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DEVELOPMENT OF CAUSAL LOOP DIAGRAM FOR UNDERSTANDING THE SUSTAINABILITY OF MALAYSIAN GLUTINOUS RICE: A SYSTEM DYNAMICS APPROACH

Muhammad Khairul Zharif Nor A'zam[1], Ahmad Afif Ahmarofi[2*]

[1] Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA (UiTM) Kedah Branch, 08400 Merbok, Malaysia.
Email: khairulzharif@uitm.edu.my
[2] Integrated Simulation and Visualisation (i-SiVi) Research Initiative Group, Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA (UiTM) Kedah Branch, 08400 Merbok, Malaysia.
Email: ahmadafif@uitm.edu.my
[*] Corresponding Author

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Abstract:

The cultivation of glutinous rice remains limited in Malaysia which occupies less than four percent of the total rice-growing area in the country. In this regard, this study examines the complex dynamics of the glutinous rice system in Malaysia using a causal loop diagram (CLD) to understand the interactions between various factors like productivity, land use, population growth, and food security. To fulfill that, a CLD based on the system dynamics (SD) approach is developed to highlight the reinforcing and balancing loops that drive and constrain the system. In the developed CLD, the causal relationships are established by connecting the identified cause-and-effect variables. Subsequently, the causal signs are determined based on a positive (+) or a negative (–) sign to each relationship between variables. As a result, balancing loops illustrate that an increase in research and development (R&D), training, and government subsidies can enhance rice production, thereby improving food security and income levels. However, these benefits are tempered by a reinforcing loop that reflects the system's limitations, which eventually curb sustainability glutinous rice production, particularly caused by the increasing Malaysian population. Furthermore, higher productivity and food security must be managed carefully to avoid over-exploitation of resources. The insights from this model are critical for policymakers to ensure the long-term sustainability of the glutinous rice sector while meeting the growing demand.

Keywords:

Causal Loop Diagram, Food Security, Glutinous Rice, Sustainability, System Dynamics

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Introduction

Glutinous rice, a staple food for millions across Asia, holds particular significance in Southeast and East Asia, where it is predominantly cultivated. Known for its low amylose content, this variety of rice becomes slightly sticky when cooked, making it a favored ingredient in various regional dishes (Asada, 2020; Setyawati et al., 2016). Its popularity spans countries like Malaysia, China, and Vietnam, with Malaysia experiencing a notable increase in demand. Between 2010 and 2018, the average annual growth rate for glutinous rice demand in Malaysia was recorded at 0.49 percent (Abubakar et al., 2018).

Malaysia's role in the global market for glutinous rice is interesting. In terms of exports, Malaysia ranked 26th, contributing around 0.26 percent of the global share, while in imports, it ranked 4th, accounting for approximately 5.84 percent. In 2023, Malaysia exported 123.03 million kilograms of glutinous rice, reflecting a 9.02 percent increase from the previous year. However, the country imported a staggering 1.40 billion kilograms, marking a 15.68 percent rise compared to the previous year (Tridge.com, 2024). Hence, this data highlights a significant gap between local production and demand, with imports steadily increasing to meet the shortfall.

Moreover, glutinous rice cultivation in Malaysia is concentrated in areas such as Baruh Gong Tebu in Hulu Besut, Terengganu, Kampung Padang Siding in Perlis, Tanjung Piandang in Perak, and Langkawi Island in Kedah. Despite its importance, limited cultivation is a key factor contributing to the inability to meet domestic demand solely through local production (Abd Rani et al., 2022; Bernas, 2023). Furthermore, despite various studies on this topic previously, there remains a lack of holistic analysis that integrates critical factors such as population growth, food security, land availability, land degradation, and government subsidies into a clear understanding of Malaysia's glutinous rice production (Dorairaj & Govender, 2023; Rahim et al., 2017; H. Rahim et al., 2023).

Even though the cultural and culinary of glutinous rice in Malaysia are vital, its cultivation faces significant challenges. These include unsustainable land-use practices (Dorairaj & Govender, 2023), labor shortages (Abdullah, 2023; Adnan et al., 2018), limited resources (Abdullah, 2023; Sheikhy Narany et al., 2017), and high production costs (Dorairaj & Govender, 2023; Rehan et al., 2020). Addressing these issues through focused research and strategic interventions is crucial for ensuring the sustainability of glutinous rice production in Malaysia.

