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Dynamic Simulation Model of Garlic Availability in Bali Using iThink Software

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Abstract

Fluctuations in local production, increasing demand, and dependence on garlic supplies from outside the island make it difficult for Bali Province to maintain a stable garlic supply. iThink software is used to model the dynamic garlic availability system in this study. This simulation method involves creating a Causal Loop Diagram (CLD), creating a mathematical model based on differential equations, and conducting table and graphical analysis of the simulation results. The simulation results show that the linear increase in garlic demand of 6,289.08 tons per year can be offset by local production increasing to 31,071.73 in 2024 and an off-island supply of 4,176 tons per year. The projection of garlic availability until 2024 is 122,895.71 tons. The results show that maintaining a stable supply of off-island garlic is the main way to ensure sustainable garlic availability in Bali.

Keywords: Garlic, Bali Province, Dynamic Simulation, iThink.

1. Introduction

Over the past decade, Bali has faced strategic challenges due to fluctuations in garlic supply, especially since the island is highly dependent on external supplies. Increasing demand and instability of local production are major barriers to supply sustainability, according to recent studies (Garside & Asjari, 2015; Krisdayanti et al., 2017). The dynamic systems approach has been successfully used in studies to map the difficulties of the garlic supply system. This includes the analysis of strategic food availability in other areas (Yulastari et al., 2018; Surya et al., 2018). Simulation is an activity that aims to understand the behavior of a system by analyzing a model that represents a cause-and-effect relationship similar to the real system (Eriyatno, 2012). Jay W. Forrester introduced dynamic systems in the 1950s. Initially, dynamic systems were used to solve industrial problems. Dynamic systems are concerned with questions about the dynamics of complex systems, namely the patterns in behavior produced by the system over time. The emphasis is on the use of dynamic systems, namely behavior that comes from the policy structure of the system itself. This knowledge is very important for successful policy planning (Rachmawati & Fitria 2016).

Reliability of simulation models in predicting the availability of a commodity. This study assesses the readiness of East Java as a national rice barn to contribute to the national rice surplus. In 2014, East Java was targeted to contribute 60% of the national rice surplus of 10 million tons in the P2NB program. Through cause-and-effect diagrams, stock and flow diagrams, and simulations, the model predicts that the availability of rice in East Java in 2014 will reach 3,944,377.7 tons. These results show East Java's inability to meet the target, while also proving the accuracy of the model in predicting commodity availability and evaluating regional readiness (Anissa and Hasyim, 2015). Research at the "X" tofu factory in Purwakarta shows that the dynamic system model is effective in managing the risk of soybean price fluctuations. Of the three scenarios tested, namely existing stock, 5% additional safety stock, and 50 kg sack-based lots, the first scenario produced the highest profit of IDR 491,898,600. This strategy was chosen as the best option to maintain the stability of profits and soybean availability (Dedy et al., 2024). cassava availability (Manihot esculenta Crantz) as a raw material for agro-industry and food in Aceh Besar Regency. The system dynamics approach is used to understand the complex behavior of physical, biological, and social systems related to cassava production and distribution. Dynamic simulation provides strategic insights to optimize the performance of the cassava availability system and improve the economic sustainability of farmers. (Lukman et al., 2023). Dynamic simulation to project food security related to the needs of corn, eggs, and chicken meat in East Java. As the largest producer of chicken eggs (28% of national contribution in 2018) and the third largest producer of chicken meat (13%), East Java plays an important role in providing national protein. However, the availability of corn as the main ingredient in chicken feed faces challenges due to land degradation, so it relies on imports from outside the province or abroad. Dynamic simulation offers a concrete strategy to improve East Java's food security, with a focus on increasing the production of corn, eggs, and chicken meat, while reducing dependence on imports (Hajar, 2020).

