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TIME SERIES FORECASTING ANALYSIS OF PADDY AND RICE INDUSTRY TOWARDS SUSTAINABLE FOOD SECURITY IN MALAYSIA: A MASS FLOW ANALYSIS

AHMAD ZUBIR IBRAHIM* AND SHARIF SHOFIRUN SHARIF ALI

School of Government, College of Law, Government, and International Studies, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

*Corresponding author: azubir@uum.edu.my

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ABSTRACT

Paddy is a vital crop in Malaysia, and it is essential to ensure that the country's rice production system is efficient, resilient, and has the potential to increase farmers' incomes along the food chain. This article aims to evaluate paddy production to support stockpiles in Malaysia. The study employed time series analysis to assess the projection of the paddy and rice industries in Malaysia, providing significant additional information on the current status of the paddy industry. The Material Flow Analysis (MFA) analysis revealed that the total production from 2004 to 2020 was approximately 57,379 metric tonnes, comprising 74.1% from the granary area and 25.8% from imports. The MFA and Root Mean Square Error (RMSE) models were used to predict rice production in hillside areas until 2030. The results of the MFA revealed that the total paddy produced in Malaysia from 2004 to 2020 was about 38,735.06 metric tonnes. The total paddy production in Malaysia is expected to increase by about 6.3% from 2021 to 2030, while the rice production will increase by about 7% in 2030. This study provides essential information for the government to develop holistic strategies that ensure future food security in Malaysia, particularly in unprecedented circumstances.

Introduction

Food security refers to a state in which all individuals consistently have physical, social, and economic access to adequate, safe, and nutritious food that meets their dietary requirements and preferences for a healthy and active life (FAO, 2003). This concept encompasses various aspects, including proper food handling, storage, and preparation to prevent contamination and ensure the population receives adequate nutrients for a balanced diet. Food plays a crucial role in everyday life, supplying essential nutrients and energy necessary for daily functioning. However, food intake goes beyond simply fulfilling caloric needs. The human body requires a diverse range of nutrients from different food sources to maintain health and prevent diseases associated with nutrient deficiencies. For this reason, food production should prioritise not just the amount of food produced but also the broader goals of food security and nutrition to encourage a well-rounded and healthy diet.

Within the framework of food security, one of the fundamental components is food availability. This element emphasises the importance of maintaining a sufficient food supply. Availability pertains not only to the national level but also to access at the household and individual levels. Ensuring a stable food supply, whether through local production, imports, or food assistance is a central concern in meeting population needs. According to United States Agency for International Development (USAID, 1992), several barriers hinder adequate food availability. These barriers include limited knowledge in agriculture, outdated or insufficient farming technologies, lack of foreign exchange, shortages in agricultural inputs, inaction from relevant departments, natural disasters (including those linked to climate change and disease outbreaks), population growth, and governmental policy decisions. These issues affect food production at the national level, thereby influencing the availability of food for the general population.

The Food and Agriculture Organization (FAO, 2021) projected that by 2023, the global population will reach 7.9 billion, with the majority living in Asia. Since rice serves as the staple food for most Asian countries, the region accounts for over 80% of the global rice output. The world's top four rice producers, China, India, Indonesia, and Vietnam are also the highest rice consumers. As population growth continues, rice demand is expected to rise accordingly. Consequently, Asian nations are consistently working to ensure an adequate rice supply to meet the growing demand for rice.

Malaysia's rice sector is both a cornerstone of national food security and a subject of increasing concern within the scientific literature on agricultural forecasting. Rice remains the staple food for nearly the entire population and supports the livelihoods of about 190,000 paddy farmers (Department of Agriculture, 2023). To safeguard the domestic food supply, the government monitors the Self-Sufficiency Level (SSL), with the current national policy setting ambitious targets for 2030 (Ministry of Agriculture and Food Industry, 2021). Achieving these goals requires an accurate understanding of future production trends, underscoring the need for robust forecasting methods that can capture complex biophysical and socio-economic drivers.