In these regards, this research aims to propose a causal loop diagram (CLD) based on the system dynamics (SD) simulation approach to understand the factors affecting the sustainability of the Malaysian glutinous rice industry. To fulfill that, key factors related to Malaysian glutinous rice are correlated to provide a holistic view of the industry. The following section discusses further the glutinous rice industry in Malaysia and the concepts of CLD. Subsequently, the methodology implemented in this study, which is CLD, is explained in more depth to achieve the objective of the research. Then, the results of the study are discussed in the next section. Finally, this study summarizes the conclusions from the results of this study.

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Literature Review

Malaysia's cultivation of glutinous rice dates back centuries, with its production deeply rooted in specific regions where traditional farming methods are blended with modern agricultural practices (Wardani et al., 2023). This blend of techniques reflects the cultural significance of glutinous rice in Malaysia, where it is more than just a crop as it is a vital part of the nation's culinary heritage and cultural traditions.

Glutinous rice is the cornerstone of various traditional Malaysian dishes, including ketupat and lemang, both of which are integral to festive celebrations like the Eid Festival (Ismail et al., 2021). These dishes hold a special place in the hearts of Malaysians, symbolizing togetherness and cultural identity.

However, despite its cultural and culinary importance, glutinous rice production in Malaysia is facing several challenges. These issues include the limited cultivation areas, fluctuating market demands, and the impact of modern agricultural changes, which threaten the sustainability and continued prominence of glutinous rice in Malaysia's agriculture landscape.

Since the 1990s, rice consumption in Malaysia has been on a steady rise, driven largely by population growth (Fauzi & Abu Bakar, 2022). From 2010 to 2018, the demand for glutinous rice grew at an average annual rate of 0.49 percent, reflecting a shift in dietary habits among Malaysians alongside the growing population. According to the Department of Statistics of Malaysia, the population grew from 32.4 million in 2020 to 32.7 million in 2022, with an annual growth rate of 0.2 percent (Department of Statistics, 2023). This population increase has exacerbated the imbalance between supply and demand, with local production unable to meet the rising demand. As a result in 2018, nearly 4 percent of glutinous rice, or approximately 57,600 tons, was imported. By 2023, this figure had surged to nearly 1.40 billion kilograms, with the majority of imports coming from major producers like Thailand and Vietnam (Ariff & Serin, 2018; Tridge.com, 2024).

The shortfall in local production has also led to a rise in rice smuggling, particularly from neighboring countries. Several cases of smuggling have been reported, including incidents where RM 182,000 worth of Thai glutinous rice was seized at locations such as Langkawi Islands and the North Expressway near Bukit Kayu Hitam. In total, almost 50,000 kilograms of smuggled Thai glutinous rice were confiscated by the Malaysian Border Security Agency (Aksem) and the Malaysian Maritime Enforcement Agency (MMEA) (Shazwani, 2017). This illegal trade persists, with operations like the Special Integrated Task Force on White Rice Operations Enforcement (OP BPT) launched on October 2023 to address the smuggling of subsidized imported white Rice (BPI) into neighboring countries (Bernama, 2023).

Glutinous rice holds a distinctive place in Malaysian culture and cuisine. Understanding its cultivation practices and the challenges faced by producers is essential for developing strategies that promote sustainable cultivation and consumption for the growing Malaysian population. The Malaysian government has implemented various strategies to boost domestic rice production, reduce reliance on imports, and combat smuggling activities. These measures include providing training for farmers, investing in research and development, and offering subsidies for rice cultivation (Baharudin & Waked, 2021; Firdaus & Rahmat, 2023). Additionally, former Prime Minister Tun Dr. Mahathir Mohamad announced a significant

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glutinous rice cultivation mega project in Langkawi Island. This initiative aims to transform the island into a major producer of glutinous rice in the Southeast Asia region (Seng, 2019).

