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Application of System Dynamics Modelling to Forecast Sustainability of The Coconut Industry in Malaysia

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ABSTRACT

Malaysia ranks as the world's 10th largest coconut producer, with the crop being its fourth most important industrial agricultural commodity. Revitalizing the industry is essential for sustaining production growth and supporting livelihoods, especially for farmers and rural communities. Historical data indicates growth in coconut production until 2013, a decline from 2014 to 2017, and an upward trend resuming by 2021. This study employs system dynamics modelling to forecast the future sustainability of Malaysia's coconut industry by simulating trends in production, imports, and exports, considering their dynamic interrelationships. The model forecasts increasing coconut production and demand, driven by population growth, while identifying fluctuations influenced by import competition, shifting industrial demand, and variable production costs. These trends point to the need for improved inventory management, predictive planning, and policy measures, such as subsidies or price stabilization, to ensure market stability. The validated model effectively replicates the complex behaviour of the industry, providing reliable forecasts to aid in strategic decision-making. This study supports Sustainable Development Goal 12 by promoting sustainable production practices and inclusive economic growth. It also establishes a foundation for intervention analysis to develop optimal strategies for enhancing the sustainability of Malaysia's coconut production in the long term.

Keywords: Coconut Industry, Malaysia, Production Trends, Sustainability Forecasting, System Dynamics

1 INTRODUCTION

The cultivation of coconuts in Malaysia traces back to the pre-independence era. During the early 19th century, coconuts served as a primary commodity, utilized as raw material to produce fats and vegetable oils. The escalating demand for these products globally propelled the growth of the coconut trade. In that era, coconuts stood as the sole fundamental ingredient for fat and oil production. However, according to Mohd Hafizudin and Tapsir [1], the land area dedicated to coconut plantations dwindled significantly to less than one-third of its original expanse, owing to competition from alternative commodities such as corn, soybeans, and palm oil. Moreover, the number of coconut growers also plummeted by half from the initial count of 102,000 growers.

Recent perspectives on this industry have undergone a transformation, portraying it as a lucrative venture for entrepreneurs. In the early 1980s, coconut plantation prices barely reached RM0.10 per nut, but by 2021, prices surged to as high as RM1.25 per nut [2]. Some palm oil companies have also begun intensive coconut cultivation, indicating a promising outlook for the industry ahead [3]. In Malaysia, coconut ranks as the fourth largest industrial crop after palm oil, rubber, and rice, with most farms situated in Sabah and Sarawak. Despite a decline in coconut production between 2014 and 2016, Malaysia remains among the top 10 coconut producers globally [4]. The array of coconut-based products currently making successful inroads into the global market has the potential to bolster growth in the downstream coconut industry. Malaysia faces a trade deficit of nearly RM60 billion in food and agriculture products, yet the global development of the downstream coconut industry is advancing rapidly, contributing to products that bolster the national economy [3]. Presently, Malaysia grapples with a shortage of coconut supply, necessitating the importation of mature coconuts from Indonesia to fulfill downstream demand.

Most coconut farmers in Malaysia are smallholders cultivating less than four hectares in rural areas. This scenario presents several challenges, including limited economies of scale, insufficient funding or training, and fragmented supply chains often reliant on intermediaries. Given Malaysia's favorable conditions for coconut cultivation, the nation should seize the opportunity to further boost coconut and coconut product production in response to both local and global market demands. This initiative would indirectly assist small-scale farmers in enhancing their standard of living through the promotion of sustainable coconut production practices.

2 BACKGROUND OF THE COCONUT INDUSTRY

Currently, Malaysia ranks as the 10th largest global coconut producer in 2020. Malaysia's coconut production productivity stands at 6.98 mt/ha, surpassing Indonesia's 6.12 mt/ha, the leading producer worldwide [4]. Despite the slight increase in productivity, the coconut cultivation area in Malaysia is dwindling [5]. Nevertheless, there is a noticeable upward trend in coconut consumption and self-sufficiency levels in Malaysia (SUA DOSM, 2005-2020). Consequently, proactive measures are necessary from various stakeholders including farmers, traders, processors, researchers, policymakers, and extension agents to foster the growth of the coconut industry and cater to the escalating domestic and global demands.