A growing body of empirical work applies time-series forecasting to paddy production in Southeast Asia and other rice-growing regions. Classical statistical approaches such as Autoregressive Integrated Moving Average (ARIMA) and exponential smoothing/Holt-Winters models, remain common due to their ability to model seasonality and short-term trends in yield and production. For example, studies in Thailand and Vietnam have shown that Holt-Winters models can outperform simple linear trend models when predicting medium-term rice output, particularly in the presence of intense seasonal cycles (Montano & Moyon, 2024; Parreño, 2025). In Malaysia, several investigations have adopted similar techniques to estimate future paddy yields and national SSL levels. Ahmad *et al.* (2017), for instance, demonstrated that ARIMA models could reasonably capture inter-annual variation in Malaysian paddy production, while Mgale *et al.* (2021) reported that Holt-Winters exponential smoothing achieved lower Mean Absolute Percentage Error (MAPE) than competing models when forecasting rice output for the Muda Agricultural Development Authority (MADA) region. These findings are reinforced by global assessments that recommend exponential smoothing as a baseline method for staple crop forecasting (Hyndman & Athanasopoulos, 2018).

More recently, Machine Learning (ML) and hybrid approaches, including random forests, Artificial Neural Networks (ANN), and Long Short-Term Memory (LSTM) networks have been explored for agricultural time-series prediction. Studies in India and China, for example, report that LSTM models can better capture non-linear dynamics in rice yield data, outperforming classical statistical models under conditions of climatic variability (Tasneem *et al.*, 2025). In the Malaysian context, however, the application of such advanced models remains limited and typically confined to pilot studies or regional case analyses. Although these techniques show promise in handling the effects of climate change such as heat stress, irregular rainfall, and sea-level rise (Malaysian Meteorological Department, 2009), their integration into national paddy production forecasting frameworks has not yet been systematically tested.

This review of literature highlights several critical research gaps. First, there is a scarcity of studies that combine high-resolution climate projections with economic variables such as fertiliser price shocks linked to global events like the Russia–Ukraine conflict (Ben Hassen & El Bilali, 2022), in a single forecasting model. Second, most Malaysian studies focus on short-term yield forecasting at the regional scale (e.g., MADA or KADA) and rarely attempt national-level forecasting beyond a five-year horizon, despite government SSL targets extending to 2030. Third, validation practices are often weakly documented: Few studies explicitly split historical data into training and hold-out periods or report error metrics beyond MAPE, leaving uncertainty about out-of-sample performance. Finally, while international literature increasingly explores ML and hybrid models to accommodate non-linear climate-production relationships, Malaysia's rice sector has yet to evaluate these techniques systematically against classical time-series benchmarks.

In summary, scientific evidence confirms that time-series forecasting methods ranging from classical ARIMA and Holt-Winters models to modern machine-learning algorithms can meaningfully inform Malaysia's rice production strategy. Yet the Malaysian literature still lacks integrated, long-horizon, climate-sensitive forecasting frameworks, and rigorous validation protocols. Addressing these gaps is essential for policymakers seeking to secure the rice supply amid climate change, global market volatility, and rising input costs.

Therefore, this study seeks to analyse paddy production in support of Malaysia's rice stockpile. Time series analysis has not yet been conducted to forecast trends in the paddy industry and provide critical insights into its current condition. The study aims to support the government in developing comprehensive strategies for the rice sector and forecasting paddy and rice production over two periods; 2004 to 2020, particularly during times of crisis and post-crisis, and 2021 to 2030. Ensuring an efficient and resilient rice production system is crucial for enhancing farmers' incomes throughout the food value chain. At the same time, the agricultural sector must be capable of delivering nutritious and affordable food, aligning with Malaysia's overarching food security goals.

According to the Khazanah Research Institute (2019), although Malaysia is among the largest rice producers, it is still highly dependent on imports to meet market demand. Therefore, analysing the paddy and rice industry in Malaysia using time series forecast analysis is crucial to understanding the current status of the paddy and rice industry and its impact on food security in Malaysia. This analysis provides valuable information for informed action to ensure future food security in Malaysia.

Materials and Methods

Study Area

Malaysia (Figure 1) is one of the countries that has experienced rapid economic, social, and physical development since its independence from British colonial rule. The geographical coordinates of Malaysia are 3°8' N, 101°41' E, and it is located in Southeast Asia. It is located south of Thailand and north of Singapore. Geographically, Malaysia has a land area of 330,803 km^2 and a population of about 33.87 million in 2022. In recent years, Malaysia has evolved from an agriculture-based country to a modern economy with industries such as oil and gas, manufacturing, and electrical-based products. Malaysia comprises 13 states, with major urban regions including Kuala Lumpur, Johor Bahru, Selangor, and Penang Island. The study took place in Malaysia, which is one of the biggest rice producers in Southeast Asia. Furthermore, rice is the crucial staple food in Asia.

