Journal of Sustainability Science and Management
Volume 18 Number 2, February 2023: 81-102
eISSN: 2672-7226
© Penerbit UMT

UNDERSTANDING PADDY PRODUCTIVITY AT MADA ESTATE FROM A SYSTEM DYNAMICS PERSPECTIVE: A MAPPING TOOL OF CAUSAL LOOP DIAGRAM

NORHASLINDA ZAINAL ABIDIN[1]*, SHRI DEWI APPLANAIDU[2], MOHAMMED BABA ABDULLAHI[3] AND SURIANIE BAKAR[4]

[1]Institute of Strategic Industrial Decision Modelling, School of Quantitative Sciences, Universiti Utara Malaysia, Sintok, Kedah, Malaysia. [2]Department of Economics and Agribusiness, School of Economics, Finance and Banking, College of Business, Universiti Utara Malaysia, Sintok, Kedah, Malaysia. [3]College of Management and Information Technology, American International University West Africa, Banjul, the Gambia. [4]Research & Statistics Branch, Muda Agricultural Development Authority (MADA), Malaysia.

**Corresponding author: nhaslinda@uum.edu.my*
Submitted final draft: 20 November 2022 *Accepted: 17 December 2022* http://doi.org/10.46754/jssm.2023.02.007

Abstract: The Muda Agricultural Development Authority (MADA) paddy estate project represents Malaysia's national effort to enhance food security. However, the Economic Transformation Programme (ETP) by Malaysia falls short of attaining the 10MT/Ha paddy productivity potential. Amidst rising food insecurity, national efforts have focused on improving the efficiency of domestic productivity, this study specifically assessed factors influencing paddy productivity under the MADA estate project. Against the econometric technique, the causal loop diagram (CLD) in the system dynamics (SD) approach was used to analyse the systemic character of productivity and its drivers. The systemic relationship was explored using expert interviews and an extensive literature reviews. Findings established four major sub-systems of the rice value chain. These include paddy production, rice production, government subsidy and self-sufficiency level. The loop polarity feature was used to establish the causal relationships and directions of causality between the sub-systems. This study contributes directly to EPP10 and EPP11 of the ETP. As a result, it supports Malaysia's effort towards strengthening food security and self-sufficiency.

Keywords: Causal loop diagram, paddy productivity, self-sufficiency level, rice value chain, system dynamics.

Introduction

The number of people who require food will grow by 2050 as the world's population surges. The global food system must expand to accommodate the increase in demand from an increasing population, while simultaneously struggling to feed the world's hungry today (Gujja & Thiyagarajan, 2010; FAO, 2015). Interestingly, rice is a main source of nutrition with about half of the global population depending on it (Krishnan, Ramakrishnan & Reddy, 2011; Fukagawa & Ziska, 2019). With the world's current population of approximately 6.07 billion expected to reach 8.92 billion by 2050, demand for rice is expected to continue growing, reaching 551 Mt in 2029/2030 (GRiSP, 2016). Increased rice production is required to meet the world's food demand, given the expected growth in global rice demand (Krishnan, Ramakrishnan, & Reddy, 2011). Especially since rice is a staple meal in majority of developing countries, accounting for 27 percent and 20 percent of the calorie and protein intake, respectively (Fukagawa & Ziska, 2019; GRiSP, 2016).

There is a need for advancing efforts towards improving rice productivity levels, particularly among those producing countries where the productivity is lower than the global average of 4.2 Mt/Ha. This is essential, given that countries with net exports or imports both share concerns for food security in relation to self-sufficiency (Mirimo & Shamsudin, 2020). However, it is critical to pursue this goal of increasing rice supply through sustainable methods such as productivity improvement per unit of land. Understanding value chain linkages may also aid in the dissemination and acceptance of innovation aimed at increasing productivity (Abdul Rahaman & Abdulai, 2020; Sospeter *et al*, 2021). Furthermore, for the effectiveness of the intervention efforts, all aspects of the value chain of rice must be considered as a system. This is considered critical for determining intervention areas and development programmes (Humphrey & Navas Aleman, 2010). However, a systematics assessment of the rice sector involving all actors or sub-systems in the rice value chain is limited to existing literature particularly in the context of developing countries such as Malaysia. It is critical to recognise practical issues and tailor solutions to local circumstances (Humphrey & Navas Aleman, 2010; Sospeter *et al*., 2021).

Malaysia, like other rice-dependent countries, has a complex value chain that demands a holistic assessment of issues before deciding on the appropriate level of action. Previous studies including ones by Chung (2018) and Bala *et al*. (2017) conceptualised the value chain for rice in the form of a system. The concepts used in these previous studies are important to the design and analysis stages used in this study because their research identified that stages across value chains are interconnected, and consequently could be considered as a system. They recognised the model for rice includes the production, processing and marketing stages, all of which are linked to the central micro component of farm profitability.

However, a critical issue in the previous analysis concerns the omission of various government interventions in the sector. The current analysis however, considers the important role of government interventions in form of subsidies, import level, and targeted self-sufficiency level (SSL). In addition, the focus is laid on paddy growth or production stage and milling sub-systems in MADA. Furthermore, unlike the Bala and Chung studies, which were primarily concerned with profitability, the current study is concerned with productivity improvement. In this way, the current study built on prior models the through the integration of other sub-systems representing the rice value chain to reflect real-world observations.

This MADA paddy estate project is our study area, and was initiated by the Malaysian government's acknowledgement of the agricultural sector's critical importance to the country's economic growth, particularly with rice as a major food security concern. This is seen in the establishment of EPP10 and EPP11 in the National Key Economic Area (NKEA) project under Malaysia's ETP, which focuses on paddy productivity. A collection of smallholders in the paddy production unit of the MADA granary area are leading the project. As a result, a system dynamics model, which allows for system-wide research, would aid in a better understanding of the factors affecting farmers' productivity potential in the MADA NKEA project, as well as the macroeconomic consequences such as lower price level and food security for Malaysia. The remaining parts of the study discuss the paddy value chain in Malaysia; then the critical review of literature and discussion of findings and this is followed by the conclusion.

The Malaysia Paddy Value Chain

Malaysia's rice value chain can be divided into five components named as paddy cultivation, milling, government involvement, importation body (BERNAS), and, most crucially, national consumption. The interplay between these components, could be considered a complicated system as none of the sub-systems in the rice value chain occurs in isolation (Bala *et al.,* 2017; Chung, 2018 & Charles, Mattee & Msuya-Bengesi, 2021). This implies that there are connections between and among the factors in the value chain sub-systems. If the paddy production sub-system is directly linked to the paddy milling unit, and the milling unit's efficiency is linked to rice output, then both self-sufficiency and rice consumption are linked to production and import. Thus, the system approach to analysing the rice sector through the interlinkages in the value chain is critical.

The paddy production sub-system includes the entire process of cultivating paddy in the field, from input selection through land management and nursing the plant to maturity. Malaysia divides paddy cultivation between granary and non-granary sectors. The granary lands produce around 74.1 percent of the domestic paddy supply, while non-granary areas produce the remaining 25.9 percent (Omar, Shaharudin & Tumin, 2019). Malaysia's paddy production is concentrated in ten major granary areas. However, the MADA granary area in Malaysia's Northern Peninsular is renowned to contribute the most to domestic paddy output. The MADA granary area provides around 38.8 percent of total national paddy production. Despite MADA's contribution to overall rice production, productivity has always been below potential (Abdul-Rahaman, & Abdulai, 2020). Thus, Malaysia has focused its food security efforts on increasing rice yield and achieving the desired self-sufficiency, with a particular emphasis on the MADA granary area.

The trend in overall paddy productivity in Malaysia has increased over time, increasing from an average of 2.0 MT/ha in the 1960s to 4.08 MT/ha in 2019. Figure 1 shows that the average productivity in MADA is 5.3 MT/Ha which is higher than the national average of 4.08 MT/Ha in 2019 (DOSM, 2019).

Although productivity varies within and across granary and non-granary areas, there are certain similarities. Malaysia's government agriculture policies are focused on increasing national rice production by addressing productivity issues in each granary (Ali *et al.,* 2019; Omar *et al.,* 2019). Furthermore, the granary areas were the focus of most government subsidies and interventions in the rice sector, making them major research and development locations (Firdaus *et al.,* 2012). Paddy milling, government involvement, rice consumption, imports, and SSL are all macroeconomic factors that have a strong link to productivity (Soullier *et al.,* 2019). Consumption growth is a major element affecting paddy productivity in Malaysia today.

