 on

Sustainable Food Agricultural Land Protection requires the preservation of agricultural land and the prevention of land conversion. The relocation of the capital to East Kalimantan will occur on government-owned and plantation land, offering the chance to utilize previously unused land for agricultural purposes.

While this scenario emphasizes expanding land allocation for rice cultivation, a notable challenge persists: numerous farmers exhibit a preference for cultivating high-value commodities, such as horticultural and plantation crops, which are considered more economically lucrative. Should this trend continue, policy orientation may shift toward the development of these high-value commodities due to their more substantial potential for enhancing farmer incomes. Nonetheless, this transition could necessitate increased rice imports from other regions to satisfy domestic consumption. Accordingly, this trade-off underscores the critical need to align land-use policy with farmer preferences and prevailing market dynamics to ensure national food security and promote the well-being of rural populations.

3.2. Scenario II: reducing rice consumption

The second scenario involves implementing a policy to decrease rice consumption through economic measures, such as adjusting income and prices. Achieving this objective requires not only food policy interventions but also consideration of other sectoral policies that can stimulate economic growth and raise household incomes. Based on Indonesian statistical data, positive economic growth is assumed each year, with annual household expenditure growth of 1.23% and the government aiming for a 5% annual GDP increase. With this consistent economic growth, the potential reduction in rice consumption can be estimated using an income elasticity value of –0.4 for rice consumption and a price elasticity of –0.4 for every 1% price increase. Rice remains a fundamental commodity for the Indonesian population, and its price stability is consistently maintained, resulting in an average price inflation rate of only 1−2%. Additionally, a 5% increase in income is targeted each year.

The Indonesian government has implemented several policies to manage the price of rice, ensuring market stability, protecting consumers, and supporting farmers. The government can purchase rice directly from farmers or through the Logistics Agency (BULOG) to create reserve stocks. The government purchase price (HPP) is the guaranteed reference price for farmers and is used to determine government purchases. This price gives farmers certainty about their crop income. The government sets the highest retail price (HET) as the maximum price at which rice can be sold to consumers, protecting them from unreasonable price hikes. The government may also sell reserve rice from BULOG stocks on the market to stabilize rice prices at the consumer level. Furthermore, the government regulates rice import and export policies to balance supply and demand in the domestic market. When supply is insufficient and prices are high, the government may import rice to reduce prices. In this context, imports refer to sourcing rice from outside the East Kalimantan province (not from foreign countries), especially when local supply is insufficient and prices rise sharply. The government closely monitors rice inflation rates to identify potential price pressures and may take preventive or interventional measures if necessary.

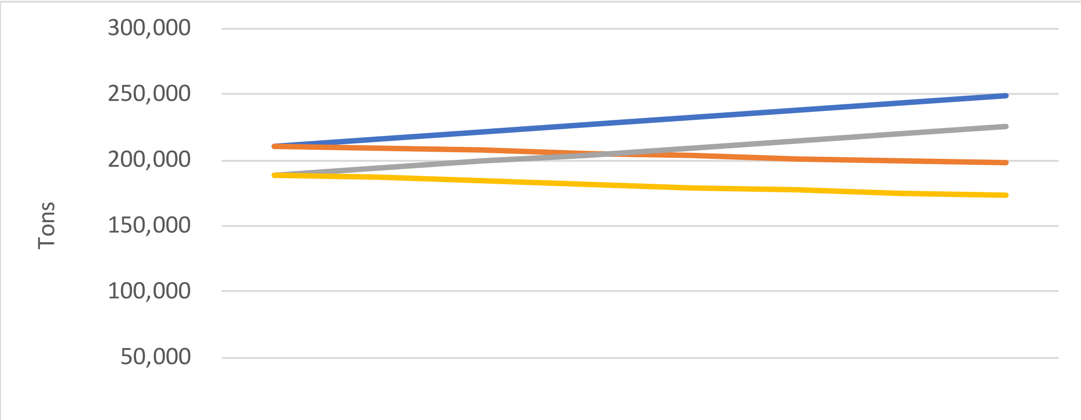
Table 8. Comparison of rice demand between business as usual (BAU) and consumption reduction programs, 2023−2030

Year	Rice demand (ton)		Gap (ton) (Scenario II - BAU)
	BAU	Scenario II (Reducing consumption via income and price)	
2023	338,012	334,625	(3,387)
2024	342,158	338,728	(3,430)
2025	346,355	342,883	(3,472)
2026	350,604	347,089	(3,515)
2027	354,905	351,347	(3,559)
2028	359,259	355,657	(3,602)
2029	363,667	360,020	(3,647)
2030	368,129	364,437	(3,692)

Rice is a commonly consumed staple food known for its inelasticity, with an elasticity value of less than one. This implies that even small changes in price or income have minimal impact on rice consumption. Based on simulation results, the estimated per capita rice consumption in 2024 is 88 kg per year, just two kilograms lower than the business-as-usual scenario. Table 8 illustrates that despite inflation and increasing income, the decrease in rice consumption is only around 3,500 tons per year compared to the current level. Various government policies that have helped reduce household rice consumption include expanding welfare programs, stabilizing prices, and prioritizing rural development. Additionally, promoting education and supporting the corn and potato industries have been instrumental in fostering food diversification (Cahyono et al. 2024).