Description of the Study Material

This study comprised materials on the paddy and rice industries in Malaysia. The time series data were collected and extracted from the Department of Agriculture of Malaysia and the Department of Statistics Malaysia, covering the period 2004 to 2020 (Table 2), including total paddy production, rice consumption, waste husk generation, the number of farmers, and consumer prices. In 2016, MADA contributed

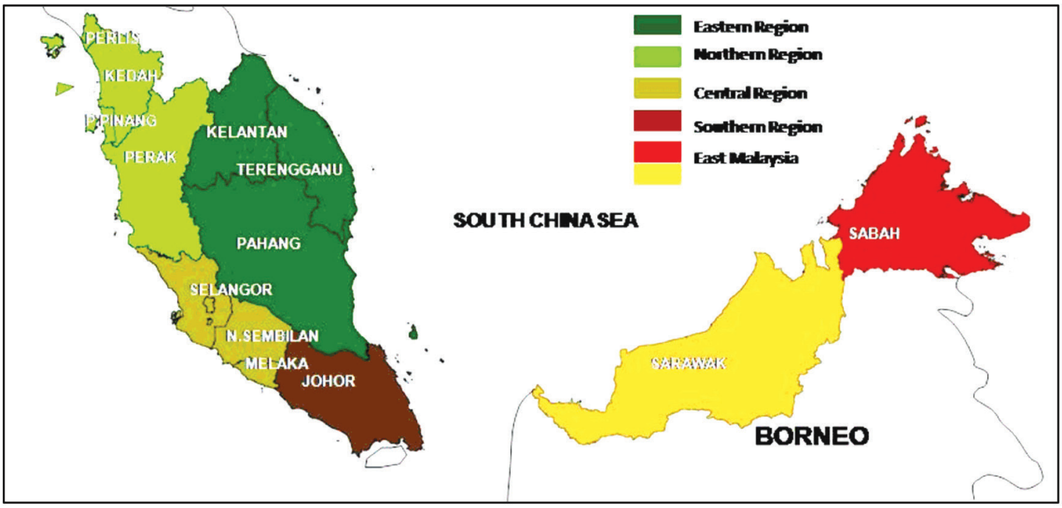


Figure 1: Map of Malaysia

approximately 38.8% or 1,063,247 metric tonnes of paddy production in Malaysia, followed by non-granary areas at 24.8% or 679,288 metric tonnes. Meanwhile, IADA Pekan and IADA Rompin were the least productive of paddy and contributed about 0.5% from both regions.

Table 1 provides an overview of the distribution of paddy farmers across Malaysia by state, highlighting major granary areas, their founding years, and the number of paddy farmers relative to the total farming population. The data shows that key granary states, particularly Kedah under MADA (56,964 paddy farmers), Kelantan under KADA and IADA Kemasin Semerak (23,319 and 5,075, respectively), and Perak under IADA Kerian and IADA Seberang Perak (21,689 and 14,598, respectively) host the majority of Malaysia's paddy farmers. Sarawak's IADA Batang Lupar also records a substantial number (33,595), while Sabah's IADA Kota Belud contributes another 9,986 farmers. In contrast, states without formal granary schemes such as Johor, Melaka, and Negeri Sembilan, show smaller paddy farming populations. Most granary institutions were established between the 1970s and early 1990s, with newer IADAs like those in Pekan, Rompin, Kota Belud, and Batang Lupar created around 2014 to expand production capacity. Overall, the table records a national total of 190,093 paddy farmers out of 466,124 farmers, underscoring the central role of paddy cultivation within Malaysia's agricultural sector and the continued significance of MADA, KADA, and IADA in sustaining national rice production.

In the present study, data were screened and filtered using Microsoft Excel to ensure that only information relevant to the paddy and rice industry was selected for analysis. The data were then organised according to annual production and consumption in Malaysia and subsequently examined using quantitative techniques, including descriptive statistics, Key Performance Indicators (KPIs), trend analysis, and forecasting. The specific forecasting method, for example, exponential smoothing or another appropriate technique, should be stated explicitly. Material Flow Analysis (MFA) was conducted using the open-source software SankeyMATIC diagram (SankeyMATIC, 2023) to map and quantify the movement of paddy and rice along the supply chain, from inputs and production through post-harvest processing, milling, and final consumption, thereby identifying critical points of inefficiency, losses, or surplus that can inform policy for food security. The researcher believes that these combined analyses will provide comprehensive