Despite government interventions such as subsidy schemes and cultivation projects, several significant endogenous factors continue to challenge the productivity of glutinous rice crops in Malaysia. Key issues include labor shortages (Adnan et al., 2018; Hashim et al., 2024), limited natural resources (Hashim et al., 2024; Sheikhy Narany et al., 2017), and the high costs associated with production (Doraaj & Govender, 2023; Rehan et al., 2020). Additionally, the reliance on commercial fertilizer (Anisuzzaman et al., 2021; Dorairaj & Govender, 2023) further exacerbates these challenges. These factors collectively pose a serious threat to the future of glutinous rice production and the broader goal of ensuring food security in the country.

It is found that various studies have been conducted on this topic previously as presented in Table 1 as follows.

Table 1: Past Studies Regarding the Implementation of System Dynamics in Rice Production

Title	Author	Year	Methods	Key Findings	Future Work
Simulation of System Dynamics for improving the quality of paddy production in supporting food security	M. R. Aprillya, Erma Suryani	2023	System Dynamics (SD) simulation	Identified key variables that impact rice production, such as irrigation and seed quality, to enhance food security	Further analysis of post-harvest management practices and climate impact on rice productivity
Simulation of China's potential rice yields by coupling land system	Manchun Li, Cong Du, Penghui Jiang, Wenbo Luan, Dengshuai Chen	2023	Grey Prediction Model-Future Land Use Simulation (GM-FLUS) integrating land system evolution with climate data	Simulated potential increases in rice yields under specific climate scenarios over the next 40 years	Expansion of the model to include more variables affecting yield predictions
System dynamics model to support rice production	Erma Suryani, Rully Agus Hendrawan,	2021	System Dynamics modeling, simulation, policy scenario evaluation	Showed how policies like land intensification and redistribution improve rice availability for food security	Future optimization of policy scenarios incorporating climate change variables

However, there remains a lack of holistic analysis that integrates critical factors. In this regard, System Dynamics (SD), a simulation modeling method can represent complex systems holistically by analyzing the interrelationship between various causes and effects (Mansur et al., 2023). This approach emphasizes the interaction between variables and feedback loops that drive real-world phenomena (Ahmarofi et al., 2022). The origins of SD can be traced back to Jay W. Forrester, who pioneered the concept of feedback loops and introduced the first SD model at MIT in the 1950s (Sapiri et al., 2017). An SD simulation model is a powerful tool for

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representing real-world complex systems. It does this by using a causal loop diagram (CLD) and stock and flow diagram (SFD) to provide a holistic view of the system (Ahmarofi et al., 2022). These graphical representations effectively capture the feedback loops and dynamic relationships within the system by correlating various endogenous factors, or variables (Duggan, 2016). Through this approach, CLD allows for a deeper understanding of how different elements within a system interact and influence each other over time.

CLD is a valuable tool for examining the cause-and-effect relationships among variables within a system (Sapiri, H., et al., 2017). It provides a graphical representation of the dynamic interactions and feedback loops that occur in complex systems. By illustrating these relationships, a CLD helps to visualize how variables are interconnected and how changes in one part of the system can influence others. This diagram is essential for capturing the interdependencies and feedback loops that are fundamental to understanding and analyzing dynamic systems (Forrester, 1961).

Methodology

This section highlights the methodology used to develop the CLD for the Malaysian glutinous rice system in a holistic view. A research methodology based on the SD is presented as follows.

