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Dynamic System Simulation Design Projected Growth and Shrinkage of to Food Production in Sukabumi

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Abstract

A rapid increase in population along with limited agricultural land can lead to shrinkage of paddy fields, which risks threatening food production and the sustainability of the agricultural sector in the region. This research uses a simulation modeling method with a dynamic system approach. The simulation model was designed based on data related to population growth and the decline in rice field area, as well as other factors that influence it. The dynamic system approach is often applied to analyze systems with many interdependent components. The iteration process in this system shows how changes in one element can affect other elements in the future through complex cause-and-effect relationships. Increased demand for land has contributed to the shrinkage of paddy fields, which in turn has reduced food production. In Sukabumi district, population growth increases land demand, thus accelerating the shrinkage of paddy fields and reducing food production in the region. Projections show that the population of Sukabumi District will grow by around 29% per year, reflecting the huge challenge of providing adequate services and infrastructure to the population.

Keywords: Dynamic simulation, population growth, shrinking paddy fields

1. Introduction

Rapid population growth and land use change are major challenges in the agricultural sector, especially in Sukabumi District. Along with the increasing need for settlements, infrastructure and industry, the area of paddy fields available for food production is shrinking (Ku et al., 2016). This can have a direct impact on food availability, food security, and the welfare of people who depend on the agricultural sector. Population growth is one of the main factors that affect various aspects of life, including food needs. In Sukabumi District, the increasing population growth has triggered serious challenges in the effort to fulfill food needs.

The limitation of agricultural land, especially paddy fields, is one of the crucial issues that need attention. The shrinkage of paddy fields due to land conversion for settlement, infrastructure and industrial needs has further exacerbated the condition. Food production, which is highly dependent on the area and productivity of paddy fields, has the potential to decline if this phenomenon is not addressed immediately. The imbalance between population growth and food production capacity can lead to various problems, such as increased dependence on food imports, food insecurity, and economic instability of local communities.

System dynamics is an appropriate approach to understand the complex interactions between population growth, land use change and food production. By simulating various scenarios, the model can provide insight into long-term projections and the impact of policies implemented. Therefore, a dynamic system simulation design is needed that is able to predict how the growth and shrinkage of paddy fields affect food production in Sukabumi.The dynamic system approach is one solution that can be used to understand the complex relationship between population growth, paddy field shrinkage, and food production. With dynamic system simulation, various related variables can be analyzed holistically, resulting in projections that can assist more effective planning and decision-making.

Therefore, this research aims to design a dynamic system simulation that can project the impact of population growth and shrinkage of paddy fields on food production in Sukabumi District. The results of this research are expected to provide a scientific basis for formulating sustainable development policies and supporting regional food security.

2. Literature Review

2.1. Population Growth

In September 2020, SP2020 recorded Indonesia's population at 270.20 million. Since the implementation of the first Population Census in 1961, the population has continued to increase. Compared to SP2010, the SP2020 results show an additional population of 32.56 million people, or an average of 3.26 million people per year in the last decade (2010-2020). During this period, Indonesia's population growth rate was recorded at 1.25 percent per year. This figure shows a slowdown of 0.24 percentage points compared to the 2000-2010 period which had a growth rate of 1.49 percent per year (Fuadi, 2021).

Population growth and land shrinkage can be obtained through the following formula.

$$PP = (TK - TM) + JP + M \quad (1)$$

Description:
PP : Population Growth (% per year)
TK : Birth Rate (%)
TM : Mortality Rate (%)
JP : Total Population
M : Migration

Shrinkage of Paddy Fields can be obtained through the following formula.

$$PSH = KP + PK \quad (2)$$

notes:
PSH : Shrinkage of Paddy Fields
PK :Percent of Population (%)

Percent of Population can be obtained through the following formula

$$PK = (PT - PS)/PS * 100\% \quad (3)$$

notes:
PT : Latest Year Population
PS : Previous Year Population

People's activities create various types of activities, as they are basically always accompanied by people's movements as part of their activities. People tend to move from one place to another as needed. In other words, people interact with each other to fulfill their various needs, such as food (rice), clothing (clothes), and shelter (housing and its contents). In addition, population science is closely related to the rate of population growth. Basically, population science aims to help organize a better life in the future. Population growth rate is one of the indicators that is often used to describe the population condition of a region, both currently and to predict its future development trends. If the population growth rate is higher than the economic growth rate, then the additional production generated by economic growth will be used up to meet the consumption of a population that is growing faster (Efendi et al., 2021).