Table 1: Number of paddy farmers in Malaysia

State	Granary Area	Year of Establishment	Paddy Farmer	Total Farmer
Johor	-	-	941	64,712
Kedah	MADA	1972	56,964	67,091
Kelantan	KADA IADA Kemasin Semerak	1972 1981	23,319	50,424
Melaka	-	-	952	5683
Negeri Sembilan	-	-	1,070	8162
Pahang	IADA Pekan IADA Rompin	2014 2014	5,056	41,384
Perak	IADA Kerian IADA Seberang Perak	1990 1983	21,689	45,048
Perlis	MADA	1972	14,520	16,222
Pulau Pinang	IADA Pulau Pinang	1983	6,272	8998
Selangor	IADA Barat Laut Selangor	1978	9,733	23,430
Terengganu	KETARA	1992	5,996	15,220
Sabah	IADA Kota Belud	2014	9,986	42,842
Sarawak	IADA Batang Lupar	2014	33,595	76,732
Total			**190,093**	**466,124**

Source: Department of Agricultural (2023)

insights into the trends and patterns of the paddy and rice industry, key performance indicators, projections for future production and consumption, and the material flow of paddy and rice in Malaysia, offering valuable guidance for strengthening national food security. The complete flows of the study are shown in Figure 2.

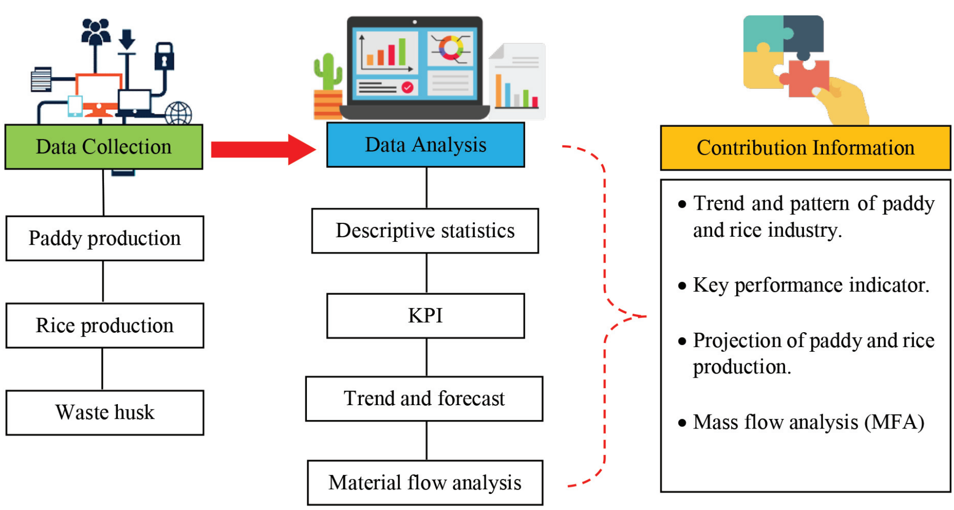


Figure 2: Process of time series forecasting of paddy and rice industry

Analysis data

Descriptive Statistics

In the first analysis, the paddy and rice production in Malaysia was presented in the form of a table and a graph to illustrate the pattern in total paddy and rice production from 2004 until 2020. The analysis is essential, allowing researchers to gain a better understanding of paddy and rice production in Malaysia. The analysis also enables researchers to present the data in a meaningful way and a more straightforward interpretation of the data (Laerd Statistics, 2023). In Malaysia, the regular season for paddy plantation is twice a year. The process involves ploughing, flooding, germination, tillering, flowering, maturing, and harvesting. In the present study, the data were classified as paddy production, rice production, husk rice, and import. The data were measured in metric tonne.

Key Performance Indicator (KPI) Quantification

The section explains the Key Performance Indicators (KPI) of paddy and rice baseline to examine the paddy production per capita, rice production per capita, and rice consumption per person. The KPI quantification is highly influenced by study conducted by Brooks (2023). However, some amendments were made in this study based on data availability and to ensure that the quantification of paddy and rice represents the population in Malaysia. The study concentrates on three indicators in examining the paddy and rice industry in Malaysia such as paddy production per capita, rice production per capita, and rice consumption per person.