Rice is a staple food in Malaysia, as it is consumed in a variety of forms daily throughout the country (Rahim *et al.,* 2017; Omar *et al.,* 2019). Rice consumption per capita in Malaysia decreased from 83.9 kilogrammes per person per year in 2009 to 80 kilogrammes per person per year in 2016 (Omar *et al.*, 2019). Malaysia's rice consumption per capita will be greater than the global average of 54.6kg per person, higher than that of India at 69.0kg per person and Japan at 54.8kg per person, but lower than Indonesia which consumes 135.0kg per person, The Philippines, which consumes 116.7kg per

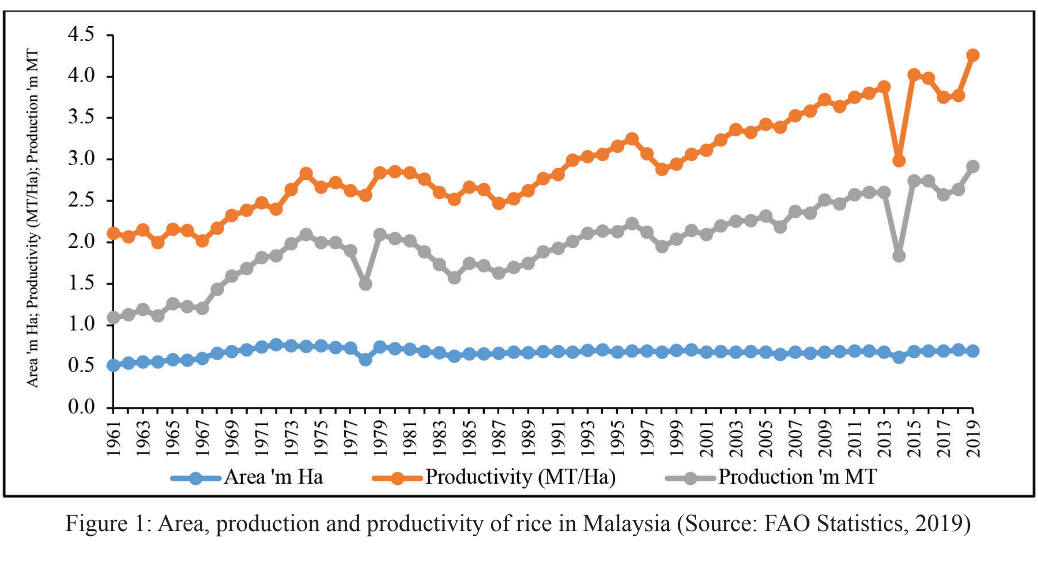


Figure 1: Area, production and productivity of rice in Malaysia (Source: FAO Statistics, 2019)

person, and Thailand needs 116.7kg per person. Rice consumption in Malaysia has increased from 1.55 million tonnes in 1990 to 2.86 million tonnes in 2010 (see Figure 2). Malaysia's local rice production meets between 60 percent to 70 percent of total demand, while imports account for the remaining 30 to 40 percent.

The paddy milling sector is directly related to the characteristics of rice production. Paddy milling is the process by which the brown outer layer of paddy is removed to produce white rice (Chung *et al.,* 2016). Paddy milling plays a critical processing role that ensures the rough paddy is converted to white rice that is edible to consumers. Remarkably, only a few empirical studies have assessed Malaysia's rice milling sub-sector (Chung *et al*., 2016). Most existing research tends to focus its attention on either the production of paddy or rice consumption. These two paddy subunits are employed by existing studies to provide an easier assessment on the performance of the paddy sector as a whole. Thus, the milling or processing units are given less research attention, thus the direct impact on rice supply in Malaysia is overlooked (Chung *et al.,* 2016).

In Malaysia, paddy processing units are considered important. Based on the processing quality, the share or composition of the broken rice is considered in grouping the domestic rice into three grades: the 'Super Tempatan 15 percent (ST15), Super Special Tempatan 10 percent (SST10), and Super Special Tempatan five percent (SST5)'. The different grade numbers indicate the percentage of broken or fragmented rice contained in the milled rice. Notably, the ST15 are those consisting of 85 percent full rice and 15 percent broken rice. The paddy and rice price are supported by the guaranteed minimum price (GMP) and farm subsidies (Johnson, 2000). According to Chung *et al*. (2016), ST15 has a fixed retail price of 1.60RM/Kg (0.50 US$/Kg) or 1.80RFM/Kg (0.55RM/Kg). The paddy mills which are not covered by milling subsidy tend to supply higher quality rice grain such as SST5. Thus, such millers receive a higher price up to 2.60 RM/Kg (0.80US$/Kg), as a ceiling price. Thus, rice milling profitability in Malaysia is controlled to a certain extent through price control.

Paddy importation has been used as an approach to complement domestic production in Malaysia. The import of rice in Malaysia is the sole responsibility of the Padi Beras *Nasional Berhad* commonly known as BERNAS. The BERNAS is the only licensed organisation charged with responsibilities that involve the import and distribution of rice into Malaysia (Rittgers & Wahab, 2017). It is responsible for ensuring a sufficient supply of paddy to meet the rice consumption demand without

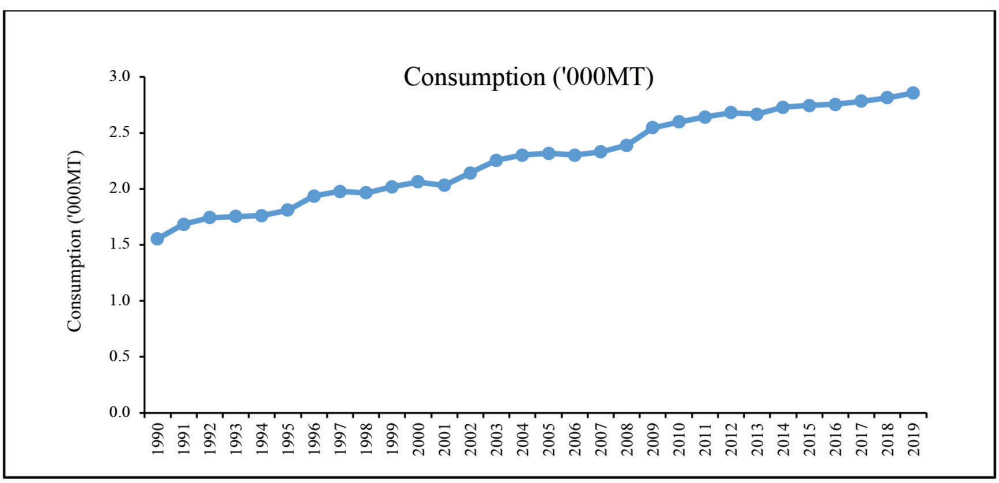


Figure 2: Rice consumption in Malaysia from 1990 to 2019

challenges. Therefore, BERNAS engages in the promotions of price and market stability to ensure affordability by the consumer. Additionally, BERNAS is also responsible for ensuring adequate rice supply and accessibility by every Malaysian citizen (Muhammad, 2013). Thus, rice enjoys high government-support and protection in Malaysia (Malaysian Agricultural Research and Development Institute (MARDI) 2013). The monopolistic arrangement of rice import has been reported by studies to influence productivity negatively and thus has remained a subject of interest among researchers. However, an interesting and major factor is the role of government policies in both milling and paddy production sub-systems in Malaysia (Chung, 2015; Chung, *et al.,* 2016). The government is engaged in providing support to the paddy sector both directly and indirectly including output and input subsidies for the growth of domestic rice production. The Malaysian government also make use of tariffs as protection and as a way to ensure competitiveness of domestic rice production.

However, studies argue that the excessive provision of farm subsidies and domestic protectionist policies accorded to the paddy farmers by Government contributes strongly to inadequate practices and poor paddy quality which then poses a challenge to rice milling (Chung *et al.,* 2016). This is despite the specified guideline and payment deducted from paddy farmers in accordance with the moisture content, and dirt found in the rough paddy. Even though, the paddy farmers seldom agree to the deduction from the subsidy payment when the moisture level and dirt in the rough paddy are high. In-view of the resistance, between 17 and 18 percent is adopted as a uniform deduction rate which is applied irrespective of the actual deduction value of between 23 and 24 percent on average (Salman, 2010). For the rice millers, paddy purchasing makes up almost 85 percent of total production costs, thus the deduction rate increases the overall production costs since paddy with high moisture content cannot be efficiently recovered (Salman, 2010; Chung *et al.,* 2016).

MADA NKEA Project and Paddy Productivity

Malaysia recognizes the crucial relevance of the agricultural sector specifically the paddy sector to its economic growth especially with respect to food security. Therefore, in view of the need to ensure national food security, many developing countries such as Malaysia have deployed policy measures to improve productivity, to ensure a steady supply to keep up with increased demands (Arshad *et al.,* 2019). Further, the policy measures are also targeted at transiting from import reliance to food self-sufficiency as an important national objective. Malaysia has fulfilled several national objectives of SSL and food security including social obligations through a variety of agricultural policies.

The agricultural policies in Malaysia have evolved over time beginning with the three National Agricultural Policies (known as NAPs I to III), the National Food Security Plan (known as NAFS 2008), and the recent National Agrofood Policy (known as NAFP) (MoA, 2011). More recently is the introduction of the Economic Transformation Programme. The NAFS policy explicitly states the goals of food security and laid out comprehensive strategies to achieve them. However, NAFS was replaced with the NAFP and the later new Economic Transformation Programme (ETP) (2011-2020) (Arshad *et al.,* 2017). Accordingly, the management at MADA granary area has aligned its objectives with the national policies as highlighted in Table 1.