2.2. Migration

Migration is the movement of people from one place to another with the aim of settling, either on a local scale (between regions within one country) or internationally (between countries). Migration can occur for various reasons, such as economic, social, political, or environmental factors. Migration or population movement was first introduced by Ernest Ravenstein in 1889. In his significant contribution to the study of migration, Ravenstein introduced the concept of “Laws of Migration.” These laws were based on an analysis of statistical data from the United Kingdom, which was later expanded using data from several major countries in Europe and North America. The Laws of Migration developed by Ravenstein include several important principles: migration and distance The closer the distance between origin and destination, the greater the likelihood of migration occurring, gradual migration, population movements tend to occur gradually through several stages, rather than directly to the final destination, stream and counter-stream Every migration flow (stream) will generally generate a counter-stream from the opposite direction.

With this, Ravenstein not only identifies migration patterns, but also provides an in-depth understanding of the factors that influence an individual or group's decision to move (Jin & Zhang, 2023).

2.3. Simulation

Simulation is a training method used to demonstrate a process or system in a mock form that resembles a real situation. This method aims to provide an overview of how a system works by utilizing a statistical model or the role played by the actor (Mayarisa & Khurtum, 2023).

2.4. Dynamic System

System dynamics simulation is an effective tool to assist in identifying the causes of a problem in a more structured manner. In addition, this method allows users to perform simulations over a period of time, thus providing an overview of how a system interacts and evolves over time. In practice, system dynamics simulation is used to model the interrelationships between various elements in an object or system. By understanding the cause-and-effect relationships between these elements, simulation can provide deeper insight into the behavior of the system, both under normal conditions and when changes occur. This approach is particularly useful in fields such as management, engineering, health, and economics, where analyzing and understanding the dynamics of complex systems is key to strategizing, solving problems, or designing more effective solutions. With the help of simulation, users can also predict the impact of various decisions or change scenarios, thus enabling more informed decision-making based on the resulting data (Annisa et al., 2022).

2.5. Causal Loop Diagram (CLD)

Causal Loop Diagrams (CLDs) are tools used to illustrate the cause-and-effect relationships between variables in a system. CLDs help in identifying emerging issues, as well as illustrating the key variables that influence the dynamics of the system. (Crielaard et al., 2024).

2.6. Software I-think or stella

Stella stands for Systems Thinking, Experimental Learning Laboratory with Animation. Stella is a visual programming language software that adopts the principles of dynamic modeling and object orientation (Richmond, 1985). The program was first designed and introduced by Barry Richmond in 1985, then developed by Isee Systems. Stella allows users to run models created as graphical representations of a system, using four basic building blocks. (Suheri et al., 2019).

3. Materials and Methods

3.1. Materials

3.1.1. System Real

Sukabumi District is faced with the challenge of rapid population growth projections, while on the other hand, paddy fields as the main source of food production are decreasing due to land conversion. In this context, a dynamic system is used to predict food production needs through 2 main variables, namely population growth and shrinkage of paddy fields. The purpose of this study is to analyze the dynamics of population growth, shrinkage of paddy fields, and their impact on future food production, as well as to examine policies that can support food security.

3.1.2. System Data

This data was collected from official sources such as the Central Bureau of Statistics (BPS) of Sukabumi District and West Java. The system data used in this study are as follows. Population Growth, this data includes the total population of Sukabumi based on birth, death, migration rates obtained through equation 1.

Shrinkage of paddy fields, this data includes data on the area of available paddy fields and the trend of land shrinkage due to conversion to non-agricultural land obtained through equation 2. Percentage of population data used to calculate land shrinkage using equation 3.

3.1.3. Abstract Model

Abstract models are designed to simplify real systems into representations that are easier to analyze, while maintaining the essence and key dynamics of the system. The model adopts a dynamical systems approach, which enables an understanding of the complex interactions between variables through the identification of causal loops. To visualize the relationships between variables, a Causal Loop Diagram (CLD) is used. This CLD illustrates how key variables, such as population growth, paddy field area, rice production, paddy field shrinkage, influence each other in a dynamic system.

3.2. Methods

The research method of designing a dynamic system simulation of population growth projections and shrinkage of paddy fields on food production in Sukabum district with Dynamic Simulation using I-Think follows the following stages.