The dynamic system approach is often used in simulation design and has been applied in various studies. For example, the development of a simulation model with a dynamic system to increase the value of the palm oil industry supply chain in Riau (Nindy Permatasari, 2022), as well as an analysis of simulation development strategies to increase the value of the palm oil supply chain (Nindy & Erma 2022). In addition, the dynamic system model is also used to increase rice productivity based on the Internet of Things (IoT).

The objectives of this study include several important aspects. First, to describe the Causal Loop Diagram (CLD) which shows the dynamics of the relationship between production, availability, demand, and supply variables per island in the form of a loop diagram to understand the system visually. Second, to develop a simulation model that can estimate the availability of garlic based on the level of production, demand, and supply on each island. Third, to compile a mathematical model based on differential equations that dynamically describe changes in garlic availability. Finally, to visualize the simulation results through graphs that show the relationship between garlic and production, demand, and supply on each island.

2. Literature Review

2.1 Simulation

Simulation To understand and predict system behavior, simulation uses a representation model that shows the cause-and-effect relationships in a real system. This is very useful for the analysis of complex systems, especially those involving dynamic interactions between their components (Banks et al., 2014; Arwidya et al., 2014). With simulation, you can explore various scenarios and find the best solution without directly interfering with the real system.

System simulation methods can be used to study how each entity in the system interacts with each other. Ultimately, this method allows the identification of improvements aimed at improving customer service and satisfaction (Arwindy et al., 2014).

In the past decade, simulation methods have been widely used in areas such as food security, logistics, and supply chain management. A study by Yulastari et al. (2018) showed that simulation can help evaluate the efficiency of the beef supply chain, and Surya et al. (2018) used it to assess the availability of broiler chicken meat. This method provides users with an understanding of how changes in policies or system conditions impact overall performance.

2.2 Garlic

Garlic (Allium sativum L.) is one of the most profitable plants that is widely used in everyday life, both as food and as herbal medicine. Antimicrobial, antioxidant, and blood pressure lowering properties are some of the health benefits offered by bioactive compounds such as allicin (Shang et al., 2019; Omar et al., 2016). Garlic is also known to boost the immune system and prevent heart disease (Ried et al., 2016). One of the important commodities that has experienced changes in production in Indonesia, including in Bali Province, is garlic. Local production fell drastically from 84.9 tons in 2012 to 31.2 tons in 2014. Then it returned slightly to 41 tons in 2016, according to BPS Bali data (BPS Bali, 2018). With dependence on imports to meet domestic demand, this situation indicates the difficulty of maintaining local supply availability. According to research conducted by Zhang et al. (2018), data-based supply chain planning is essential to improve the efficiency of garlic distribution and production.

2.3 iThink Software

iThink, which is part of the STELLA software suite, is a visual simulation software intended for modeling dynamic systems, particularly those related to business. Using a graphical approach, it allows users to visually view the dynamics of a system. Using elements such as stocks, flows, modifiers, and connectors, users can map relationships between variables and create models. This allows simulation of various policy scenarios or system changes for a comprehensive evaluation. iThink has been used in various studies in the literature. For example, iThink was used to create a model that simulates the case of a k-out-of-n weighted multi-state system in dynamic modeling of multi-state systems. In addition, iThink was used to model the changing internal systems of a company. This helps managers and decision makers understand their specific business environment and become more aware of common and specific dynamic problems.

In recent years, isee systems has begun developing web-based solutions such as isee Runtime and Stella Online, which allow users to access their models without the need for special software installations. These software tools are used to help organizations, academics, and professionals understand and analyze complex systems through stocks and flows modeling approaches and causal loop diagrams. Think has evolved by adding more flexible data import and export features, allowing it to be used in conjunction with other analytical tools such as Python, R, and Excel. Improvements in the visualization of simulation results have also made iThink increasingly attractive to users who want to present data in a more interactive way.