The coconut industry's challenges and complexities attract attention across various research disciplines, encompassing social, economic, and quantitative modeling. In terms of quantitative modeling, numerous forecasting models have been developed to predict future trends in the coconut industry [6]–[8]. Although extensive research has been conducted on predictive modeling, dynamic modeling of the coconut industry, particularly in Malaysia, is still limited. Hence, this study aims to explore the dynamic behavior of key variables affecting measured outputs such as local and international coconut supply, coconut production, and productivity. Subsequently, various interventions will be tested to ensure the sustainability of Malaysia's downstream coconut sector based on observed output behaviors. This research is crucial as its findings will contribute to: (1) understanding the current coconut industry scenario and forecasting future trends, and (2) formulating effective strategies to promote the sustainability of Malaysia's coconut industry for socioeconomic development. Thus, the objectives of this research are to identify the primary factors determining the sustainability of coconut production in Malaysia, analyze the relationships and interdependencies among these factors, and recommend effective strategic policies to ensure the industry's sustainability and socioeconomic growth in Malaysia based on the conducted analysis.

3 METHODOLOGY

The research process consists of five phases. This research employs system dynamics modeling as its methodology. Within the research design phase, activities encompass data gathering and constructing a system dynamics model. For the creation of a system dynamics model concerning coconut sustainability, the initial step involves determining the problem. Subsequently, dynamic hypotheses are crafted to encapsulate the mental framework of system functioning, followed by identifying and simulating the primary issue to analyze system behavior and potential enhancements.

3.1 System Dynamics Modelling Process

This research has been analyzed using the System Dynamics (SD) approach. In practice, SD has five iterative stages that need to be completed for the modeling process (Figure 1). It starts with the articulation of the problem, where the problem is clearly identified through several modeling activities such as defining the purpose of the model, identifying key variables, developing reference modes, and setting the time horizon [9].

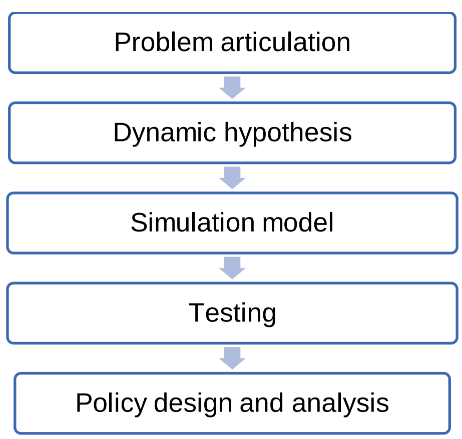

Figure 1 : System dynamics modelling process

The subsequent step involves crafting dynamic hypotheses. During this phase, a functional theory is devised to elucidate the origins of the problem by illustrating the interconnections among key variables. This entails developing a conceptual model termed the subsector diagram of the coconut production system, delineating the principal variables influencing coconut production and their interrelations. Following the conclusion of this phase, the modeling process advances to formal SD model formulation. Model formulation denotes the creation of the model structure. At this juncture, the earlier conceptual model is translated into a stock and flow diagram (SFD) utilizing SD software, integrating model equations to assess model performance.

Upon successful completion of model development, testing ensues to verify the model's fidelity in replicating the actual structure and dynamics of the coconut production system, the focal point of this investigation. Subsequently, the validated model will be deployed for intervention purposes. However, this paper solely concentrates on stages 1 (problem articulation) through 4 (model testing) as the development of forecasting trends necessitates only the resolution of these four stages.

3.2 Data Sources and Collection

The types of data used to analyze the variables involved are primary and secondary. Source of primary data included interviews with coconut industry stakeholders to gain a better picture and understanding of the current issues in the coconut industry in Malaysia. Meanwhile, secondary data was obtained from local and international statistical databases such as The United Nations Commodity Trade Statistics Database (COMTRADE), Food and Agriculture Organization Statistics (FAOSTAT), Federal Agricultural Marketing Authority (FAMA) and Department of Statistics Malaysia (DOSM). The secondary data is mostly used to collect information about the production and productivity of coconut products. The time series data used in this study covers from 2005 to 2020. This information will be used to measure the status and potential of local and global coconuts in terms of production and trade.

3.3 The Input-Outputs of SD Coconut Production Model

Table 1 and Figure 2 show the inputs and outputs for the SD coconut production model. The variables are categorized into endogenous, exogenous, and excluded factors as stated in Table 1. Endogenous variables are the variables within a dynamic system that are influenced and determined by the system itself. These variables are the internal state variables or components of the system that evolve over time based on the system's own dynamics and interactions. In other words, endogenous variables are the outcomes or results of the system's internal processes. They are often described by differential equations or recursive relationships. Changes in endogenous variables are dependent on the current values of other endogenous variables in the system. Exogenous variables, on the other hand, are external to the system and are not influenced by the system itself. These variables are typically considered as inputs or driving forces that affect the system from the outside. Unlike endogenous variables, exogenous variables are not determined within the system, and their values are often given or assumed to be constant over time. For example, price is exogenous because manipulating the price will affect many other external factors that are not included in the boundaries of the model such as pollution and economic effects. Just like climate and irrigation have many other dependencies, which are not the focus of the model.