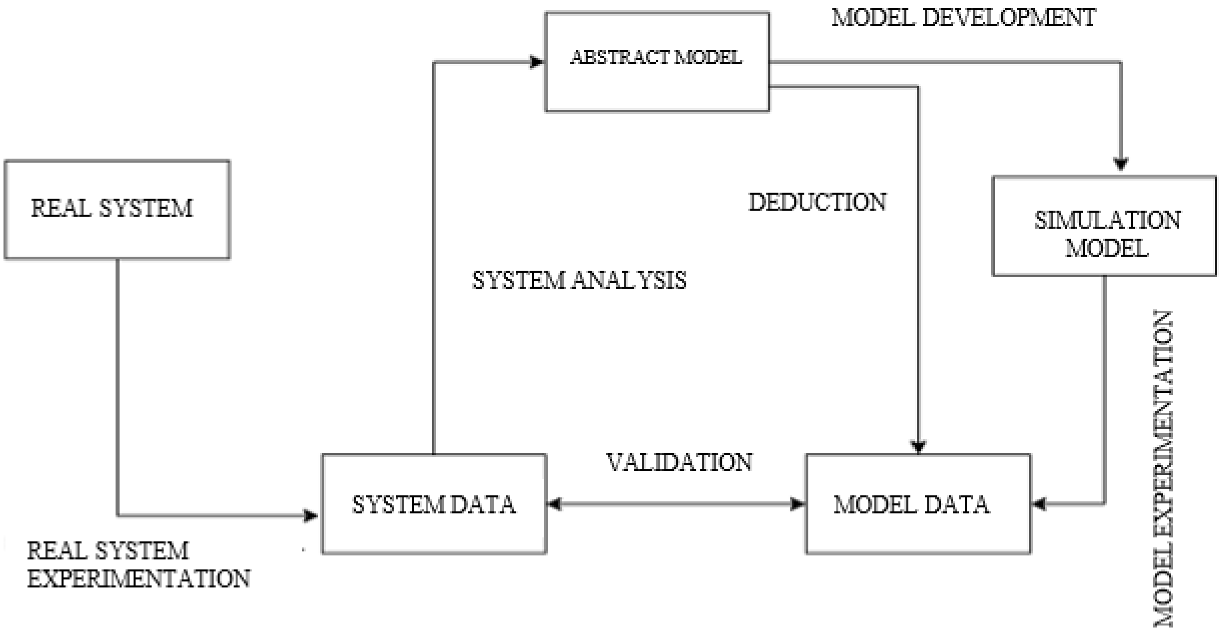

Figure 1: Simulation Model

3.2.1. Simulation Model

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

a. Variable definition, the main variables are identified, such as stocks (population, rice field area), flows (births, deaths, migration, rice field shrinkage, rice food production), and converters (population growth and population percentage).
b. Model structure construction, A visual model is designed using elements such as stocks, flows, converters, and connectors to represent the system.
c. Model validation, the model is tested using historical data to ensure compatibility between the simulation and the real system.
d. Scenario simulation, Simulation models are used to evaluate various policy scenarios that can affect the system, such as: Increasing Local Production, Optimizing Distribution, Adjusting Public Consumption, Land Use Change Control Policy, Climate Change Adaptation.
e. Analysis of results, the simulation results of the various policy scenarios are then visualized in the form of graphs and tables to facilitate interpretation. Graphs can show the dynamics of changes in key variables such as population growth, paddy field area, rice production, and shrinkage of paddy fields over time. Tables can present quantitative comparisons between scenarios, such as differences in rice production, land shrinkage rates, or environmental impacts (e.g. carbon emissions) under each scenario. This analysis assists stakeholders in making data-driven decisions to maintain food security and the sustainability of paddy fields.

3.2.2. Data Model

The data used in this simulation model includes data on Population Growth and the Area of Rice Fields that get the predicted results of Food Production needs (for example rice) generated through simulations using Stella or Ithink.