3.3. Scenario III: a combination of extensification policies, reducing land conversion, and reducing consumption

The third scenario combines elements from scenarios I and II. The results from the scenario simulation in Figure 6 indicate that implementing a combination of extensification policies, reducing land conversion, and decreasing consumption through increasing income and stabilizing rice prices leads to the lowest level of rice deficit compared to both the status quo and the other scenarios.



	2023	2024	2025	2026	2027	2028	2029	2030
BAU	211,333	216,879	222,209	227,594	233,034	238,530	244,083	249,694
Scenario I	211,333	209,450	207,350	205,304	203,311	201,374	199,492	197,666
Scenario II	188,847	194,117	199,167	204,268	209,421	214,627	219,886	225,199
Scenario III	188,847	186,688	184,308	181,978	179,699	177,471	175,295	173,171

Figure 6. Rice imports with several scenarios in East Kalimantan, 2023−2030

The difference between scenario I and the status quo (business as usual) is more substantial than that between scenario II and the status quo. It is promising that increasing rice production by adding paddy fields is feasible due to the availability of uncultivated agricultural land. On the other hand, in scenario II, the simulation results indicate that an increase in economic variables, such as income and prices, is unlikely to result in a significant decrease in consumption. However, a substantial increase in income can reduce rice consumption. For example, with a 5% annual increase in expenditure, the demand for rice consumption per capita can be reduced by around 1 kg per capita.

The third scenario highlights the potential for addressing the rice deficit in East Kalimantan by implementing a combination of policies to increase production and reduce consumption. Due to the region's limited development as a food crop production center, particularly for rice, it currently depends on other regions to meet its production shortfalls. However, with an annual economic growth rate of 2-5% and ample agricultural land, the third scenario offers a promising policy approach to addressing the rice deficit through imports.

This study extends previous studies that estimated rice consumption needs based solely on projected dietary patterns, which indicated that rice demand in East Kalimantan would surpass production capacity, particularly under the scenario of population relocation from Jakarta, with an estimated requirement of approximately 498,000 tons in the first year (Deshaliman and Gantina 2019).

As a more empirical alternative, the present study incorporates actual consumption patterns, yielding a lower initial-year demand estimate of around 334,000 tons. Complementary studies on regional food balance suggested that a combined strategy of increasing production and reducing consumption could narrow the production–consumption gap by up to 141,561 tons (Adi et al. 2021). However, the mechanism underlying the reduction in consumption was not specified. Addressing this gap, the current study develops a consumption reduction scenario grounded in economic factors, specifically price and income. It demonstrates through simulation that this approach effectively decreases the disparity between rice production and consumption in East Kalimantan.

4. Conclusions and policy implications

This study presents a dynamic simulation of rice production and consumption in East Kalimantan in response to projected population migration from Jakarta and the region's anticipated economic development. By employing a system dynamics model, the analysis captures the interrelationships between population growth, rice consumption, land use, income levels, and price. The findings offer critical insights into how East Kalimantan can reduce its reliance on rice imports through strategic interventions. The conclusions drawn from the simulation are followed by a set of policy implications aimed at supporting local rice production, ensuring food security, and strengthening interregional collaboration.

4.1. Conclusions

This study uses a system dynamics simulation model to project rice consumption in East Kalimantan as a result of potential population migration from Jakarta. The simulation takes into account population growth and the expected increase in rice consumption in the region.

The analysis results show that East Kalimantan can reduce its dependence on rice imports by utilizing 10% of temporarily unused agricultural land, without the need to convert existing agricultural land. The simulation shows a decrease in imports of 3% in 2024 (209,450 tons) and 21% in 2030 (197,666 tons) compared to the business-as-usual scenario.

In addition, the economic policy scenario, which involves increasing income and stabilizing prices, is projected to reduce imports by 10% per year compared to the baseline scenario. In 2024, imports are estimated at 194,177 tons and in 2030 at 225,199 tons. By implementing a combination of policies such as reducing land conversion, implementing extensification programs, and controlling rice consumption, East Kalimantan has the potential to reduce imports by 14% in 2024 and 31% in 2030. However, East Kalimantan is still not a major producer of food crops, especially rice, and is still highly dependent on supplies from other regions.

4.2. Policy implications

Local governments should encourage the use of temporarily unused agricultural land as a strategic measure to increase rice production without damaging existing agricultural land. Support for agricultural extensification programs must be strengthened, including through incentives for farmers, provision of production facilities, and development of supporting infrastructure. Efforts to reduce rice consumption can be done through food diversification and public education regarding healthy and sustainable consumption patterns.

Policies to increase community income, especially for farmers, and stabilize food prices will have a direct impact on rice consumption and production patterns in the region. To ensure food security, East Kalimantan needs to strengthen cooperation with other rice-producing regions and build inter-regional trade networks. The use of a systems dynamics approach shows the need for synergy between actors in the production and consumption system. Strengthening institutions and cross-sector coordination are key to the success of food policies. Although the expansion of land for rice cultivation presents potential benefits, a key challenge lies in farmers' preference for cultivating higher-value commodities such as horticultural or plantation crops, which offer greater economic returns. Should this tendency continue, policy priorities may shift toward promoting these commodities due to their positive impact on farmer incomes. However, such a shift would necessitate ongoing rice imports from other regions to fulfill local consumption demands. This trade-off underscores the need to align land use policies with farmer preferences and prevailing market conditions to ensure food security while simultaneously enhancing rural livelihoods.

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