In summary, endogenous variables are the internal state variables determined within the dynamic system, while exogenous variables are external factors that influence the system but are not directly influenced by the system itself. The variables identified in Table 1 were organized into inputs and outputs for the SD model as shown in Figure 2.

Table 1 : Variables of the coconut production system

Endogenous variables	Exogenous variables	Excluded Variables
Stock Demand Supply Production SSL	Import Export Price Population Plantation area Cost Seeds Government incentives	Climate change Irrigation Soil type Technology Economic impact Environment Pollution

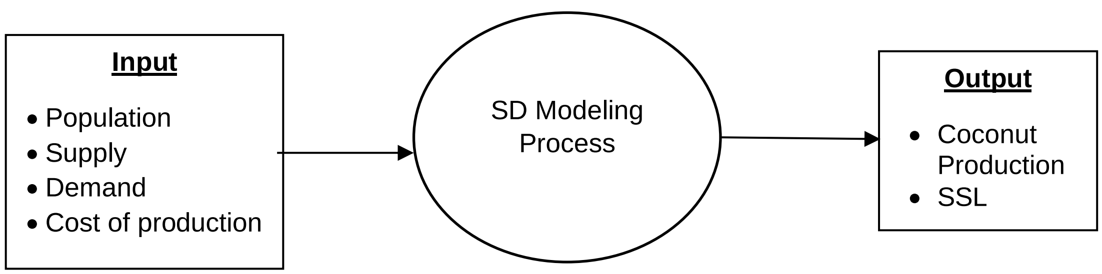

Figure 2: Input-output of SD coconut production model

3.4 SD Coconut Production Model Framework

Figure 3 displays the structure of the coconut production model, comprising four primary interconnected sectors: population, coconut production, self-sufficiency level (SSL), and cost. These sectors are then elaborated into a causal loop diagram (CLD), depicted in Figure 4, to elucidate the dynamic relationships among the interconnected variables within the coconut production system. This CLD illustrates how variables within coconut production influence each other. A positive sign (+ve) denotes that the variables change in the same direction, whereas a negative sign (-ve) indicates a change in the opposite direction [9]. For instance, the positive sign relationship between population and demand implies that as the population increases, so does the demand. Conversely, the negative sign relationship between coconut production and imports signifies that as coconut production rises, imports decrease.