Paddy production per capita can be referred to as the whole paddy production by each of farmers in specific year. The calculation is beneficial to understand the overall production of paddy per farmers and providing significant data for government in decision making. The quantification of paddy production per capita can be measured using the equation below:

$$Paddy\ production\ per\ capita = \frac{\sum_{i=1}^{n} Xi\ (paddy\ production)}{\sum_{i=1}^{n} Yi\ (number\ of\ paddy\ farmers)}$$

Xi refers to the total paddy production in each year, while Yi is the number of paddy farmers in each year. Therefore, the total paddy production per capita can be calculated by dividing total paddy production and total population of paddy farmers in each year.

Rice production per capita can be referred to as the total rice production from each farmer in a year. The quantification of rice production per capita is significant to the government to clearly understand the quantity of rice production that can be used in decision-making in supporting food security at the national level. Therefore, the calculation of rice production per capita can be measured using equation below:

$$Rice\ production\ per\ capita = \frac{\sum_{i=1}^{n} Mi\ (rice\ production)}{\sum_{i=1}^{n} Yi\ (number\ of\ paddy\ farmers)}$$

Mi refers to the total rice production in each year, while Yi is the number of paddy farmers. The present study also investigates the rice consumption for each population in Malaysia. Thus, the quantification of rice consumption per person can be calculated using equation below:

$$Rice\ consumption\ per\ person = \frac{\sum_{i=1}^{n} Mi\ (rice\ production)}{\sum_{i=1}^{n} Ri\ (total\ population)}$$

Mi refers to rice consumption per person, while Ri is the number of populations in every year. The determination of rice consumption is vital for measuring the supply and demand of rice in Malaysia. This aspect will ensure the food security as rice is the main food staple in Malaysia. Understanding rice consumption will provide additional information which beneficial for government policy and action for sustainable consumption.

Forecast Analysis

The Excel FORECAST function predicts a value based on existing values along a linear trend. The Microsoft Excel FORECAST family of functions, particularly FORECAST.LINEAR and FORECAST.ETS provides a practical and theoretically robust approach for forecasting paddy production because it operationalises two well-established time-series techniques: Ordinary Least Squares (OLS) linear regression and Holt-Winters exponential smoothing the FORECAST.LINEAR function applies a simple linear regression to capture systematic upward or downward movements in yield or output over time, a method that has long been employed as a baseline in agricultural forecasting to generate quick policy scenarios and to benchmark more complex models (Islam & Huda, 2021).

Meanwhile, the FORECAST.ETS function implements Holt-Winters exponential smoothing (AAA model), which accommodates additive error, trend, and seasonality components and has been widely adopted in rice and paddy studies for medium-term yield and production projections, often performing competitively with Autoregressive Integrated Moving Average (ARIMA) models when assessed using Mean Absolute Percentage Error (MAPE) and other standard metrics (Brunner & Rechberger, 2017; Westbroek *et al.*, 2021). The method's ability to capture the cyclical nature of rice cultivation and adapt to gradual structural changes makes it particularly suited to agricultural time-series data. Empirical studies in agricultural economics have highlighted the practicality of both linear trend analysis and exponential smoothing for forecasting staple crop production, reinforcing that the algorithms embedded in Excel correspond directly to these established techniques and provide an accessible, transparent, and replicable platform for researchers and policy makers who may lack specialised statistical software (Ben Hassen & El Bilali, 2022).

The forecast analysis calculated a new value using the simple straight-line equation:

$$y = a + bx$$

where:

$$a = \bar{y} - b\bar{x}$$

and

$$b = \frac{\Sigma(x - \bar{x})\,(y - \bar{y})}{\Sigma\,(x - \bar{x})^2}$$

The values of x and y are the sample means (the averages) of the known x-values and the known y-values. The known values for this study consist of data on paddy and rice production from 2004 until 2020, while the unknown value is forecasted data from 2021 until 2030. The selected year is made which aligns with Malaysia Food Security Policy Action 2021-2025. For this analysis, data by year were inserted into Excel software. After that, the known data were selected and a function forecast sheet was selected to generate the forecasted unknown data from 2021 until 2030. The confidence interval was set at 95%. The method will generate an information such as smoothing coefficient (alpha, betta, gamma) and error metrics [Mean Absolute Error (MAE), Mean Absolute Scaled Error (MASE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Symmetric Mean Absolute Percentage Error (SMAPE)]. These values were used to determine the accuracy of the forecast analysis.