4. Results and Discussion

4.1. Black Box Diagram

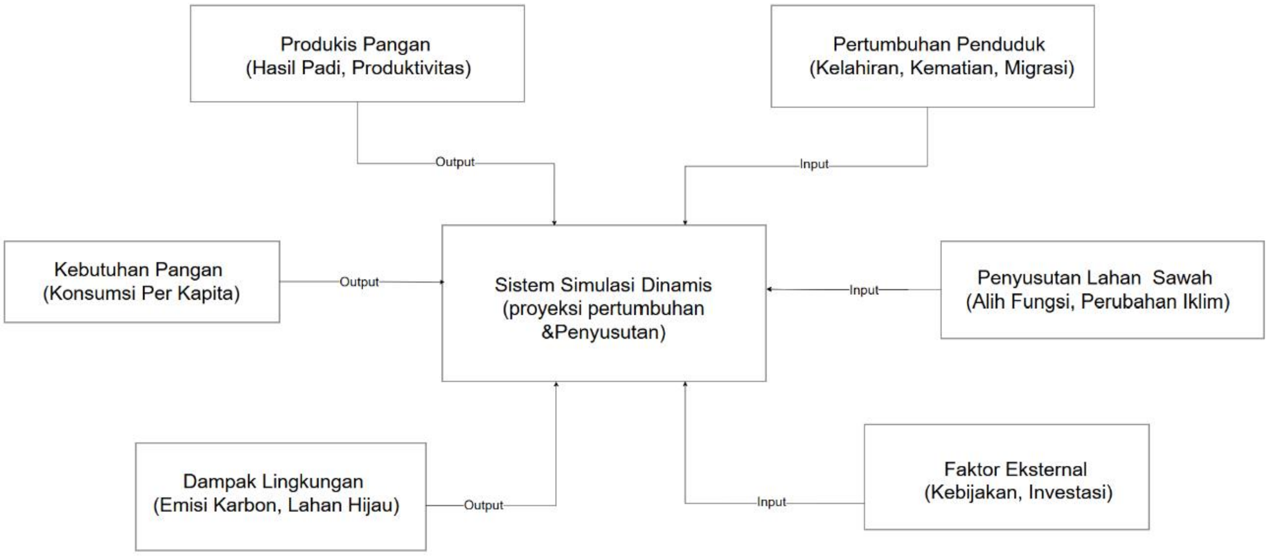

Figure 2: Black Box Diagram

This Black Box diagram depicts a dynamic simulation system used to project population growth and shrinkage of paddy fields, and their impact on food production and the environment. The system receives several main inputs, such as population growth (influenced by births, deaths, and migration, shrinkage of paddy fields (due to land conversion and climate change).

(due to land conversion and climate change). In addition, external factors such as government policies and investments also affect the system. The inputs are processed in a "black box" (dynamic simulation system) to produce outputs that include food production (in the form of rice yield and productivity), environmental impacts (such as carbon emissions and greenfield changes), as well as projections of population growth and paddy field shrinkage.

The output of this system provides an overview of how the interaction between population growth, shrinking paddy fields and external factors can affect food security and the environment. For example, an increase in population growth will increase food demand, which in turn can accelerate the shrinkage of paddy fields if not matched with appropriate policies. Environmental impacts such as carbon emissions and reduced green land are also important considerations in this system. By understanding these cause-and-effect relationships, dynamic simulation systems can be used to design sustainable policies to maintain a balance between population growth, food production and environmental sustainability.

4.2. Abstract Model

This abstract model describes the dynamic relationship between variables in the system, namely Population, Paddy Fields, Food Production. The model shows how these variables interact with each other in the long term. For example, an increase in population influenced by birth, death and migration rates will increase land shrinkage, while the shrinkage of paddy fields will reduce the area of paddy fields which will lead to a decrease in rice food production. The following is a picture of abstract modeling (CLD).

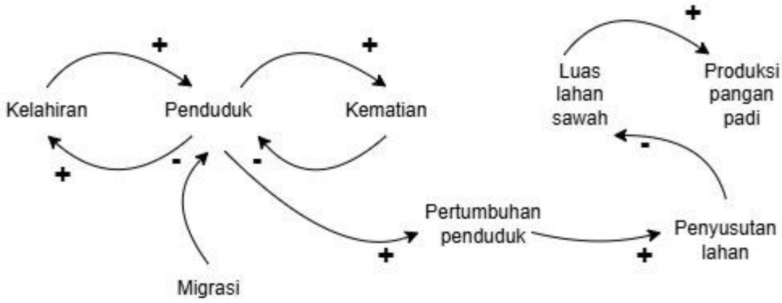

Figure 3 :. Casual Loop Diagram

4.3. Simulation Model

This simulation model was built using Stella or ithink software to model the relationship between elements in a dynamic system. Stock and Flow Diagrams are used to depict changes in system variables, such as population growth, shrinkage of paddy fields, and food production. The following is a picture of simulation modeling using stella or ithink.