3. Research methods

This Dynamic Availability Simulation is designed and built using the following methodology:

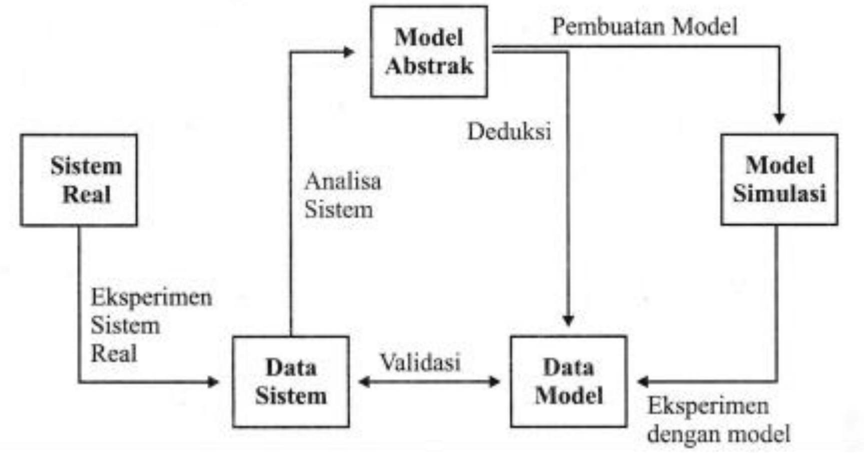

Figure 1: Research Stage Diagram

3.1 Real System

The real system that is the focus of this research is the garlic supply chain in Bali Province. This system involves various components, such as production, demand, supply, distribution, and consumption. The relationship between components is analyzed to identify factors that cause fluctuations in garlic availability. Literature studies and secondary data are used to understand the characteristics of the system and the main variables involved.

3.2 System Data

The data used in this study include garlic production data from 2012 to 2016, obtained from the Central Statistics Agency (BPS) of Bali Province. In addition, data related to demand, distribution, and other supporting factors, such as community consumption levels, are also estimated using a literature approach and expert interviews. This data will be used as input to develop a simulation model.

3.3 Abstract Model

Abstract models are designed to simplify real systems into representations that are easier to analyze. This model adopts a dynamic system approach, by identifying key variables that form a cause-and-effect loop. Causal Loop Diagram (CLD) is used to visualize the relationship between variables, such as production levels, demand, supply, and consumption of garlic.

3.4 Data Model

The data used in the model is quantitative data from real systems that have been processed to match the model structure. This data includes:

- Planted Area (Stock), Representation of the total land area used for planting commodities (garlic). With Inflow Extensification (addition of new planted land) and Outflow Land Conversion (conversion of planted land to non-agricultural).
- Harvested Area (Stock), The area of land that has been successfully harvested in a certain period. With Inflow calculated based on Planted Area multiplied by Planting Productivity.
- Production (Flow), The amount of harvest from the harvested land area. With Inflow calculated based on the Harvested Area multiplied by Harvest Productivity.
- Availability (Stock), The amount of garlic available in the market or warehouse in one period. With Inflow of Production and Supply Outside the Island, and Outflow of Demand and Adjustment to Minimum Stock.

- Population (Stock), Human population that contributes to the need for garlic consumption. With Inflow of Births and Immigration, and Outflow of Deaths and Emigration.
- Demand (Flow), Total garlic needs consisting of household consumption, HORECA (hotels, restaurants, catering), and industrial needs. With Inflow calculated from Household Consumption (Number of Households × Consumption per Capita) and other needs.
- Out-of-Island Supply (Flow), Supply of garlic brought in from other areas to cover stock shortages in the province.
- KK Conversion (Flow), Change in the number of heads of families (KK) from the total population based on the average number of members per KK.

3.5 Simulation Model

The simulation model was developed using iThink software, with the following steps:

- **Definition of variables,** Key variables are identified, such as stocks (garlic production), flows (supply and demand), and converters (prices and consumption).
- **Model structure development,** Visual models are designed using elements such as stocks, flows, converters, and connectors to represent the system.
- **Model validation,** the model is tested using historical data to ensure good agreement between the simulation and the real system.
- **Scenario simulation**, the model is used to evaluate various policy scenarios, such as increasing local production, optimizing distribution, and adjusting community consumption.
- **Analysis of results**, the simulation results are visualized in the form of graphs and tables, which show the dynamics of garlic availability under various scenarios.