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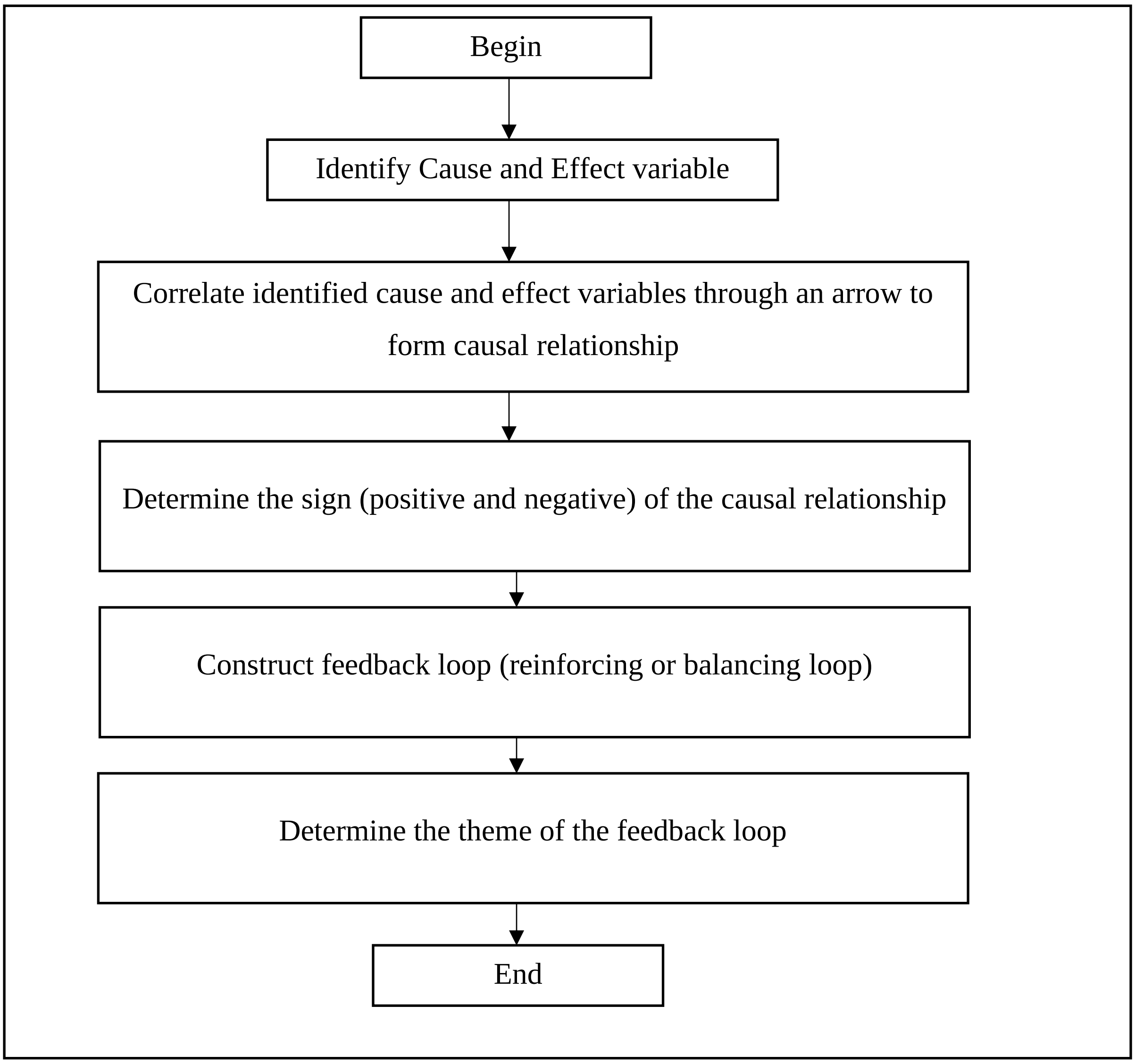

Figure 1: Research Methodology for the sustainability of Malaysian Glutinous Rice

Figure 1 illustrates the process for developing the proposed CLD as a qualitative approach. The development process involves the following steps. The first step comprises identifying and reviewing existing literature on SD related to glutinous rice systems. This review includes examining key concepts, theories, and methodologies used in past research to determine cause and effect variables. After that, the correlation of the identified variables is constructed. The causal relationships are established by connecting the identified cause-and-effect variables.

Subsequently, the causal signs are determined based on a positive (+) or a negative (–) sign to each relationship between variables. A positive causal link, denoted by a "+" sign, signifies that two variables move in the same direction. When one variable increases, the other variable also increases, and when one decreases, the other decreases as well. This type of relationship often results in reinforcing loops, which can lead to exponential growth or decline within the system. In a reinforcing loop, the effects of the variables amplify each other, creating a cycle of continuous growth or decline. For example, an increase in the size of the area planted might increase the farmers' revenue, which in turn further boosts the farmers' gross income.