According to MADA (2021), the MADA Irrigation Scheme (RPM) was launched in 1965 with the help of a loan from the World Bank as a developmental project in Malaysia. During this period, the productivity at MADA was about 3.36MT/Ha. In 1976, with the introduction of double cropping, productivity improved by an average value of 4.178 MT/Ha. However, among these policies, the average productivity at MADA was highest during the National Food Security Guaranteed Policy (6.15MT/Ha) even when compared with productivity of 5.69 MT/Ha under the current Economic Transformation Programme (ETP).

Table 1: Policies summary and programs for MADA

Year	MADA's Programme/ Government Policy	Average Gross Productivity (MT/Ha)	Total Production (MT)	Description
1965	Muda Irrigation Scheme (RPM)	3.37	316,992	Single Cropping/ Year
1976	Implementation of RPM and - double cropping / year	4.178	770,815	Double Cropping Entirely the Whole MUDA Area
1980	Paddy fertiliser subsidy scheme	4.674	866,183	The Scheme Started in Year 1979
2004	Implementation of the 10 Mt package	5.475	1,055,457	The Package Started in Season 2/2001 (Focus on Technology)
2008	Paddy production incentive scheme	5.7	1,100,695	Started in Season 1/2007 (Focus on Technology and Management)
2009	National Food Security Guaranteed Policy	6.15	1,187,663	Started in Season 2/2008
2011-2020	National Key Economic Area (NKEA) EPP10	5.688	1,140,440	Started in Year 2011

Source: MADA (2019)

The ETP expands on the directions established in the Tenth Malaysia Plan to create a significant new strategy for achieving the Government's goals (Performance Management Delivery Unit (PEMANDU), 2010). The implementation of tangible improvements in certain sectors and areas of the economy was the ETP's starting point. As a result, 12 National Key Economic Areas (NKEA) were chosen as the ETP's core, among which is the agriculture sector (MADA, 2019). The agriculture NKEA aims to increase total Gross National Income (GNI) contribution from RM34 billion to RM49 billion by 2020. The NKEA will provide 75,000 employments, especially in rural areas, with the goal of increasing the earnings of farmers who participate in programmes by two to four times. The agriculture NKEA intends to bridge this gap through 16 Entry Point Projects (EPPs) worth RM28.9 billion in GNP. These EPPs will enhance the formation of large scale, market-driven, and integrated agribusinesses centred on four themes that: exploit competitive advantages, open premium markets, and ensures food security objectives are in line with the increase in GNP and expansion in participation level across value chain in the region.

Among the 16 EPPs under the agriculture NKEA, EPP10 is primarily aimed at increasing and improving paddy farming productivity in the Muda area. As a result, MADA built the paddy estate project, with a potential paddy productivity objective of 10MT/Ha. MADA was primarily focused on providing incentives to encourage land management outsourcing and the establishment of an integrated rice business or paddy estate. Despite efforts to promote the MADA paddy estate project's goal of producing 10MT/Ha, productivity has fallen short of the target. As a result, there is a need for an assessment of the reasons for the inability to meet the targeted production potential.

The subsequent sections of this research paper are arranged as follows. The literature review is next. It presents the studies that were examined, and the series of factors associated with the rice production value chain. It is followed by the methodology of the study, which uses the system dynamics (SD) causal loop diagram and highlights a causal relationship between the variables in the rice value chain. Finally, a discussion on the findings and recommendations of this study rounds out the sections.

Review of Relevant Literatures

Review of Studies Related to Model Used in Paddy Research

By definition, the model is a representation of a system, which is made up of functionally related elements that makes up a complex whole (Sterman, 1991). Models are classified into two types named as static and dynamic. For static model, Indicators, input-output (IO), social accounting matrix (SAM), and geographic information system (GIS) are all the examples where each of them has particular strengths and limitations. For example, an indicator's limitation is that it is restricted to quantitative variables. As for IO, it highlights the value chain analyses and the cross-sectoral ripple effect. The IO primary's shortcoming is that the material flows are not readily available across sectors, which is one of the important elements highlighted in the SD model. Meanwhile, SAM measures economic flows between the major economic actors and is limited to monetary flows, although it does not incorporate feedback relationships. On the other hand, GIS is an approach that records geophysical data which lacks behavioural explanations.

For the dynamic category, the types of dynamic models include econometric, optimisation, and system dynamics approaches (Uehara *et al.,* 2018). These dynamic models, particularly the econometric models are widely used to forecast economic events. Among econometrics' shortcomings are that it is fully dependent on historical data, has a restricted feedback relationship, and does not capture new phenomena (Sterman, 1991; Uehara *et al.,* 2018). The primary shortcoming of the optimisation techniques is the assumption of linearity, which is mathematically handy but is incorrect in practice. Additionally, it lacks a feedback link.

Based on the review in this paper, it is found that the SD modelling approach has many advantages that address the research problems that inspired this investigation. It is a rigorous strategy that entails the development of formal computer simulations in order to gain a better understanding of complex systems and to design more effective policies and organisations. This approach is derived from systems thinking, a field concerned with comprehending a specified system through an examination of the relationships and interactions between the components that compose that defined system (Trimble, 2013; Senge, 1996).

The strength of SD stems from its distinct characteristics in comparison to other modelling approaches. The SD model is used to comprehend and anticipate changes in complex systems across time (Trimble, 2013). According to Senge (1996) and Trimble (2013), the system's complexity is a result of the following primary factors:

i. Circular causality or interdependence connects everything to everything else.

ii. Effect non-linearity is rarely proportionate to cause.

iii. Behavioural events are path or history dependent.

iv. It's counterintuitive to focus on the symptoms of a problem rather than the root cause.

v. Characterized by trade-offs due to feedback channel delays, with the long-run reaction of a system to an intervention commonly differing from the short-run response.

In light of this, the SD model has its own set of research steps, each of which is iterative. The

SD approach differs from other approaches in that it uses a graphical representation known as causal loop diagram (CLD) to conceptualise the complex system. Among the benefits of SD are:

i. It provides tools for visualising systems, hence supporting qualitative modelling.
ii. It assists in the creation of adaptable, clear models and a comprehensive grasp of the problem.
iii. It can keep track of long-term patterns and trends in behaviour.
iv. The model's structure and results are more transparent.
v. That the model encourages people to work together to create their vision.
vi. The model assists in the analysis of 'what if' scenarios for policy evaluation.

This study proposed the SD approach for the strengths mentioned above and since it provides a reliable framework for analysing paddy systems based on the aggregated examination of its components.

Review of System Dynamics Studies on Paddy Related Topics

Empirical research has employed SD in exploiting various factors that influence the growth of the paddy sector (Bala *et al*., 2017; Chung, 2018) from productivity growth, production expansion and self-sufficiency level (SSL). Generally, to achieve optimal rice growth there is a need for certain environmental factors (Yang *et al.,* 2018; Dubey *et al.,* 2018), and these factors can either be provided by nature or by the farmers. Thus, the productivity of paddy is mainly controlled by a combined effect of nature dependent factors like precipitation, temperature and CO_2 (Yang *et al.,* 2018), and human-related factors such as input usage, management practices and policies. The literature covers several factors across the rice value chain that include policies such as input usage, climate, cropping system, socio-economic factors, post-harvest management (milling and harvesting techniques), research and development import and consumption pattern. These factors could be either positively or negatively related to the dependent variable of interest. Thus, reviews are presented based on different variables in the studies.

Input Usage and Paddy Productivity

Among the relevant factors are the type and level of input usage in the rice model. Several production inputs in the rice system have been examined by earlier literature. For instance, a study by Rahim, Hawari and Abidin (2017) examined the relationship between land availability, technology and selling prices with rice production. The findings indicated three major factors in their study that influenced rice production viz: rice prices, land availability and technology. Furthermore, Reinker and Erica Gralla, (2018) in Uganda assessed the use of improved agricultural inputs and the combination of quality verification with education-oriented interventions using SD model. Findings show that investing in a system for verifying the quality of seeds is important and both verification quality and education-based interventions have a greater effect than just quality verification. Finally, capital availability to farmers was examined by Sardjono *et al*., (2019). The study suggested an intervention strategy is needed to maintain balance in the rice sector. Furthermore, the study recommends an improvement of capital availability to farmers, especially since future conditions expect to threaten the availability of rice.

Climate Factor and Paddy Productivity

Temperature represents an important requirement for paddy growth, and productivity. Temperature exerts a strong effect on paddy seed germination (Yoshida 1981). At the germination stage, rice seeds require a minimum temperature of 6°C and a maximum of 41°C while the optimal temperature for normal growth is 37°C, while in the growth stage, the optimal temperature ranges between 20°C and 35°C is required (Yang *et al.,* 2018; Dubey *et al.,* 2018). At the specific stages of rice growth, the rice plants have varying sensitivity to temperature changes therefore, the variation in the optimal temperatures during the growth stage, is usually between 20°C and 35°C (Dubey *et al*., 2018). At the seedling development stage, the minimum, optimum, and maximum temperatures are 8°C, 37°C, and 44°C, respectively (Dubey *et al.,* 2018). In terms of water requirement for paddy growth, the rice plants require seasonal rainfall of between 300 and 500mm (Bahri, 2017). Under dryland conditions, rice needs an estimated average of 1,000mm of seasonal rainfall. Thus, considering the water requirements d, the cultivation of rice is more suitable at locations that have higher rainfall. This also results in serious water stress in rice production when drought and flood occur.