4. Results and Discussion

4.1 Model Design

Dynamic simulation modelling of garlic availability is limited by several factors that are not related to the availability system itself. This model is divided into three submodels: garlic production, garlic availability, and garlic consumption. This modeling is used for all types of garlic in Bali Province from 2012 to 2016. The amount of demand for the meatball industry, extracts, and other industries is considered the same. Between 2012 and 2016, the intensification and land conversion rates are considered constant. The average extensification rate is 0.419 fractions per year and the average land conversion rate is 0.202 fractions per year (BPS Bali Province, 2018). The average birth fraction is 0.0146 fractions per year and the average death fraction is 0.0034 fractions per year (BPS Bali Province, 2017). The simulation analysis period starts in 2012

4.2 System Data

Table 1: Availability of Garlic

Year	Population (People)	Area planted with garlic (Ha)	Garlic production (Tons)	Harvested area (Ha)	Out-of-island Supply (Tons)	Availability of garlic (tons)	Demand for garlic (Tons)
2012	75,029.64	12.00	1,906.88	12.00	4,176	1,348	6,289.08
2013	150,059.28	14.87	2,363.51	14.87	4,176	38.80	6,289.08
2014	225,088.92	18.44	2,929.49	18.44	4,176	45.04	6,289.08
2015	300,118.56	22.85	3,631.00	22.85	4,176	52.65	6,289.08
2016	375,148.20	28.32	4,500.49	28.32	4,176	61.91	6,289.08

The system data obtained describes the availability of garlic that is interrelated with other variables in the period 2012-2016. Furthermore, this data becomes an initial description of the input data in the dynamic simulation model with iThink.