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In contrast, a negative causal link is represented by a "-" sign, indicating that the two variables change in opposite directions. When one variable increases, the other decreases, and vice versa. This type of relationship typically forms balancing loops, which work to stabilize the system by counteracting deviations. For example, if the average human lifetime were to decrease, then the death rate would increase, leading to a decrease in the number of populations. Balancing loops are crucial for maintaining equilibrium within the system.

In the fourth step, the signs are analyzed to classify the relationships as either reinforcing or balancing loops. The reinforcing loop (R) indicates the relationship to a cycle of growth or decline while the balancing loop (B) works to stabilize the system. Finally, in the fifth step, the overall theme of the feedback loops is determined to summarize the dynamic interactions and their implications within the system. The next section discusses further the results based on the development of CLD.

Results
The findings from the development of the proposed CLD for the glutinous rice system are highlighted. The results are derived from a systematic review of existing literature and the subsequent correlation of key cause-and-effect variables. The process involved identifying causal relationships, assigning signs to these relationships, and classifying the feedback mechanisms within the glutinous rice system, offering insight into the factors influencing production, demand, and overall system behavior.

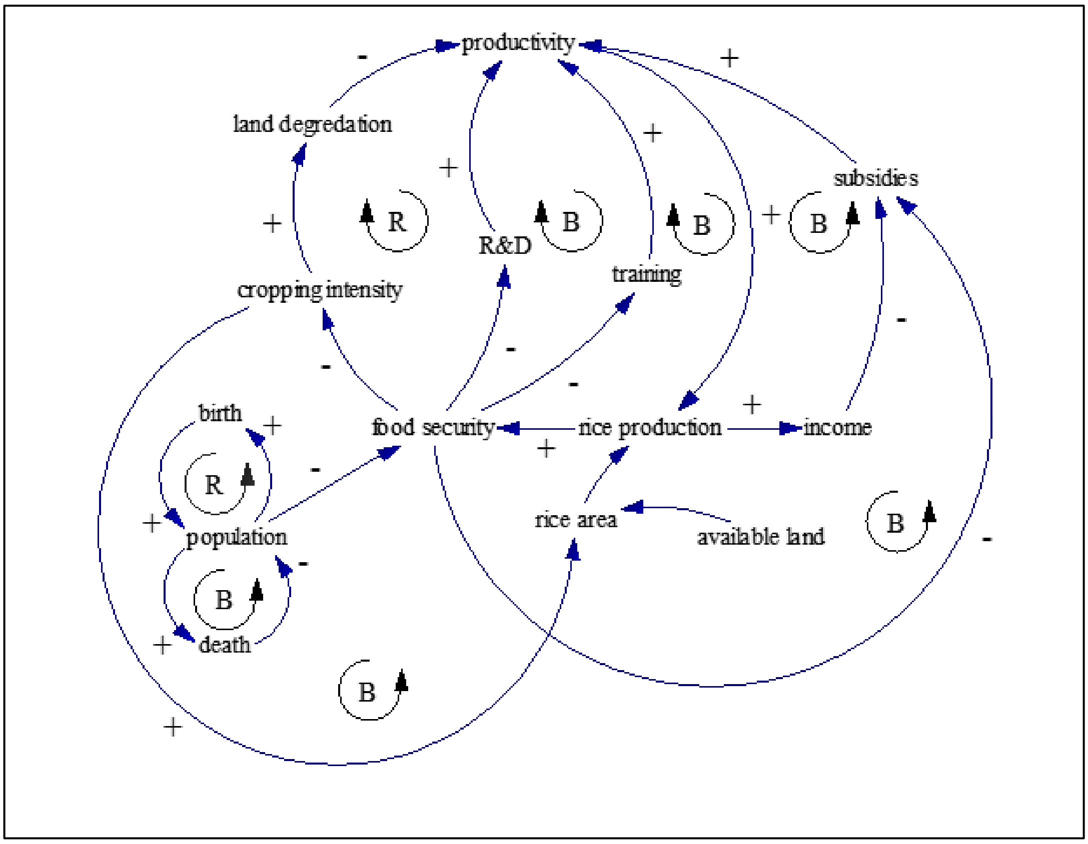

Figure 2: Causal Loop Diagram of System Dynamics Model for Malaysian Glutinous Rice

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Figure 2 illustrates the proposed CLD for the Malaysian glutinous rice industry. It depicts the dynamics of a glutinous rice production system, focusing on how various factors interact to influence productivity, food security, and overall system stability.