Carbon dioxide (CO_2) is another critical input required for paddy growth and productivity. CO_2 is used by plants in the manufacture of food through the process of photosynthesis. There are variations in the manner in which plant species respond to CO_2 levels in the atmosphere. Based on the natural manner plants fix atmospheric CO_2, are classified into C4, C3 and Crassulacean acid metabolism (CAM) pathways (Boretti & Florentine, 2019; Webber *et al.,* 2020). Most plant species (about 90 percent) including rice, wheat, and soybean utilise a photosynthetic process known as C_3 photosynthesis. Rice is a C3 plant, and therefore an increase in CO_2 can increase its productivity (Verma & Sinha, 2020). Despite the fact that, in comparison to the C4 pathway, C3 photosynthesis is inefficient at converting inputs into the grain (IRRI, 2018). However, a combination of precipitation, temperature, and CO_2 regulates productivity (Yang *et al.,* 2018).

The SD study of Suryania *et al*., (2014) developed different sub-models including population and rice demand, land area, productivity, rice stock and distribution in the SD sector to examine their effects on rice productivity and food security in Malaysia. The study found that productivity depends on temperature, humidity, sunshine, land surface height, rainfall, fertiliser, seed volume, and the availability of irrigation. In a unique approach that combines both crop simulation and SD approaches, Vaghefi *et al*., (2016) assessed the impact of climate on rice production and food security in Malaysia. Based on the crop simulation under the DSSAT model, during the 2 growing seasons, both temperature increases and alteration in rainfall patterns respectively reduced rice productivity by 12 percent and 31.3 percent by the year 2030. Meanwhile, the SD's results showed a decline in rice productivity is projected to lead to a decline in income by farmers and the national rice SSL.

Policy Factors and Productivity

The policy factors constitute the rules and regulations that are enacted by the government or established a body to facilitate the achievement of targeted objectives in the rice sector or agriculture sector in general. The policies can be in the form of input subsidy, price control or guaranteed minimum price, cash transfers, trade policy or import control. These factors can influence rice production, SSL, productivity and farm income in different dimensions. Employing the use of SD, several studies have thus shown how individual factors or a combination of these factors influences the dependent variable of interest. Numerous earlier studies that examined the relationship between policies and the dependent variables (productivity, production and SSL) include those by Rahim, Hawari and Zainal Abidin, (2017); Chung, (2018); Emmy *et al*., (2015); Ramli *et al*., 2012); and Arshad *et al*., (2011).

The usage of the SD technique supported the efforts towards overcoming the rice supply shortage in Egypt (Khodeir & Abdel-Salam, 2015). Through evaluation of policies related to productivity, production losses, the growth in population and income. Similarly, in Iran, using SD, the long-term influence of policies on the exchange rate and fixed prices were identified on Iran's food SSL. The use of floated prices along with exchange rates was examined as counter policies to the current policy (Parvizian & Karimi-Tabar, 2002). Earlier studies have also examined price subsidy and found it to be negatively related to SSL. Notably, Rahim, Hawari and Zainal Abidin, (2017) established a negative relationship between price subsidy and rice SSL in Malaysia using an SD approach. Variables in the model include rice production and SSL, local, import, demand, population and price of rice. Findings show that an increase in the price subsidy leads to a substantial increase in demand as the price of rice drops. When demand increases, SSL decrease. Although the local production increases, the rice SSL decreases slightly as the increment in local production is insufficient to meet the huge rise in demand due to which the rice price drops because of the price subsidy.

Cash subsidy was also found to show a negative effect on SSL in the study by Arshad *et al*., (2011). The study examined several factors including cash subsidies and its effect on SSL. Other factors include physical loss along with paddy area, paddy production, income and rice SSL, fertiliser, land conversion and fertility. Results indicate that for paddy production; an increasing trend in paddy production is observed, which is influenced by continuous R&D and subsidies, though the SSL was found to decline. Similar studies by Parvizian and Karimi-Tabar, (2002) also found a negative effect between fixed price and SSL. SD was employed to examine the long-term effect of fixed price and exchange rate policies on the food SSL in Iran. Results show that with the fixed price policy, the normal nutrition index increased steadily. The SSL decreased from 1.0 to 0.92 by 2030. Alternatively, the study tested the floating price and exchange rates as counter policies to the fixed price policy. As anticipated, when the relative price is higher than the profit while demand reduces. The findings show that SSL increases from 0.92 to 1.01 consequently declines as demand is experienced. This indicates an increase of 8.9 percent which is lesser than the 18 percent increase in the case where the price is not fixed.

Contrarily, Chung (2018) found a positive relationship between the removal of the price control and SSL. The study examined the effects of withdrawing price control measures along with the import monopoly on both rice SSL and general prices in Malaysia. The result indicates that the removal of price controls leads to an increase in rice prices, reducing demand which could help achieve an SSL of 100 percent. Another alternative policy dimension examined by various studies is the fertiliser subsidy. Many studies have shown a positive effect of fertiliser subsidies on production. Notably, is the study on the fertiliser subsidy's impact on Malaysia's rice sector comprises productivity as a variable of concern (Ramli *et al.,* 2012). Fertiliser subsidy upsurges the productivity and hence increases the production of paddy. Similarly, Arshad *et al*., (2011) examined the association of cash and fertiliser subsidies, land fertility, physical losses, area conversion and then SSL. The result points to the positive effect of these factors on productivity and SSL.

Alternatively, an SD model by Emmy *et al*., (2015) showed that the policy related to cash subsidy can help to improve Malaysia's SSL to 80 percent by 2050. Furthermore, Rusli, Arshad, and Ibragimov, (2017) studied the MADA granary area by developing a causal loop for paddy deduction system. Findings indicate the possibility of farmers to expand income from paddy through better farm practices. This involves the maximum use of suggested practices which has the capacity to lower the moisture content of paddy, which leads to a lower deduction rate. However, price control as observed by the study will lead to suppression of paddy miller's growth as influenced by increased processing cost.

Cropping System and Productivity

Cropping system is another factor that influences paddy productivity. A study by Cui, Huang and Tang (2009) considered the effect of three crops per year by employing the SD approach and field experiment in China. The findings showed that the development of three crops per year in paddy fields may improve long-terms productivity and stainability of paddy field ecosystems. Alternatively, Chapman, *et al*., (2016) assessed the effect of triple-cropping as a sustainable adaptation strategy on rice production at Mekong Deltas in An-Giang Province of Vietnam. The findings of the SD model indicate that even though recent shift to triple-cropping annually provides short-term income boost however, there is high risk of productivity decline and similarly for profitability.

Research and Development and Paddy Productivity

A study by Bala *et al*., (2014) employed a different set of factors in the SD model. The study examined the effects of Research and Development (R&D) for higher productivity varieties, using bio-fertilisers and emergent techniques on extension for rice productivity and food security in Malaysia. The outcome suggests the need for gradual evolution towards the use of bio-fertilisers, more funds for R&D, particularly for high productivity hybrid rice and increased cropping intensity assures better productivity. Similarly, Arshad *et al*., (2011) also examined food security in terms of SSL of rice in Malaysia using the SD modelling. Among the considered other variables are physical loss, along with paddy area, paddy production, income and rice self-sufficiency, fertiliser, cash subsidies, land conversion and fertility. For the intervention scenarios, the results showed that increasing trends of paddy production are influenced by continuous R&D and subsidy.

Rice Production, Consumption and Trade Factors

Studies have shown that consumption is negatively related to SSL. Notable among these studies is Mirimo and Shamsudin, (2018). The study was carried out using the SD approach to compare the rice sector of Malaysia with certain ASEAN nations. The study employed factors that include population, rice consumption, rice imports, GDP, paddy planted area, paddy productivity, rice production, production cost, trade liberalization, import price and export price for Thailand and Vietnam. An SD model was thus developed to stimulate the rice sector for the period of 2013-2025. Five price scenarios based on the export prices for Thailand, Vietnam as well as Pakistan were used. The baseline scenario was based on the World Bank's commodity price forecast. The simulation outcome according to the base-line scenario shows main variables including, consumption, rice production, and Malaysia's importation quantity are on the rise during the baseline simulation period between 2013 to 2025. The SSL experienced a decline in trend resulting in the widening of the gap from consumption to production during the simulation period.

Similarly, Sulistyo, Alfa and Subagyo (2016) modelled Indonesia's rice demand and supply through the SD approach to highlight the positive effect of rice productivity along with land conversion rate, and rice consumption rate on SSL. Among the factors considered in the model are rice supply and dried paddy demand, rice conversion factor, climate anomalies, and delayed harvest time. The findings of the study showed that rice importation will still be required to fulfil the rice demand in 2020, given the business-as-usual situation. Consequently, three scenarios named productivity increment, land conversion rate, and rice consumption rate are proposed in order to achieve rice SSL. Of the three scenarios, scenario 1 which involves improving productivity gave the most promising result.