4.3 **Models Framework**

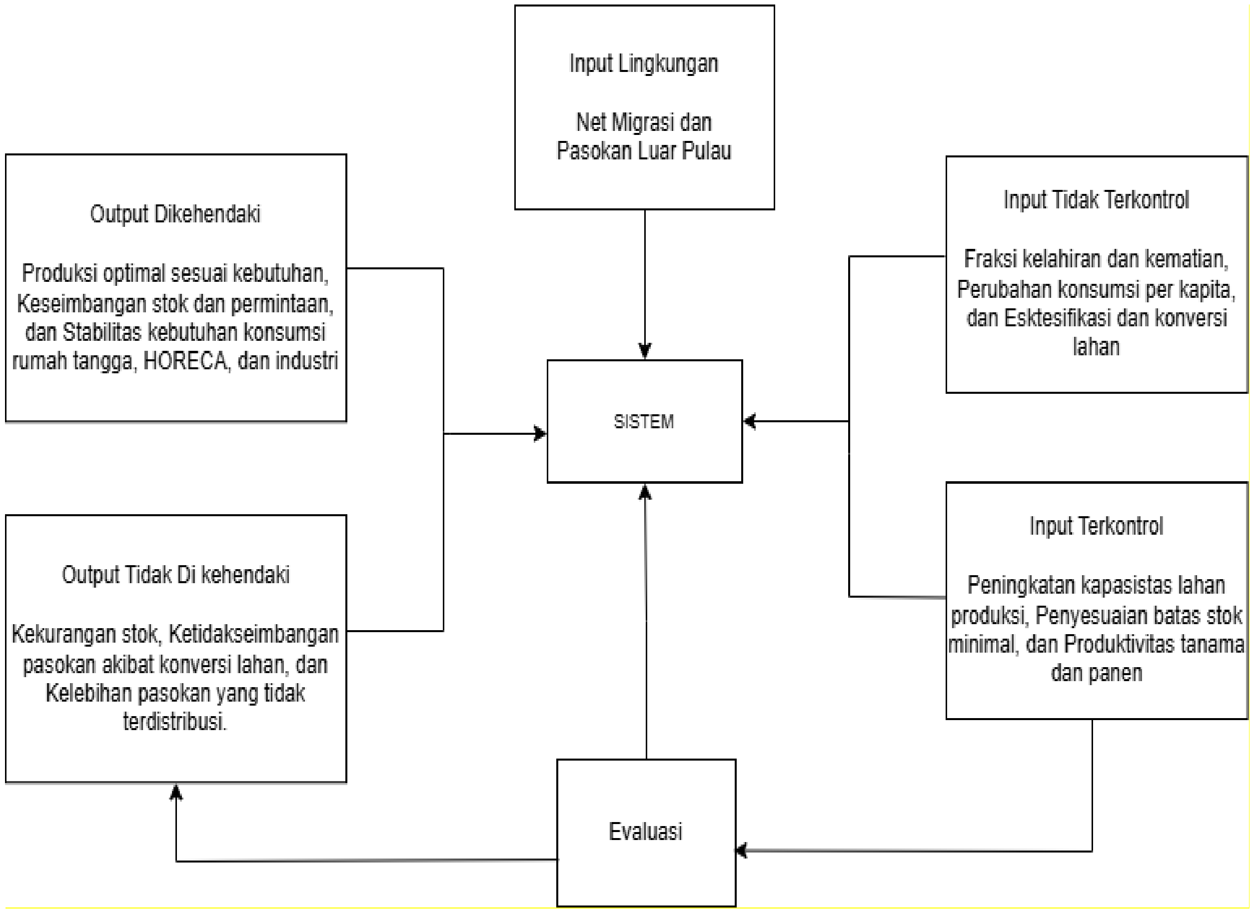

Figure 1: Blackbox Diagram

This blackbox diagram models the relationship between inputs, processes, and outputs in a system that focuses on the dynamics of food supply and demand in a region. The system receives several types of inputs, namely environmental inputs such as net migration and off-island supply, uncontrolled inputs including birth and death fractions, changes in per capita consumption, and land extensification and conversion, and controlled inputs including increasing production land capacity, adjusting minimum stock limits, and crop and harvest productivity. This system produces two types of outputs: desired outputs, in the form of optimal production according to needs, balance of stock and demand, and stability of household consumption, HORECA (hotels, restaurants, catering), and industry; and undesired outputs, such as stock shortages, supply imbalances due to land conversion, and undistributed excess supply. The evaluation process is used to assess system performance and determine corrective measures for controlled inputs to achieve desired outputs while minimizing undesired outputs. This diagram highlights the importance of the interaction between controlled and uncontrolled variables in the system, as well as the need for continuous adaptation to maintain supply and demand stability.

The black-box model also emphasizes the importance of monitoring and data-driven decision-making in managing complex systems. By analyzing patterns of relationships between inputs, processes, and outputs, managers can identify critical points that affect system stability, such as significant changes in per capita consumption or increased conversion of land to non-productive uses. In addition, adaptation strategies through controlled inputs, such as optimizing crop productivity, setting minimum stock limits, or diversifying supply sources, can help the system adapt to external changes such as population growth or market fluctuations. This evaluation process can also be integrated with modern technologies, such as simulation models and artificial intelligence, to estimate the impact of changes in inputs and formulate more efficient scenarios in maintaining a sustainable balance between food supply and demand.