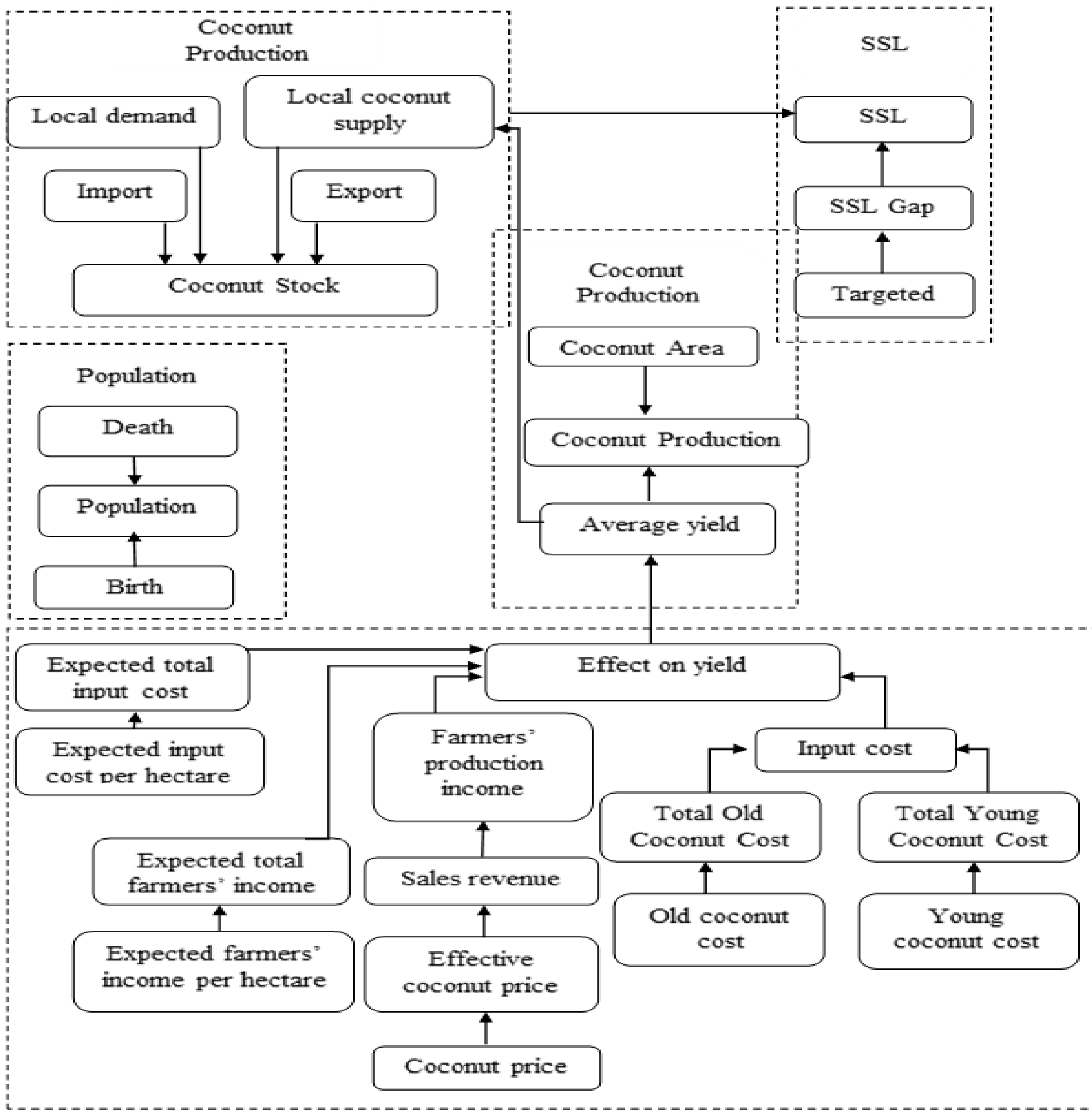

Figure 3: Coconut production model framework

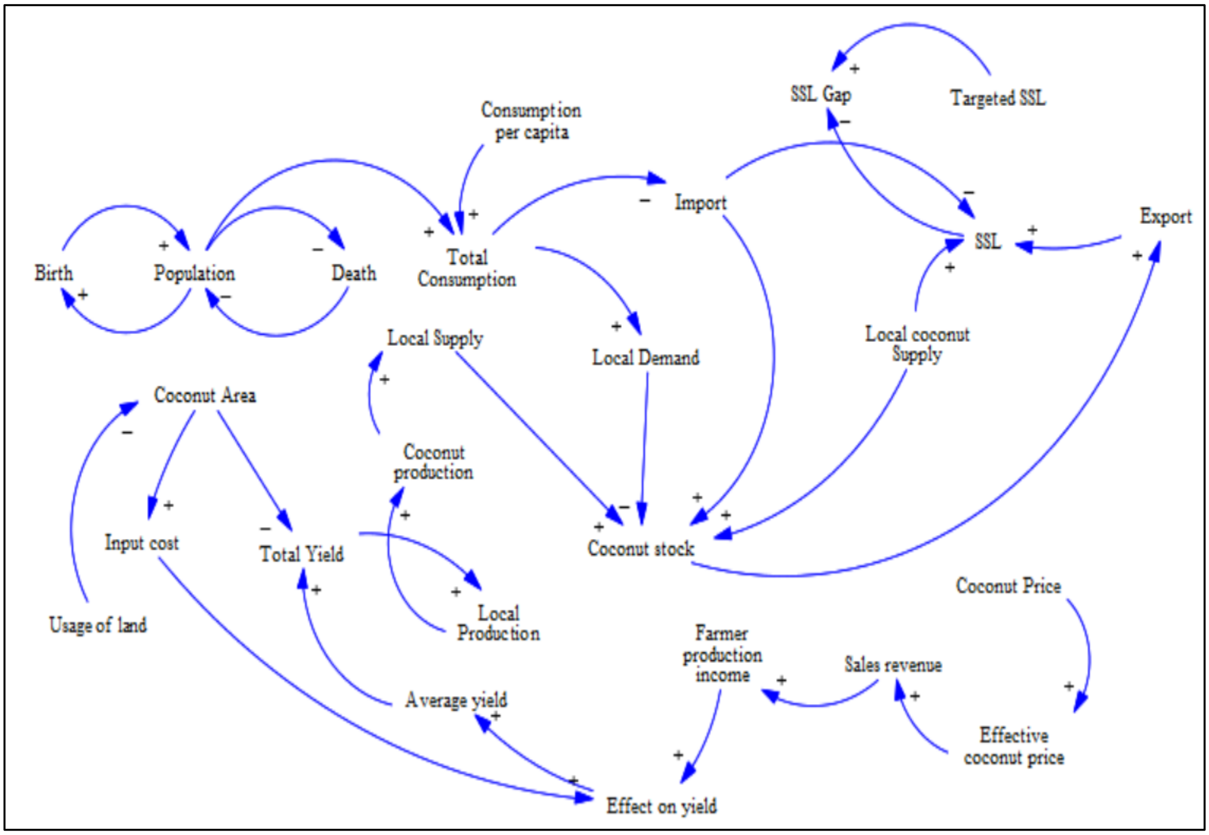

Figure 4: Dynamic hypothesis of coconut production model

3.4.1 Population

Figure 5 illustrates the relationship among variables influencing Malaysia's population. A rise in birth rates corresponds to an increase in the projected population, while an escalation in death rates leads to population decline. This figure depicts the balancing loop between population and death, alongside the reinforcing loop between birth and population. Furthermore, the population size dictates the level of coconut consumption, as elaborated in the subsequent section.

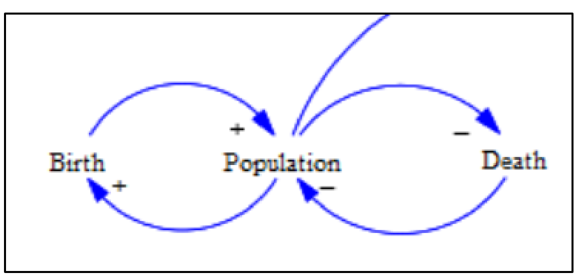

Figure 5: Dynamic hypothesis of the population

3.4.2 Coconut Production

The rising population in Malaysia correlates with an escalating demand for coconuts, consequently driving up coconut production. Figure 6 illustrates the interconnectedness among variables within the subsectors of coconut production. Total consumption is determined by population size and per