In Indonesia, Napitupulu and Abdurachman (2016) employed SD modelling to develop a model to simulate the rice stock in Indonesia. The factors considered in the model include paddy stock, rice stock, BULOG rice stock, supply and demand of rice, total rice consumption, rice consumption per-capita, rice production, paddy production, prices of rice, operation to flood the market with rice policy, rice procurement, population size, population growth, and coefficient of converting paddy to rice. This study developed a prototype SD model for controlling stock and the price of rice for Indonesia with several alternative scenarios built in.

***Post-Harvest* Management and Milling Efficiency**

Harvesting techniques and agricultural practices were examined by Aprillya, Suryani and Dzulkarnain, (2019). Using the current harvesting techniques and agricultural practices, the study found that increasing the adoption of the postharvest mechanisms coupled with the application of appropriate Good Agricultural Practices (GAP) would significantly increase paddy production in East Java. According to certain researchers, large-scale investments in processing plants and/or contract farming have taken place. These have been observed in maize value chains in Ghana (Ragasa, Lambrecht & Kufoalor, 2018) and Nigeria (Ofuoku & Agbamu, 2016). Even the rice value chains in Nigeria have had a series of investments made in them as reported by Awotide, Fashogbon, and Awoyemi (2015) in Nigeria; Maertens and Vande Velde (2017) in Benin; and Maertens and Vande Velde (2017); Bidzakin, Fialor and Yahaya (2018) in Ghana.

Furthermore, a study examining the post-harvest loss effect on SSL was carried out by Emmy *et al*., (2015). This study developed a model constitutes for variables such as rice's SSL, post-harvest losses, and other factors such as subsidies, paddy land conversion and organic farming. The simulation analysis involves six scenario interventions including the business-as-usual scenario, the post-harvest loss scenario, the subsidies withdrawal, paddy land conversion, organic farming and the inclusion of structural breaks. Results from the scenario analysis indicate Malaysia may be able to achieve an SSL of 80 percent by 2050. This will be achieved based on the desired paddy productivity when combined with other four policy strategies: land management, improvement in post-harvest losses, organic farming and cash subsidy.

Further study by Arshad *et al*., (2011) examined physical losses and food security in terms of rice SSL in Malaysia using SD modelling. The factors considered were; physical loss of the paddy planting area, paddy production slowdowns, income and rice self-sufficiency, fertiliser use, availability of cash subsidies, land conversion and fertility. Using these factors, six different scenarios were analysed. Scenario 1 covers the current situation, while scenarios 2-6, involve combinations of the independent variables. The results indicated that paddy areas in Scenarios 1 through 3, found similar levels of decline in the size of the planted area due to land conversion losses. For paddy production, an analysis of Scenarios 1 through 4 found a similar increasing trend of paddy production which was influenced by continuous R&D and subsidies. The analysis also found that rice production was insensitive to land conversion and physical loss since the initial values were so small. with regard to income earned, all scenarios indicate higher income levels follow an increase in productivity. For SSL, all scenarios indicate a downward trend except for Scenario 6.

In the context of Malaysia, previous literature outlined categories of constraints for rice productivity and the productivity gaps through various approaches including expert surveys, household surveys, on-farm field surveys, on-farm experiments, crop simulation models, system dynamics and remote sensing or alternatively a combination of two or more of these approaches (e.g., Becker *et al.,* 2003; Boling *et al.,* 2010; Fischer *et al*., 2014; Yin *et al.,* 2015; Tanaka *et al.,* 2015). Although, each of these methodologies has its weaknesses and strengths as highlighted in the review above.

However, there are only a few researchers in Malaysia that have applied SD modelling to study rice production systems. Nonetheless, evidence on a holistic assessment of the NKEA paddy estate is rare among extant studies, including Chung (2018), Bala *et al*. (2017), Chung *et al*. (2016), Ramli *et al*. (2012), and Arshad *et al*. (2011). In Chung (2018), an SD model was developed to describe the dynamic structure of and decision-making processes occurring in the Malaysian rice value chain. This study further investigated the impact of removing price controls and import monopolies on rice prices and SSL in the country. Similarly, Ramli *et al*. (2012) examined how fertiliser subsidies influence Malaysia's rice sector by considering the productivity of rice as a variable of interest. A similar study also considered rice production in the country with an emphasis on four factors – physical loss, fertiliser subsidies, land fertility and paddy area conversion issues (Arshad *et al.,* 2011).

Arshad *et al*. (2011) for example, delved into the issue of how the rice production industry was facing challenges in competition for land use. It also examined challenges in heavy chemical fertiliser usage to the point that soil fertility in arable lands was affected; to partly mitigate these challenges. What they concluded was that Malaysia was at risk of being unable to sustain its SSL of rice production due to climatic threats and sub-optimal rice production. In an earlier study, Arshad and Hameed (2010) also cautioned on how hikes in global food prices could threaten the very existence of rice production, which is touted as Malaysia's security crop. Similarly, Siwar *et al*. (2014) also analysed similar challenges to rice production in which a focus is made on the increase in food price, environmental changes, arable land resource scarcity, and booming population growth. The most recent SD study on rice supply and demand in Malaysia is done by Rahim *et al*. (2017). The study included price, land availability and technology as factors affecting rice production. Likewise, Rahim, Hawari and Abidin, (2017) established a negative relationship between price subsidy and SSL in Malaysia.

It is apparent that SD is a very reliable approach in analysing the rice production system. To date, and to the best of our knowledge, it seems that there are yet to be any studies on the development of decision-making systems that could contribute to better rice production so that Malaysia could be self-sufficient in the production of its staple food. Additionally, limitations exist among the current studies concerning the examination of the causal factors at the early growth stages of the rice plant. This has likely happened as a result of limitations on the availability of data at the early growth stages of rice plants such as the number of panicles, spikelet number, the proportion filled and grain weight. Thus, the current study will extend the scope of knowledge by applying the SD approach to analyse the causal relationships among factors influencing rice productivity within and across units in the value chain system.

Methodology

This section explains the methodology used in this study which is the SD modelling process. It begins with an explanation on the principles of SD. Next, the discussion focuses on the research process being offered. Then, an in-depth explanation of the framework paddy system is presented. Finally, a summary of the content closes this chapter.

System Dynamics Modelling Process

System Dynamics (SD) is a simulation approach for framing, understanding, and analysing complex issues (Cavana & Maani, 2000). In this study, the model of paddy systems is constructed based on linkages across the value chain using an SD approach. There are five stages involved in an SD modelling process however, this study is limited to steps 1 and 2 which are; Step 1: problem articulation; Step 2: formulation of dynamic hypothesis (Sterman 2004). This study only focuses on what is essentially involved in identifying the causal loop diagram (CLD) of the paddy system.

Problem Articulation

The development of the SD model starts with problem articulation. This stage involves the determination of the model's purpose and setting the model boundaries which are the key variables that influence the overall paddy system. The purpose of this paper is to analyse the factors that affect the productivity of rice with a focus is made on the number of seeds and the percentage of BERNAS rice which have failed to achieve the target for the 1st and 2nd seasons. This has become a serious issue in MADA for the Paddy Estate project. The actual data did not meet the target of 10 Mt/ha of paddy per season. This also contributed to the failure of MADA to further increase the percentage contribution to Malaysia.

Formulation of Dynamic Hypothesis

The modelling process continues with the development of the causal loop diagram (CLD). The elements of the system and its interaction is important in SD. The CLD explains how the system behaves by showing a group of nodes that are interconnected by arrows and the feedback loops created by the connections (Trimble, 2013). This relationship is then translated into the CLD to show the behaviour of the system by the nodes of the variables that are interconnected by the arrows and feedback loops.

The Principles of Causal Loop Diagram

CLD is one of the mapping tools in SD, which consists of various variables connected by arrows denoting the hypotheses and a framework that conceptualises the modeler's idea or the feedback structure of any complex system (Sterman 2004). The variables with plus (+) and minus (–) signs as shown in Figure 3 are assigned in the arrows to indicate the direction of influence. The plus sign means changes in the cause result in changes in the effect in the same direction. In contrast, the minus sign means otherwise (Cavana, & Maani, 2000; Sapiri *et al*. 2015). The positive feedback represents the growth pattern (see Figure 4) while the negative feedback represents goal-seeking (see Figure 5). The combination of this feedbacks will produce various behaviours that represent the real system. The polarity shows the loop either is reinforced (R) or balanced (B).