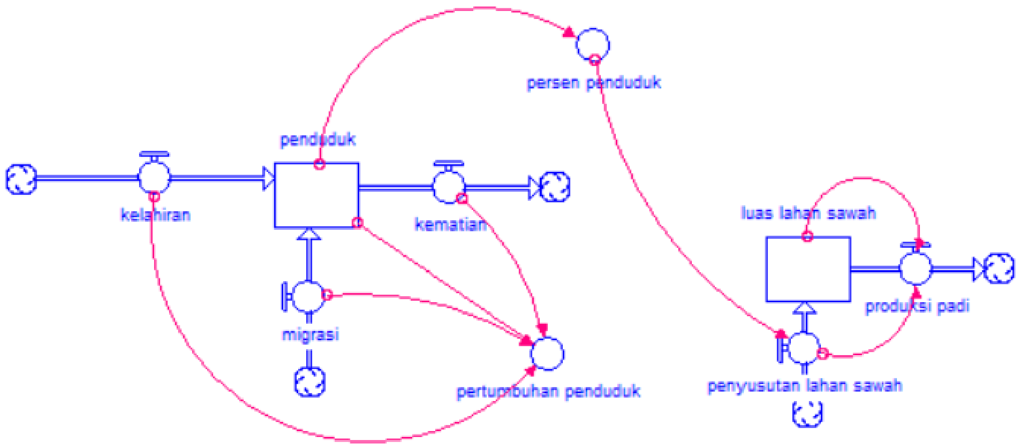

Figure 4: Stock and Flow Diagram

a. Stock

Population Accumulation of population in Sukabumi District. rice field area accumulation of hectares of available rice field area.

b. Flow

Births Inflows that increase the population of the district, deaths Outflows that decrease the population of the district. Migration: An inflow or outflow from the District's population stock caused by population movement.Shrinkage of Paddy Fields: An outflow that reduces the size of paddy fields caused by land conversion or other factors. Rice paddy food production: The flow of output from the system generated from the stock of paddy field area.

c. Auxiliary Variables

Population growth is the change in population due to births, deaths, and migration of population percentage: population proportion in the period 2018-2019.

The total population in Sukabumi district during the period 2015 to 2019 experienced a growth trend of 0.33%, indicating an increase in population. The condition of population growth in Sukabumi district is presented in Table 1.

Table 1: Population in Sukabumi District

Year	Population
2015	2,434,221
2016	2,444,616
2017	2,453,498
2018	2,460,693
2019	2,466,272

The amount of paddy fields in Sukabumi district during the period 2015 to 2019 experienced a shrinkage of paddy fields by 14.86%, the trend of paddy field area showed an increase and management. The condition of paddy fields in Sukabumi district is presented in Table 2.

Table 2: Number of Rice Fields in Sukabumi District

Year	Population
2015	66,692
2016	66,579
2017	66,516
2018	55,780
2019	56,783

The average number of births in Sukabumi district during the period 2015 to 2019 was 29.5%, the trend shows an improvement. The condition of births in Sukabumi district is presented in table 3.

Tabel 3: Number of births in Sukabumi Regency

Year	Births (Percent)
2015	30.72
2016	27.57
2017	32.29
2018	28.26
2019	28.97
Average	29.5

The total number of deaths in Sukabumi district during the period 2017 to 2019 was 2.04%. The mortality conditions for each household in Sukabumi district are presented in Table 4.

Table 4: Number of deaths per household in Sukabumi District

household	Number of Death
1 death	50,671
2 death	662
3 death	31
4+ death	0
Total	51,364

notes :

- There were 50,671 households in Sukabumi district that experienced 1 death of a family member.
- There are 662 households in Sukabumi district that experienced 2 deaths of family members.
- There are 31 households in Sukabumi district that experienced 3 deaths of family members.
- No households in Sukabumi district experienced 4 or more deaths of family members.

Total migration in Sukabumi district during the period 2017 to 2019 was -0.80%. A comparison of migration conditions in West Java and Sukabumi district is presented in Figure 5.

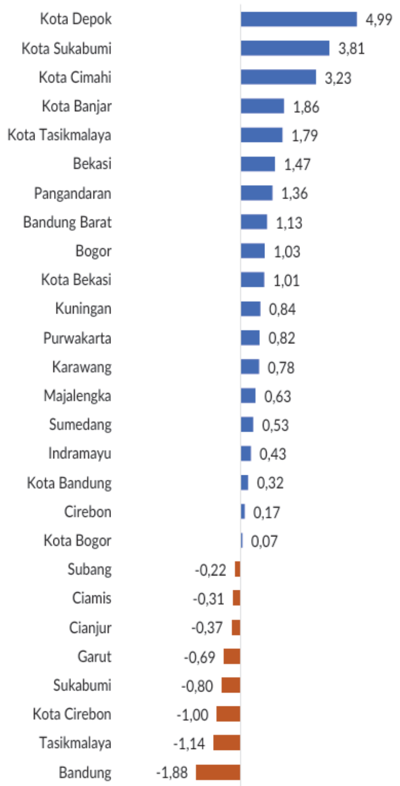

Figure 5: Comparison of net upward migration in West Java

The net migration figure of -0.80% indicates that Kabupaten Sukabumi experienced a decrease in population due to migration. This means that the number of people leaving Sukabumi District (out-migration) is greater than the number of people coming to Sukabumi District (in-migration).