capita consumption rates. As overall consumption increases, so does the local demand for coconuts. The interplay between production and consumption constitutes a foundational element of any economic system, representing the intricate relationship between coconut production and household or consumer consumption.

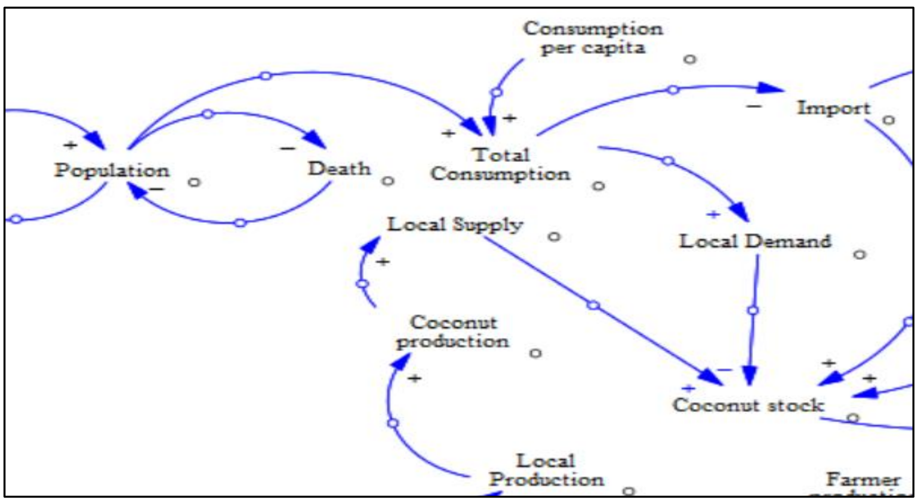

Figure 6: Dynamic hypothesis of coconut production

3.4.3 Self-Sufficiency Level (SSL)

Ultimately, the self-sufficiency level (SSL) of coconut relies on local coconut supply, imports, and exports. Figure 7 elucidates the correlation among these variables to ascertain SSL in coconut. An uptick in local coconut supply corresponds to an increase in SSL. Similarly, heightened exports lead to an increase in SSL. Conversely, an escalation in imports results in a decrease in SSL. The targeted SSL stands at 100% by 2024. To gauge the remaining distance to this target, the SSL gap is calculated by the variance between the SSL target and the current SSL. Consequently, augmenting SSL will narrow the SSL gap by attaining the SSL target.