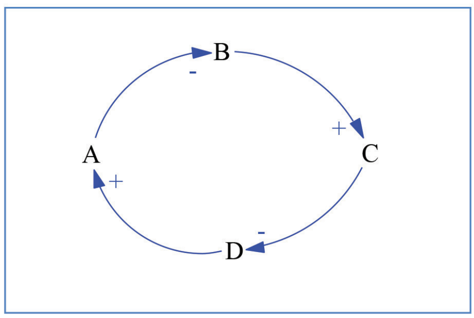
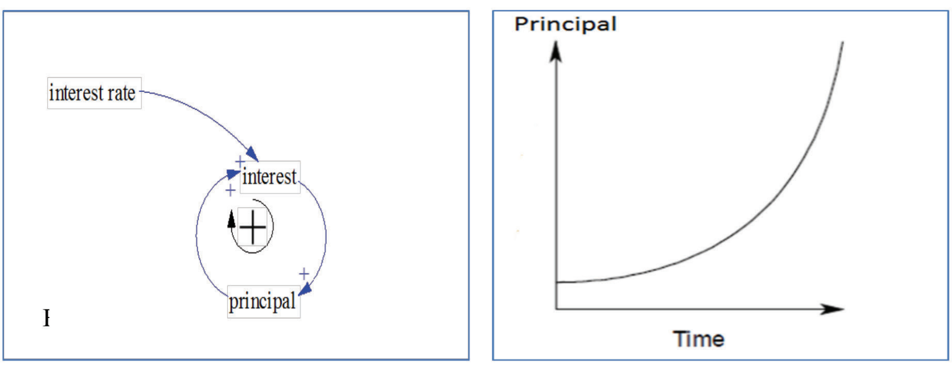
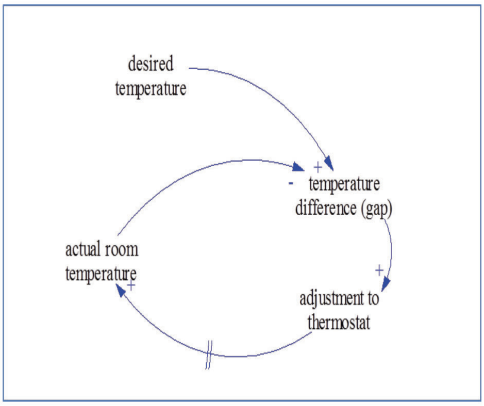


Figure 3: A basic causal loop diagram

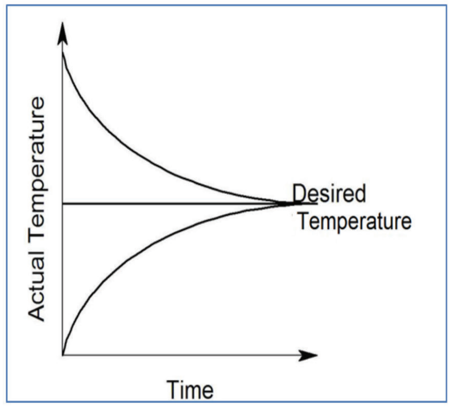


(a) (b)

Figure 4: Example of positive feedback loop and behaviour over time of reinforcing loop



(a)



(b)

Figure 5: Example of negative feedback loop and behaviour over time of balancing loop

Using the CLD, a framework showing the causal relationship between the factors in the SD model is developed. For this study, we developed a CLD consisting of four sub-systems covering the value chain activities of the paddy and rice sector in Malaysia. The four sub-systems are:

(1) The paddy production unit,

(2) The rice production unit,

(3) government subsidies, and

(4) SSL unit.

The CLD provides a diagrammatic representation of the causal relationship among these units. The causal direction shows the relationship within each unit or sub-systems and also between units. Thus, CLD is used as general guidelines to understand the relationship between factors.

Causal Loop Diagram of Paddy System

Figure 6 indicates the CLD as a framework that shows the causal relationships between and within units in the paddy system. The positive sign (+ve) indicates that an increase of a factor will lead to an increase in the value of a factor influenced by it and vice versa a decrease in a factor will lead to a corresponding decrease in the factors affected by it. Whereas a negative (-ve) relationship is an inverse one, which shows that an increase in a factor will reduce the factor affected by it. A detailed description of the factors in each unit, the paddy production unit, the rice production unit, government subsidies, and the SSL unit is presented as follows. The green and red coloured factors are variables of concern specific to MADA and Malaysia respectively.

Paddy production: This unit highlights the total amount of unmilled rice produced annually in MT. The Paddy production unit is related to several indirect inputs such as labour use, seed quantity, fertiliser, type of paddy, temperature and management practices (schedule compliance). Figure 6 shows how these variables in the rice production system affect one another. For example, paddy productivity, land area and paddy production have a positive relationship. It shows that paddy productivity increases as the planted land area increases. While the positive relationship between the domestic production and SSL indicates that as the domestic production increases, the SSL increases. Then, the paddy production determines the domestic rice production. The paddy production unit is affected by paddy productivity per season. The paddy productivity is further influenced by factors such as the farmers' education level, labour skill level, fertiliser type and quality, as well as temperature and CO_2 levels. Thus, paddy productivity is an important contributor to the paddy production unit.

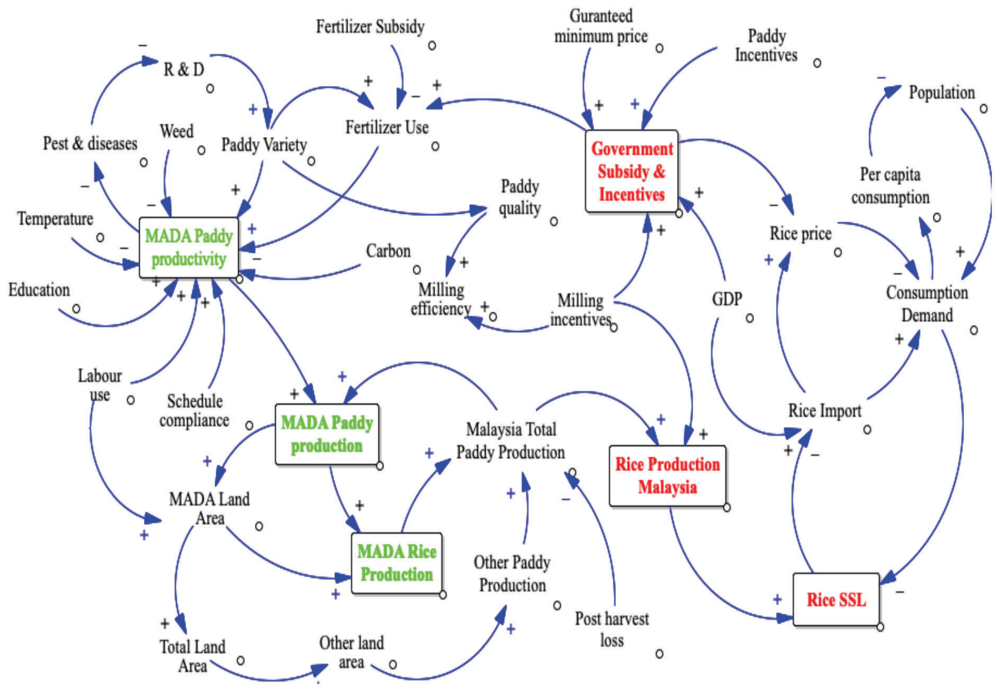


Figure 6: Causal loop diagram of holistic paddy system

Rice production: This is the total amount of milled paddy produced annually in MT. As shown in Figure 6, rice production is related to some key variables which are identified to influence paddy production, milling efficiency, post-harvest losses, rice SSL, import and consumption. The increase in paddy production will indirectly increase the SSL level of rice in general. Rice production is a function of the milling efficiency and paddy quality. Then the total rice production in Malaysia influences the SSL and consequently, the food security status as the completing sub-system of the CLD.

Government Subsidies: These constitutes all forms of government interventions in the paddy and rice sector such as guaranteed minimum price (GMP), gross domestic product (GDP) and other input subsidies. This is considered as a unit as it has multiple effects on other subunits that is the paddy production unit through input usage, rice production unit through milling incentives, farmers' income, and research and development (R&D).

Self-Sufficiency Level: Rice Self-Sufficiency Level (SSL) implies the measure of the extent to which any country can satisfy its rice needs from the total domestic production (Clapp, 2019). The SSL units have three subunits comprising of total production, import, and consumption demand. Domestic production is linked to the self-sufficiency level (SSL) and then the import level. While rice import refers to the total quantity of rice that is acquired from another country to supplement domestic production to meet consumption demand. The overall importation is a factor that is affected by the level of consumption, prices, SSL target, population growth and food security of the country. Furthermore, the SSL is influenced by population size and consumption. Higher SSL levels are indirectly related to less rice imports, and indirectly influence the higher consumption of rice. R&D capacity is instrumental in producing a potentially high productivity variety of paddy. However, the adoption of the high productivity variety and technology is also a function of extension services.

Conclusion and Future Work

This study proposed the CLD mapping tool diagram of the SD approach to gain insights into the complexity that characterises the rice value chain in order to support paddy productivity in MADA. In detail, this study employed the CLD tool to highlight causality between the important variables to further understand the factors that influence productivity in the MADA region. Interestingly, four major units were integrated into the overall paddy value chain system in Malaysia. These units include paddy production units, rice production units, government subsidies, and SSL units. Particularly the analysis of all the units identified the main variables in the rice value chain especially pertaining to paddy productivity and SSL in Malaysia.