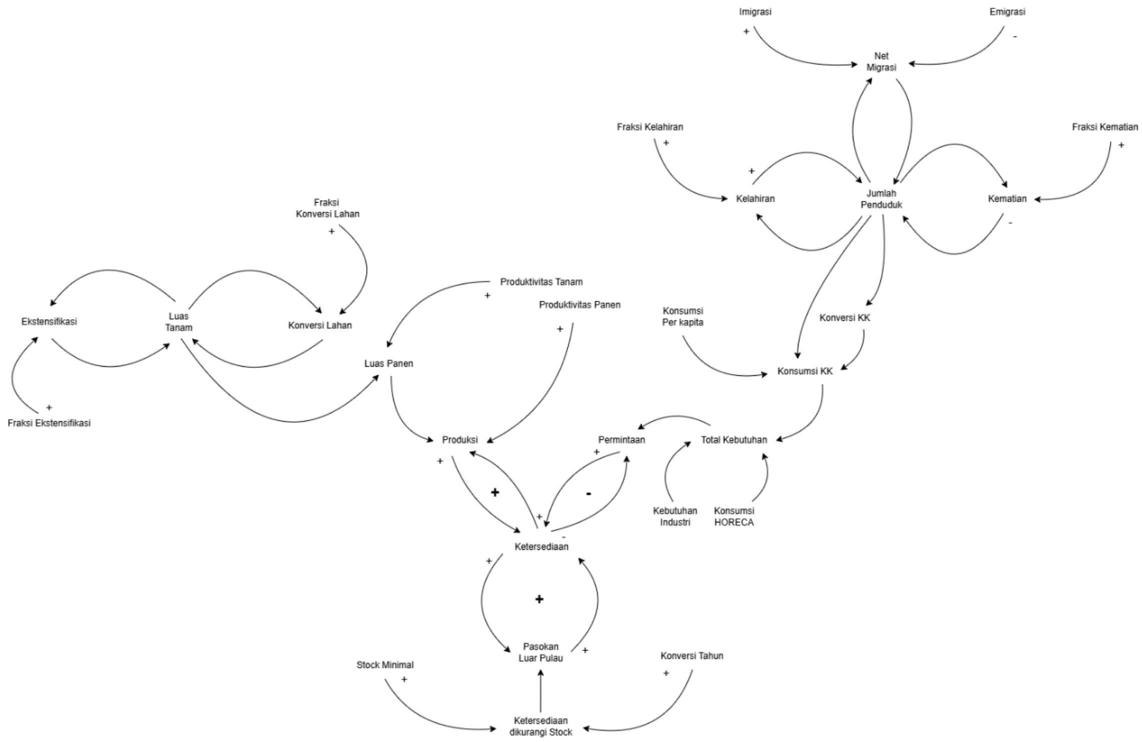

Figure 2: Causal Loop Diagram

The Causal Loop Diagram (CLD) in this simulation model illustrates the dynamic relationship between population, food availability, production, and demand in an integrated system. Population is one of the main elements, which is influenced by births, deaths, immigration, and emigration. This relationship creates two types of feedback: a balancing loop, where population growth can increase the death rate leading to population stabilization, and a reinforcing loop, where population growth increases births leading to further growth. Food availability is influenced by production, external supply, demand, and stock reduction. Food production depends on the harvested area and harvest productivity, while the harvested area is influenced by land extensification and conversion. This system shows the existence of a reinforcing loop, where increased productivity and production support food availability, and a balancing loop, where if availability falls below the minimum stock, the system encourages increased production or external supply.

On the other hand, food demand is determined by household consumption, industry, and the HORECA (Hotel, Restaurant, and Catering) sector. Household consumption is calculated based on population and per capita consumption, creating a direct relationship between population growth and increased food demand. The system also has a balancing loop, where a high increase in demand can reduce availability, thus triggering consumption control. Cultivated land plays an important role in food production. Extensification increases the area planted, while land conversion reduces it. This relationship creates a reinforcing loop, where an increase in the area planted supports production, and a balancing loop, where high land conversion reduces production and causes imbalances in the system. Overall, this CLD shows how the various elements in the system influence each other through complex feedbacks, providing insights for understanding food security and resource planning.

4.4 Data Model

The data used in the model is quantitative data from real systems that have been processed to match the model structure.The following is a quantitative data model on the availability of onions, using the System Dynamics (SD) approach with data-based variables and equations as shown in Table 2.