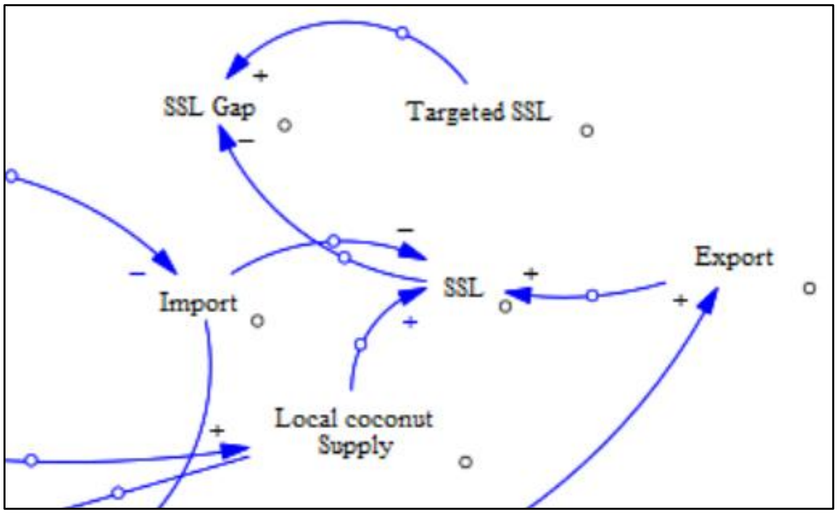

Figure 7: Dynamic hypothesis of SSL

4 COCONUT PRODUCTION MODEL ANALYSIS

Once the dynamic hypothesis of coconut production system is formalized to a simulation model, the model will go through the process of model testing for validation. In SD, verification refers to replication of the actual structure of the problem while validation is to imitate the actual behavior pattern of the coconut production system [10]. For structural verification tests, dimensional unit consistency tests are used to validate the model. Figure 8 below shows that the model has passed the unit check test by showing the "Unit OK" box. For validation testing, behavioral testing is used to validate the model. Formula Mean Square Error (MSE) was used to calculate the percentage error between the simulated and real data behavior flow. The lower the MSE, the closer is forecast to actual. Figure 9 illustrates the results of the behavioral validation test. Based on the calculation, the MSE value is 5%. With this value, it shows the model has passed this test by replicating the coconut system according to the trend of the behavior pattern.