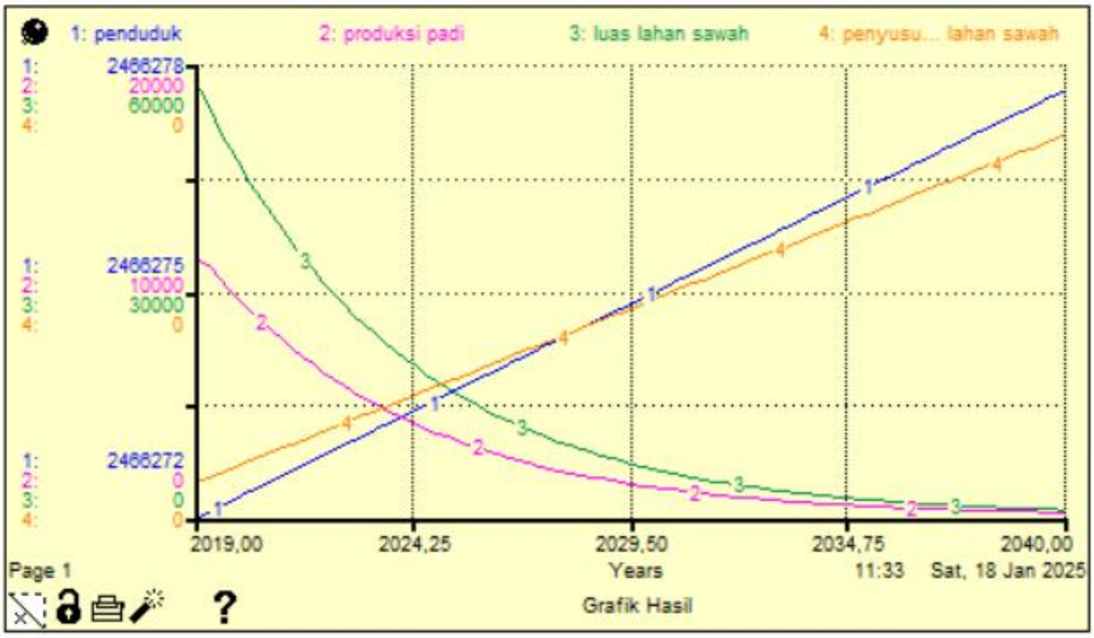

Figure 6: Graph of Simulation Results using Ithink or Stella

The simulation results of the dynamic system model shown in Figure 6 indicate that the population, shrinkage of paddy fields in Sukabumi district is expected to continue to grow with a relatively high growth rate until 2040. Meanwhile, rice production and the size of paddy fields will continue to decline at a relatively high rate until 2040.

5. Conclussion

Population growth in Sukabumi district has resulted in a demand for land, which has led to an increase in the shrinkage of paddy fields, resulting in a decline in food production. The projected population growth of Sukabumi District shows an increase of 0.33% per year, which can give an idea of the burden faced by the region in providing services and infrastructure for the growing population. The analysis shows a significant relationship between population growth and the shrinkage of paddy fields to meet food production needs. This indicates that population growth could be one of the causes of the shrinkage of paddy fields. The shrinkage of paddy fields can have serious impacts such as a decrease in food production, especially rice, which is the main commodity in Sukabumi District.

Based on the results of the dynamic system simulation design, it can be concluded that changes in the area of paddy fields in Sukabumi have a significant impact on food production. Projections show that without appropriate policy interventions, the shrinkage of paddy fields could lead to a decline in food production, potentially threatening regional food security.

The simulation illustrates various scenarios that can be applied to overcome this problem, including land use optimization, increasing agricultural productivity, and implementing policies that support the sustainability of paddy fields. By implementing the right strategies, the balance between population growth, land use change and food production needs can be maintained.

Therefore, concrete steps are needed from local governments, stakeholders and communities to maintain the sustainability of paddy fields and ensure sufficient food production to meet future needs.

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