Table 2: Quantitative Data

Variables	Equation/Parameter	Information
Population_Number(t)	Population(t-dt) + (Births + net_migration - Deaths) * dt	Population dynamics.
INIT Population_Number	(Births + net_migration) - Deaths	Initial value of population.
Birth	4007200 * Birth_Faction	The number of births per certain time.

net_migration	Immigration - Emigration	The difference between immigration and emigration.
Death	4007200 * Death_Faction	The number of deaths per specific time.
Availability(t)	Availability(t-dt) + (Production + Supply_off_island - Demand) * dt	Dynamics of food availability.
INIT Availability	Production + Supply_off_island - Demand	Initial value of food availability.
Production	Harvested Area * Harvested Productivity	Food production based on harvest area and productivity.
Supply_off_island	-	Supply from outside the island.
Request	Total_Needs	Total amount of food requirements.
Planted Area(t)	Planted Area(t-dt) + (Extensification - Land_Conversion) * dt	Dynamics of planted land area.
INIT Planted Area	12	Initial value of planted land area.
Extensification	Planted Area * Extension Fraction	Addition of planted land area.
Land_Conversion	Planted Area * Land Conversion Fraction	Reduction in the area of planted land due to land conversion.
Emigration	53394	Number of emigrations.
Birth_Faction	0.0146	Birth fraction.
Death_Faction	0.0117	Death faction.
Faction_Extensification	0.419	Land extensification fraction.
Land_Conversion_Faction	0.202	Land conversion fraction.
Immigration	83543	Number of immigration.
Availability_reduced_stock	(1348 - Minimum_stock) * Conversion_Year	Evaluation of availability compared to minimum stock.
HORECA_Consumption	3082	Consumption by the Hotel, Restaurant and Catering (HORECA) sector.
Consumption_KK	(Population * Consumption_per_capita) / Household_Conversion	Consumption per household.
Convert_KK	Population / 4	Number of households (average 4 people per household).
Harvest Area	Planted Area * Planted Productivity	Area of crop harvest.
Productivity_Planting	12	Crop productivity.
Stock_minimum	1000	Minimum food stock.
Total_Needs	Industrial_Needs + HORECA_Consumption + KK_Consumption	Total food requirements, including industry, HORECA, and households.

4.5 Model Simulation

This model consists of several main components, namely population, consumption, production, and food availability. The population section models the dynamics of population numbers influenced by births, deaths, immigration, and emigration. Changes in population have a direct impact on total food needs, which are calculated from household consumption, per capita consumption, HORECA (Hotel, Restaurant, Catering) consumption, and industrial needs. Meanwhile, food production is influenced by the area of planted land, crop productivity, and harvest productivity.