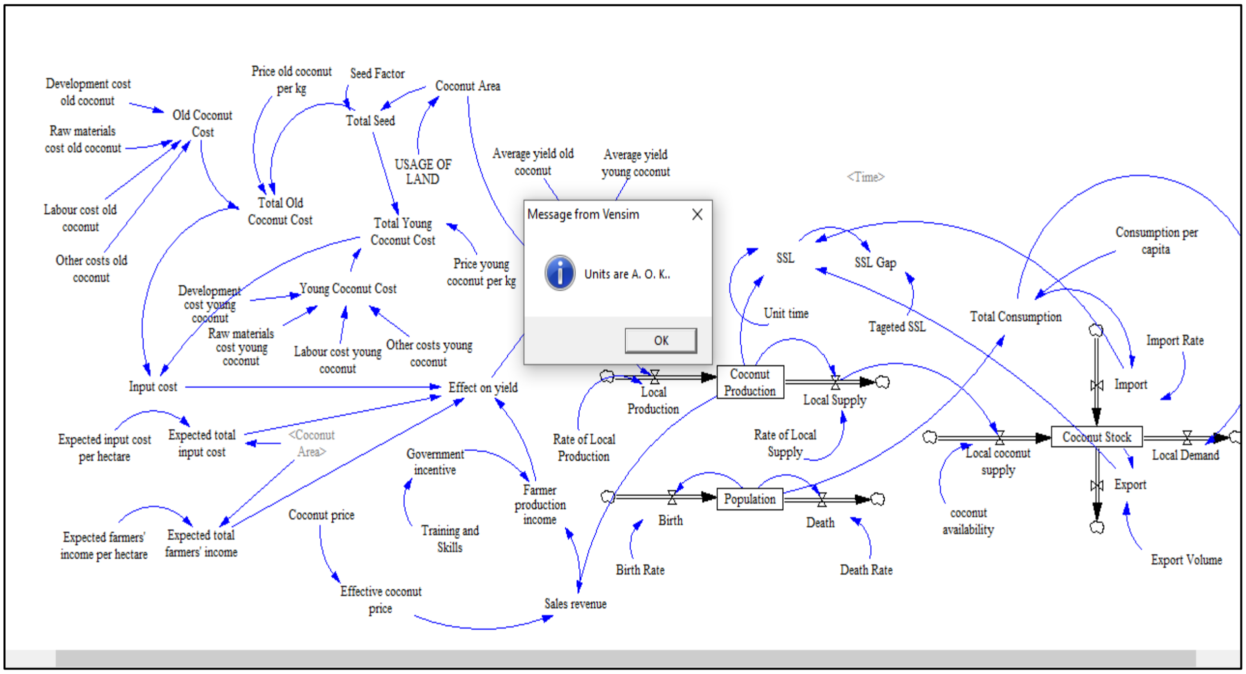

Figure 8: Dimensional unit consistency test result

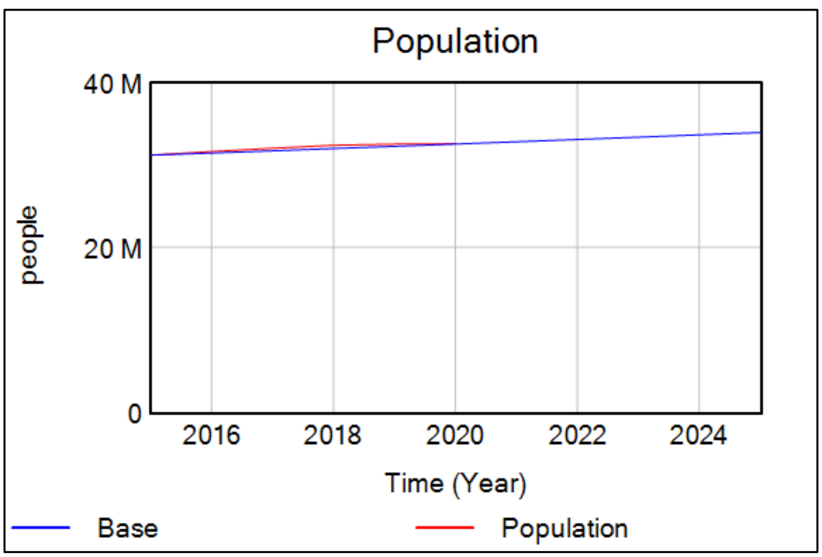

Figure 9: Behavioral reproduction test result

5 RESULT AND DISCUSSION

Results derived from the model reveal a rising trend in the Malaysian population. As depicted in Figure 10, the population has surged from 31 million in 2015 to around 34 million by 2025.

Concurrently, the local demand for coconuts in Malaysia follows a similar trajectory, as illustrated in Figure 11. Regarding coconut production, the trend exhibits fluctuations attributed to industrial demand and import competition, yet in the long term, coconut production consistently rises over the years, as portrayed in Figure 12.