This CLD is limited in its ability to foresee the cause-and-effect variables of the productivity and SSL of paddy because this study only covers Step 1 and Step 2 of SD modelling, with emphasis on framework mapping. As a future work, the CLD could be used to provide more details by quantifying the relationship. The use of numerical data and uncertainty analysis is proposed in future studies. The current study is only focused on establishing the causal relationship and direction of causality among important variables in the rice value chain of Malaysia using CLD. Against this limitation and as a continuation of this study, stock and flow diagrams (SFD) of paddy system models should be developed to test the impact of chosen variables on the achievement of the 10MT/Ha paddy production target via conducting intervention scenarios. In this SFD model development, the proposed CLD will be quantified by differentiating the variables, whether they are stock, flows, parameters, or auxiliary variables. The variables will then be quantified by using the units and equations to run the model. This process, as covered in Step 3 of the SD modelling process, will generate the behaviour pattern of focus variables. The produced behaviour trends from this simulated model will then serve as a guide on what would be the best strategy to implement in order to achieve the output of 10 Mt/Ha as a long-term plan.

Acknowledgement

This research was supported by Ministry of Higher Education (MoHE) of Malaysia through Fundamental Research Grant Scheme (FRGS/1/2019/WAB01/UUM/02/2). We also want to thank Research and Innovation Management Centre (RIMC) Universiti Utara Malaysia, Kedah for the administration of this study.

References

Abdul-Rahaman, A., & Abdulai, A. (2020). Social networks, rice value chain participation and market performance of smallholder farmers in Ghana. *African Development Review*, *32*(2), 216-227.

Ainsworth, E. A. (2017). Understanding and improving global crop response to ozone pollution. *The Plant Journal*, *90*(5), 886-897.

Ali, R. B., Luckstead, J., Durand-Morat, A., & Wailes, E. J. (2019). The impacts of trade and self-sufficiency policies on heterogeneous rice farms in Malaysia. *Review of Development Economics*, *23*(4), 1659-1673.

Aprillya, M. R., Suryani, E., & Dzulkarnain, A. (2019). System dynamics simulation model to increase paddy production for food security. *Journal of Information Systems Engineering and Business Intelligence*, *5*(1), 67-75.

Arshad Mohamed, F., & Hameed, A. A. A. (2010). Global food prices: Implications for food security in Malaysia. *Journal of Consumer Research and Resource Centre,* 21-38. https://ageconsearch.umn.edu/record/119073/?ln=en

Arshad, F. M., Alias, E. F., Noh, K. M., & Tasrif, M. (2011). Food security: self–sufficiency of rice in Malaysia. *International Journal of Management Studies*, *18*(2), 83-100.

Arshad, F. M. (2017). *Food Policy in Malaysia. Reference Module in Food Sciences* (pp. 1-12). http://dx.doi.org/10.1016/B978-0-08-100596-5.21173-6.

Arshad, F. M., Arifin, B., & Tey, Y. S. (2019). Effectiveness of state trading enterprises in achieving food security: Case studies from BERNAS in Malaysia and BULOG in Indonesia. *Center for Indonesian Policy Study,* https://core.ac.uk/download/pdf/287122738.pdf.

Awotide, B. A., Awoyemi, T. T., & Fashogbon, A. (2015). Factors influencing smallholder farmers' participation in cooperative organization in rural Nigeria. *Journal of Economics and Sustainable Development*, *6*(17), 87-96.

Bahri, M. (2017). *Integrating statistical and system dynamics modelling to analyse the impacts of climate change on rice production in West Nusa Tenggara, Indonesia*. [Doctoral thesis, Victoria University of Wellington]. researcharchive.vuw.ac.nz http://hdl.handle.net/10063/6438.

Bala, B. K., Alias, E. F., Arshad, F. M., Noh, K. M., & Hadi, A. H. A. (2014). Modelling of food security in Malaysia. *Simulation Modelling Practice and Theory*, 47, 152-164.

Bala, B. K., Bhuiyan, M. G. K., Alam, M. M., Arshad, F. M., Sidique, S. F., & Alias, E. F. (2017). Modelling of supply chain of rice in Bangladesh. *International Journal of Systems Science: Operations & Logistics*, *4*(2), 181-197. https://doi.org/10.1080/23302674.2016.1179813

Becker, M., Johnson, D. E., Wopereis, M. C., & Sow, A. (2003). Rice yield gaps in irrigated systems along an agro-ecological gradient in West Africa. *Journal of Plant Nutrition and Soil Science*, *166*(1), 61-67.

Bidzakin, J. K., Fialor, S. C., Awunyo-Vitor, D., & Yahaya, I. (2018). Impact of irrigation ecology on rice production efficiency in Ghana. *Advances in Agriculture*, *2018*, 1-10. https://doi.org/10.1155/2018/5287138

Boling, A. A., Tuong, T. P., Van Keulen, H., Bouman, B. A. M., Suganda, H., & Spiertz, J. H. J. (2010). Yield gap of rainfed rice in farmers' fields in Central Java, Indonesia. *Agricultural Systems*, *103*(5), 307-315. https://doi.org/10.1016/j.agsy.2010.02.003

Boretti, A., & Florentine, S. (2019). Atmospheric CO2 concentration and other limiting factors in the growth of C3 and C4 plants. *Plants*, *8*(4), 92. https://doi.org/10.3390/plants804009232.

Cavana, R., & Maani, K. (2000). A methodological framework for integrating systems thinking and system dynamics. *Proceedings of the 18th International Conference of the System Dynamics Society*, 6-10.

Chapman, A. D., Darby, S. E., Hồng, H. M., Tompkins, E. L., & Van, T. P. (2016). Adaptation and development trade-offs: fluvial sediment deposition and the sustainability of rice-cropping in An Giang Province, Mekong Delta. *Climatic Change*, *137*(3), 593-608.

Charles, S. J., Mattee, A. Z., & Msuya-Bengesi, C. P. (2021). Factors affecting interactions between different key actors in improved rice varieties innovation system in the Eastern Zone of Tanzania. *African Journal of Science, Technology, Innovation and Development,* 1-13. https://doi.org/10.1080/20421338.2021.1906522.

Chung, B. (2015). Impacts of liberalizing rice milling sector in Malaysia using system dynamics framework. [Doctoral thesis, University Putra Malaysia]. http://psasir.upm.edu.my/id/eprint/56823/1/IKDPM%202015%201RR.pdf.

Chung, B., Arshad, F. M., Noh, K.M. & Sidique, S. F. (2016), «Cost analysis of rice milling: A case study of 7 rice mills in Malaysia", *Journal of Agribusiness in Developing and Emerging Economies*, 6(2), 173-190. https://doi.org/10.1108/JADEE-05-2014-0019.

Chung, B. (2018). System dynamics modelling and simulation of the Malaysian rice value chain: Effects of the removal of price controls and an import monopoly on rice prices and self-sufficiency levels in Malaysia. *Systems Research and Behavioral Science*, *35*(3), 248-264.

Clapp, J. (2019). *Food self-sufficiency and international trade: a false dichotomy?* Food and Agriculture Organization of the United Nations. https://www.researchgate.net/publication/292315166_Food_Self_Sufficiency_and_International_Trade_A_False_Dichotomy

Cui, J., Huang, G., & Tang, Y. (2009). System dynamic simulation of three crops per year in paddy field. *World. Journal. Model. Simulation*, *5*(2), 144-150.

Dubey, A. N., Verma, S., Goswami, S. P., & Devedee, A. K. (2018). Effect of temperature on different growth stages and physiological process of rice crop-a review. *Bulletin of Environment, Pharmacology and Life Sciences*, *7*(11), 129-136.

Emmy, F. A., Fatimah, M. A., Kusairi, M. N., Muhammad, T., & Setyo, P. (2015). Alternative formula for rice Self-Sufficiency Level (SSL) calculation. *Proceedings of the Second Rice Research Colloquium 2015,* 119-124. Universiti Putra Malaysia, Serdang, Malaysia.

Engku A. E. A. (2013). *MARDI: Three Decades of Achievements in Research and Development*. Malaysian Agricultural Research and Development Institute. www.mardi.gov.my

FAO. (2020). *FAO Statistical Pocketbook 2020.* Food and Agriculture Organization of the United Nations. https://doi.org/978-92-5-108802-9.

FAO. (2015). *FAO Statistical Pocketbook 2015. Food and Agriculture Organization of the United Nations*.

FAOSTAT. (2019). *Food and Agriculture Data.* https.www.fao.org

Firdaus, R. R., Latiff, I. A., & Borkotoky, P. (2012). The impact of climate change towards Malaysian paddy farmers. *Journal of Development and Agricultural Economics*, *5*(2), 57-66.

Fischer, R. A., Byerlee, D., & Edmeades, G. (2014). Crop yields and global food security. *ACIAR: Canberra, ACT*, 8-11.

Fukagawa, N. K., & Ziska, L. H. (2019). Rice: Importance for global nutrition. *Journal of nutritional science and vitaminology*, *65*(Supplement), S2-S3.

GRiSP (2016). *Rice crop proposal version March 3*. http://www.grisp.net/main/summary accessed at 1 April 2016.

Gujja, B., & Thiyagarajan, T. M. Producing more with less: Exploring farm-based approaches to improve productivity and providing options to farmers in adapting to climate change. *Environments: Coping with Adverse Conditions and Creating Opportunities*, 2.

Humphrey, J., & Navas-Alemán, L. (2010). Value chains, donor interventions and poverty reduction: A review of donor practice. *IDS Research Reports*, *2010*(63), 1-106.