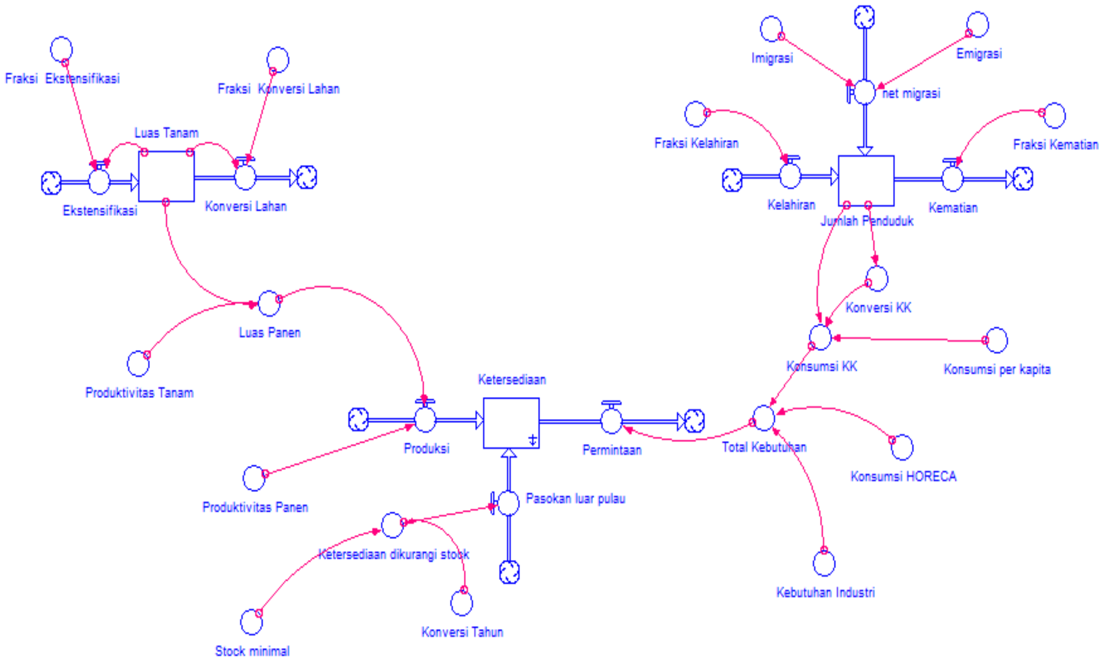

Figure 4: Simulation Model

This production then contributes to food availability, which is also influenced by off-island supply and initial stock. On the other hand, the area of planted land is determined by the process of land extensification and conversion, which affects overall food productivity. This model also considers minimum stock as an evaluation parameter to assess whether availability can meet needs. The imbalance between availability and needs triggers adaptation, either through increasing land area, productivity, or adjusting external supplies. The design of this model provides a framework for understanding the dynamics of the food system and can be used as a basis for simulation and data-based decision making.

Figure 3: iThink Simulation Result Diagram

This graph visualizes the dynamic relationship between population, availability, and planted area in the garlic supply system. Specifically, the graph shows that the increase in planted area and availability is able to keep up with the increasing demand along with population growth. Although the population tends to increase over time, the increased production capacity through the expansion of planted areas and effective stock management allows the demand for garlic to be met. This reflects the importance of sustainable agricultural resource management strategies, including optimizing crop productivity and implementing policies to maintain the balance between supply and demand. Furthermore, this pattern shows that with the right interventions, such as the extension of productive land or minimal stock adjustments, the system can remain stable even when facing pressures due to population growth. Therefore, this graph provides empirical evidence of the importance of adaptive planning and management in maintaining food security in areas with significant population growth.

5. Conclussion

The simulation results show that the demand for garlic which increases linearly by 6,289.08 tons per year can be balanced by local production which increases by 31,071.73 in 2024 and the supply outside the island by 4,176 tons per year. The projection of garlic availability until 2024 is 122,895.71 tons. The results show that maintaining a stable supply of garlic outside the island is the main way to ensure sustainable garlic availability in Bali.

Based on the results of the analysis, it can be concluded that the sustainability of the food supply and demand system, especially garlic, is greatly influenced by the interaction between the variables of population, planting area, and stock availability. The increase in population significantly increases demand, but these needs can be met if there is an effective intervention through increasing planting area, harvest productivity, and sustainable stock management. The simulation model used shows that controlled variables, such as land extensification, management of minimum stock limits, and increasing crop productivity, play an important role in maintaining system stability. In addition, uncontrolled factors, such as land conversion and changes in per capita consumption, must be anticipated so as not to cause an imbalance in supply and demand.

To achieve food system stability, strategic steps need to be taken, such as improving land planning through sustainable expansion of planting areas and optimizing technology to increase harvest productivity. In addition, adjustments to minimum stock limits and monitoring of stock availability must be carried out periodically to prevent shortages or excess supply. The government and policy makers are also advised to educate farmers and the community about the importance of optimal and sustainable land use. Mitigating uncontrolled factors, such as land conversion and changes in per capita consumption, also requires adaptive policies. The simulation model used in this study can be implemented more widely for other scenarios, such as the impact of climate change or spikes in demand in certain sectors, so that strategic and data-based decisions can be taken to maintain food security.

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