It is found that the correlation between productivity and investment in research and development (R&D) leads to higher productivity (+), which in turn improves food security by increasing rice production (+). However, increased productivity may also lead to land degradation (-) which negatively affects long-term productivity.

Moreover, training farmers improves their skills and practices, leading to enhanced productivity (+). Besides, the total area for rice cultivation directly increases the overall rice production (+). However, the availability of land is finite and can decrease in several years (-). If the related ministry provides subsidies to the farmers, it can increase farmer's income (+), enabling them to invest more in inputs like fertilizers and better seeds, thereby increasing rice production (+).

Furthermore, as food security improves, there is a potential to reduce cropping intensity. In contrast, if cropping intensity increases per year on the same land (+), it can lead to land degradation (-), which would eventually reduce productivity. For the land degradation variable, implementing high cropping intensity can be beneficial in the short term, but it can cause land degradation (-), which eventually reduces the land's future productivity. This happens because when crop intensity is high, it is only beneficial in the short term, but in the long term, it can cause land degradation (-), which ultimately reduces the future productivity of the soil.

In terms of income to the farmers, the higher rice production increases farmers' income (+), which could further improve their ability to invest in better practices for the continuous improvement of their farming. As income increases, more land may be used for rice cultivation, but the availability of the land is a limiting factor (-).

Besides, it is found that population growth increases food demand, which pressures the system to produce more food. Even though the increase in food security contributes to higher rice production and consequently supports population growth (+), this leads to more demand on the food system. Consequently, this causal relationship creates a reinforcing loop (R). It indicates that by having more population, the demand for food needs critically higher productivity and production.

However, the balancing loops (B) from the research and development (R&D), training, and government subsidies on rice productivity counter back the reinforcing loop created by the population loop. The investments enable farmers to adopt better practices and technologies, leading to higher yields and, consequently, improved food security and income levels. This loop illustrates a virtuous cycle where an increase in productivity fuels further investments in the sector, driving continuous improvements and ensuring that the growing population's food needs are met.

Moreover, the analysis also recognizes the presence of certain balancing loops that impose natural limits on the system's growth. Land degradation emerges as a factor that counteracts the benefits of increased productivity. As productivity and cropping intensify, the risk of soil depletion and environmental degradation increases, ultimately reducing the land's long-term fertility and productivity. These balancing loops serve as a warning against over-exploitation of agricultural land, highlighting the need for sustainable farming practices that preserve the soil's health for future generations.

Another crucial balancing loop is related to the availability of land for glutinous rice cultivation. As the population grows and the demand for food increases, more land is needed for glutinous rice production. However, the finite nature of available land means that there is a limit to how much the area under cultivation can be expanded. This limitation forces a trade-off between expanding glutinous rice production and preserving other land uses, such as natural limits on land and productivity, which prevent indefinite growth. This dynamic illustrates the challenges of meeting the food needs of a growing population while ensuring that the agricultural system remains sustainable in the long term.

Conclusion

The development of CLD for the Malaysian glutinous rice system highlights the complex interactions between productivity, land use, population dynamics, and food security. The system is characterized by balancing loops (B) that drive growth and ensure the sustainability of the Malaysian glutinous rice industry while reinforcing loops (R) impose natural limits on the industry. Moreover, the study reveals that while Malaysia has made significant strides in enhancing productivity and meeting the growing domestic demand for glutinous rice, the system's sustainability is highly contingent upon managing the delicate balance between reinforcing and balancing feedback loops. To ensure the long-term sustainability of the glutinous rice sector, policymakers must carefully manage these dynamics by promoting sustainable farming practices, investing in R&D and training, and optimizing land use. By doing so, Malaysia can continue to meet the growing demand for glutinous rice while preserving the health of its agricultural system and environment. This insight from this analysis is crucial for guiding policy decisions that will shape the future of Malaysia's glutinous rice industry and its contribution to national food security.

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