International Rice Research Institute (IRRI). (2017). *Yield-paddy*. Retrieved from http://ricestat.irri.org:8080/wrsv3/entrypoint.htm

Johnson, C.L. (2000), “Government intervention in the Muda irrigation scheme, Malaysia: ‘actors’, expectations and outcomes”, *The Geographical Journal*, *166*(3), 192-214.

Khodeir, M. H., & Abdel-Salam, H. (2015). A simulation model for wheat-related policies and food insecurity in Egypt. *System Dynamics Conference*, *1*, 20.

Krishnan, P., Ramakrishnan, B., Reddy, K. R., & Reddy, V. R. (2011). High-temperature effects on rice growth, yield, and grain quality. *Advances in agronomy*, *111*, 87-206. https://doi.org/10.1016/B978-0-12-387689-8.00004-7.

MADA. (2019). Overview of the development of the rice sector of the young area.

https://www.mada.gov.my/wp-content/uploads/2019/09/Pn.-Sakinah-Bt.-Ahmad-Tarmizi.pdf

MADA. (2021) *Unveiling the history of the Muda agricultural development authority: From policy to implementation project*. https://www.mada.gov.my/?page_id=3959&lang=en.

Maertens, M., & Velde, K. V. (2017). Contract-farming in staple food chains: The case of rice in Benin. *World Development*, *95*, 73-87.

Mirimo, D., & Shamsudin, M. N. (2018). Price relations between Malaysia rice sector and selected ASEAN countries. *International Journal of Community Development and Management Studies*, *2*, 131-144.

MOA. (2011). *Agriculture Statistics Handbook, 1980-2010*. Ministry of Agriculture, Malaysia.

Muhammad, S. (2013). Role of BERNAS as government linked company (GLC)–supporting and complementing national (Malaysia) food security food policies. *Journal of Tropical Resources and Sustainable Science (JTRSS)*, *1*(2), 35-41.

Napitupulu, T. A., & Abdurachman, E. (2016). Simulation of rice stock using system dynamics modelling. *2016 11th International Conference on Knowledge, Information and Creativity Support Systems (KICSS)*, 1-6. IEEE.

Ofuoku, A. U., & Agbamu, J. U. (2016). Maize contract farming experience in Delta State, Nigeria. *Journal of Northeast Agricultural University (English Edition)*, *23*(1), 65-73.

Omar, S. C., Shaharudin, A., & Tumin, S. A. (2019). The status of the paddy and rice industry in Malaysia. *Khazanah Research Institute. Kuala Lumpur*.

Parvizian, J., & Karimi-Tabar, A. (2002). State policies on self-sufficiency in agricultural section of Iran. *20th International Conference of the System Dynamics Society*.

PEMANDU. (2010). *Economic transformation programme: A roadmap for Malaysia*. Putrajaya, MY: Performance Management and Delivery Unit, Prime Minister's Department.

Ragasa, C., Lambrecht, I., & Kufoalor, D. S. (2018). Limitations of contract farming as a pro-poor strategy: The case of maize outgrower schemes in upper West Ghana. *World Development*, *102*, 30-56.

Rahim, F. H. A., Abidin, N. Z., & Hawari, N. N. (2017). Analyzing the impact of price subsidy on rice self-sufficiency level in Malaysia: A preliminary finding. *AIP Conference Proceedings*, *1905*(1), 040025). AIP Publishing LLC.

Rahim, F. H. A., Hawari, N. N., & Abidin, N. Z. (2017). Supply and demand of rice in Malaysia: A system dynamics approach. *International. Journal of Supply Chain Management*, *6*, 1-7.

Ramli, N. N., Shamsudin, M. N., Mohamed, Z., & Radam, A. (2012). The impact of fertilizer subsidy on Malaysia paddy/rice industry using a system dynamics approach. *International Journal of Social Science and Humanity*, *2*(3), 213.

Reinker, M., & Gralla, E. (2018). A system dynamics model of the adoption of improved agricultural inputs in Uganda, with insights for systems approaches to development. *Systems*, *6*(3), 1–27. https://doi.org/10.3390/systems6030031

Rittgers, C., & Wahab, A. G. (2017). *Malaysia Grain and Feed Annual*. *GAIN Report*. https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Grain%20and%20Feed%20Annual_Kuala%20Lumpur_Malaysia_3-27-2017.pdf.

Rusli, R., Arshad, F. M., & Ibragimov, A. (2017). The causal structure of paddy deduction system in the MADA granary area: A system dynamics approach. *Economic and*

Technology Management Review, 12(2017), 1-10.

Salman, M. (2010), "Grading systems and rice quality control". In Othman, S., Man, A., Mokhtar, A., Rahman, Z.A., Razak, A.A., Hashim, S. and Said, W. (Eds), *Proceedings of National Rice Conference 2010, Malaysian Agricultural Research and Development Institute, Lumut,* 156-173.

Sapiri, H., Ahmad, N., Aziz, N., & Zainon, F. (2015). Using causal loop diagram in understanding financial activities of Malaysia Pension Fund. *Global Journal of Business and Social Science Review*, *1*(2), 359-364.

Sardjono, W., Christian, L., Juwitasary, H., & Putra, E. P. (2019). Rice Development Availability Model using System Dynamics Method. *International Journal of Recent Technology and Engineering*, 8(3), 2741-2746. https://doi.org/10.35940/ijrte.C3871.098319.

Senge, P. M. (1996). *Leading learning organizations: The bold, the powerful, and the invisible*. Cambridge, MA: Center for Organizational Learning, Massachusetts Institute of Technology.

Senge, P. M. (2006). *The fifth discipline: The art and practice of the learning organization*. Currency.

Siwar, C., Diana, N., Idris, M., Yasar, M., & Morshed, G. (2014). Issues and challenges facing rice production and food security in the granary areas in the east coast economic region (ECER), Malaysia. *Research Journal of Applied Sciences, Engineering and Technology*, *7*(4), 711-722. https://doi.org/10.19026/rjaset.7.307

Sospeter J. Charles, Amon Z. Mattee & Catherine P. Msuya-Bengesi. (2021). Factors affecting interactions between different key actors in improved rice varieties innovation system in the Eastern Zone of Tanzania. *African Journal of Science, Technology, Innovation and Development*, https://doi.org/10.1080/20421338.2021.1906522.

Soullier, G., Moustier, P., & Lançon, F. (2019). Risks of smallholder exclusion from upgrading food chains. *Food Systems at Risk,* 79.

Sterman, J. D. (1991). A skeptic's guide to computer models. In *Managing a nation: The microcomputer software catalog* (2nd ed.), Routledge.

Sterman, J.D. (2004). *Teaching takes off: Flight simulators for management education*. http://web.mit.edu/ jsterman/www/SDG/beergame.html.

Sulistyo, S. R., & Alfa, B. N. (2016). Modeling Indonesia's rice supply and demand using system dynamics. *2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 415-419. IEEE.

Suryani, E., Hendrawan, R. A., Mulyono, T., & Dewi, L. P. (2014). System dynamics model to support rice production and distribution for food security. *Jurnal Teknologi*, *68*(3).

Tanaka, M. C., Fernandes, J., & Bessa, W. M. (2015). Fuzzy Feedback Linearization with Applications to the Control of Mechanical Systems. *DINAME 2015-Proceedings of the XVII International Symposium on Dynamic Problems of Mechanics*.

Trimble, J. (2013). Boundary concepts in system dynamics. *Computer Science,* https://proceedings.systemdynamics.org/2014/proceed/papers/P1175.pdf

Uehara, T., Cordier, M., & Hamaide, B. (2018). Fully dynamic input-output/system dynamics modeling for ecological-economic system analysis. *Sustainability*, *10*(6), 1765.

Vaghefi, N., Shamsudin, M. N., Radam, A., & Rahim, K. A. (2016). Impact of climate change on food security in Malaysia: economic and policy adjustments for rice industry. *Journal of Integrative Environmental Sciences*, *13*(1), 19-35.

Verma, N., & Sinha, A. K. (2020). Modern tools in improving rice production. *Advancement in Crop Improvement Techniques* (pp. 67-75). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-818581-0.00004-8.

Webber, H., Hoffmann, M., & Rezaei, E. E. (2020). Crop models as tools for agroclimatology. *Agroclimatology: Linking Agriculture to Climate*, *60*, 519-546.

Yang, M., Xiao, W., Zhao, Y., Li, X., Huang, Y., Lu, F., Hou, B., & Li, B. (2018). Assessment of potential climate change effects on the rice yield and water footprint in the Nanliujiang catchment, China. *Sustainability*, *10*(2), 242.

Yin, Y., Tang, Q., & Liu, X. (2015). A multi-model analysis of change in potential yield of major crops in China under climate change. *Earth System Dynamics*, *6*(1), 45-59.

Yoshida, S. (1981). *Fundamentals of rice crop science*. International Rice Research Institute, Los Baños, Laguna, 269.

Yoshida, S. (1983). Rice. In Smith, W.H. & Banta, S.J., (Eds.), *Potential productivity of field crops under different environments*. International Rice Research Institute, Los Baños, 103-127.