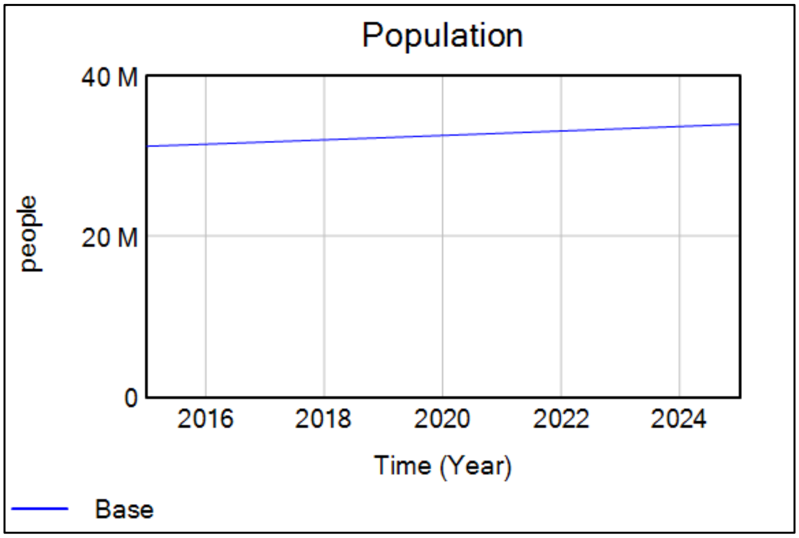

Figure 10: Behavioral trends of the population

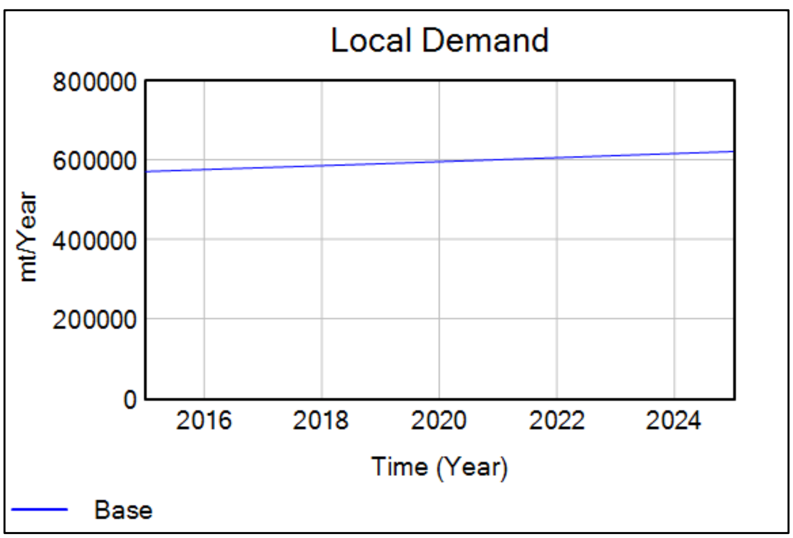

Figure 11: Behavioral trends in coconut demand

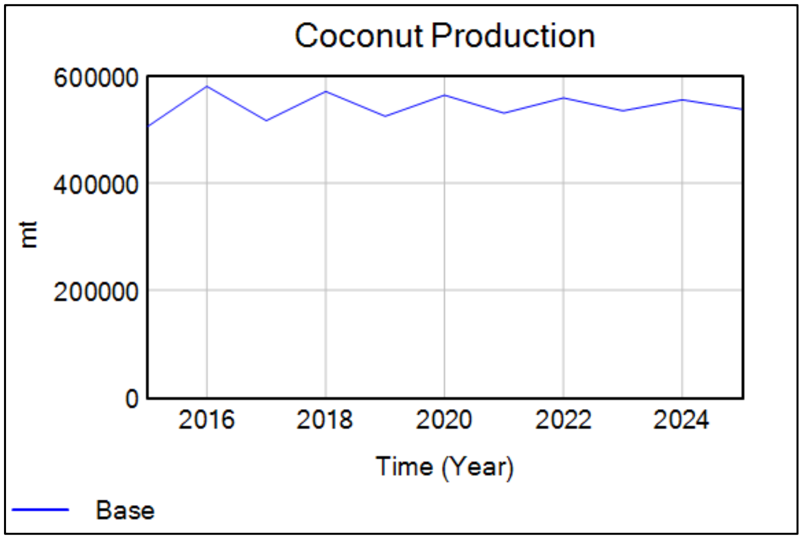

Figure 12: Behavioral trends in coconut production

The fluctuations observed in coconut production (Figure 12) can be attributed to external market factors, including competition from imports and fluctuating industrial demand. Additionally, disruptions in the supply chain and variability in production costs contribute to these trends. For instance, higher production costs during certain seasons force smallholders to scale back their operations, leading to temporary declines in production.

These fluctuations pose challenges for market stability and planning. As such, the findings suggest the need for better inventory management and predictive models to mitigate the impacts of demand-supply imbalances. Government support, such as subsidies or price stabilization programs, could further help stabilize production and ensure sustainable growth.

6 CONCLUSION AND WAY FORWARD OF THE STUDY

This study presents a forecast regarding the future sustainability factors affecting the Malaysian coconut industry. Initial findings suggest that both demand and production of coconuts will rise in tandem with population growth over the same period. The outcomes of this investigation align with Sustainable Development Goal (SDG) 12, emphasizing responsible consumption to foster inclusive economic growth that benefits all layers of society. The culmination of this study is the development of a model subjected to both structural and behavioral verification processes, affirming its capacity to replicate the intricate dynamics of the Malaysian coconut industry. This model demonstrates a near-accurate projection of all considered parameters within the dynamic system. Throughout the application of this model, any identified weaknesses and recommendations will be duly addressed to enhance its efficacy in future applications. Building upon this work, an intervention analysis will be undertaken to pinpoint optimal strategies for mitigating the issue of dwindling coconut supply associated with coconut production in Malaysia.

ACKNOWLEDGEMENT

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