Material Flow Analysis

Material Flow Analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time (Brunner & Rechberger, 2000). This analysis enables quantification of material flows, starting from the input of materials, transformation process, and generation of outputs. Westbroek *et al.* (2021) explained that MFA is the only tool that can illustrate the complete flow of material in complex systems. The fundamental of MFA is based on a linear relationship, which is restricted to the balance of input and output material in a system. Therefore, the balance of flow is vital for the stability and sustainability of the systems (Islam & Huda, 2019).

As a systematic assessment, three important aspects in the MFA are system, process, and flow. The system is referred to as a group of elements, interactions, and other elements in space and time. A system can also be defined as an area where the study is taking place. The process can be defined as the transformation, transport, or storage of the material, while flow can be defined as the rate of mass flow (Bruner & Rechberger, 2017). The urban population is expected to reach 50% of the global population, where the majority of the urban population is located in Asia and African countries. As a result, a high human population has led to a high demand for food, which significantly affects the sustainability of resource management. Therefore, MFA has become one of the most significant assessment tools that can provide valuable information on food security.

The final objective is to identify the flow of paddy and rice production in two periods of time, which are from 2004 to 2020 and from 2021 to 2030. The comparison of MFA will be discussed to understand the status of paddy and rice production, which is significant for food security in Malaysia. The MFA analysis is portrayed using SankeyMATIC diagram to show the complete flow of paddy and rice production in Malaysia.

Results

The Trend of Paddy and Rice Production in Malaysia

Table 2 demonstrates the inconsistency of paddy and rice production in Malaysia from 2004 to 2020. The big amount of paddy production had generated higher rice and husk production significantly. The result of paddy production showed a fluctuating trend, where the highest paddy production recorded in 2014 was 2,845 metric tonnes compared to other years, while

Table 2: Paddy and rice production in Malaysia

Year	Paddy Production (Metric Tonne)	Average Production (Kg/Hectare)	Rice Production (Metric Tonne)	Rice Husk (Metric Tonne)	Import (Metric Tonne)
2004	2,291	3,434	1,467	824	558
2005	2,314	3,471	1,490	824	585
2006	2,187	3,236	1,407	780	843
2007	2,375	3,514	1,531	844	799
2008	2,353	3,584	1,516	837	1,093
2009	2,511	3,720	1,620	891	1,130
2010	2,465	3,636	1,588	877	935
2011	2,599	3,797	1,675	924	983
2012	2,599	3,797	1,675	924	983
2013	2,604	3,876	1,677	927	853
2014	2,845	4,188	1,835	1,010	863
2015	2,741	4,022	1,767	974	961
2016	2,740	3,978	1,766	974	748
2017	2,571	3,750	1,656	915	726
2018	2,639	3,770	1,700	939	776
2019	2,353	3,501	1,516	837	890
2020	2,356	3,654	1,624	732	1,110

Source: Department of Agricultural (2023) the lowest production was recorded in 2006 with 2,187 metric tonnes. Meanwhile, in the same year, the highest rice production was produced in 2014 with 1,835 metric tonnes while the lowest rice production was in 2006 with 1,407 metric tonnes. The highest rice husk was generated in 2014 with 1,010 metric tonnes, while the lowest rice husk was generated in 2020 with 732 metric tonnes. In terms of import, the highest imported rice was recorded in 2009 and 2020, with total imported rice being 1,130 metric tonnes and 1,110 metric tonnes, respectively. The high import volume of rice in 2008 and 2009 was due to low paddy production, which was influenced by the financial crisis and paddy-related diseases.

Performance of Paddy and Rice Per Capita in Malaysia

This section presents the main results of the performance of paddy per farmer and rice per farmer (paddy production per capita and rice production per capita) as shown in Figure 3. The study revealed that paddy production per farmer is higher than the total across all farmers, particularly from 2014 to 2020. The highest paddy production per farmer (kg) was recorded in 2016 with 14,056 kg per farmer, followed by 2018, when the total paddy production per farmer was 13,647 kg. Furthermore, the study also depicted that the lowest paddy production per farmer was recorded in 2006, with only 7,796 kg of paddy being produced. Meanwhile, the study also found that the highest rice production per capita was recorded in 2015, with total rice production per farmer being about 294.04 kg. Similarly, the lowest rice production per farmer was also recorded in 2006, with total production per farmer being about 190.54 kg.

The study also indicated a negative relationship between total farmers and paddy production per capita. This indicated that although the number of farmers is high, paddy

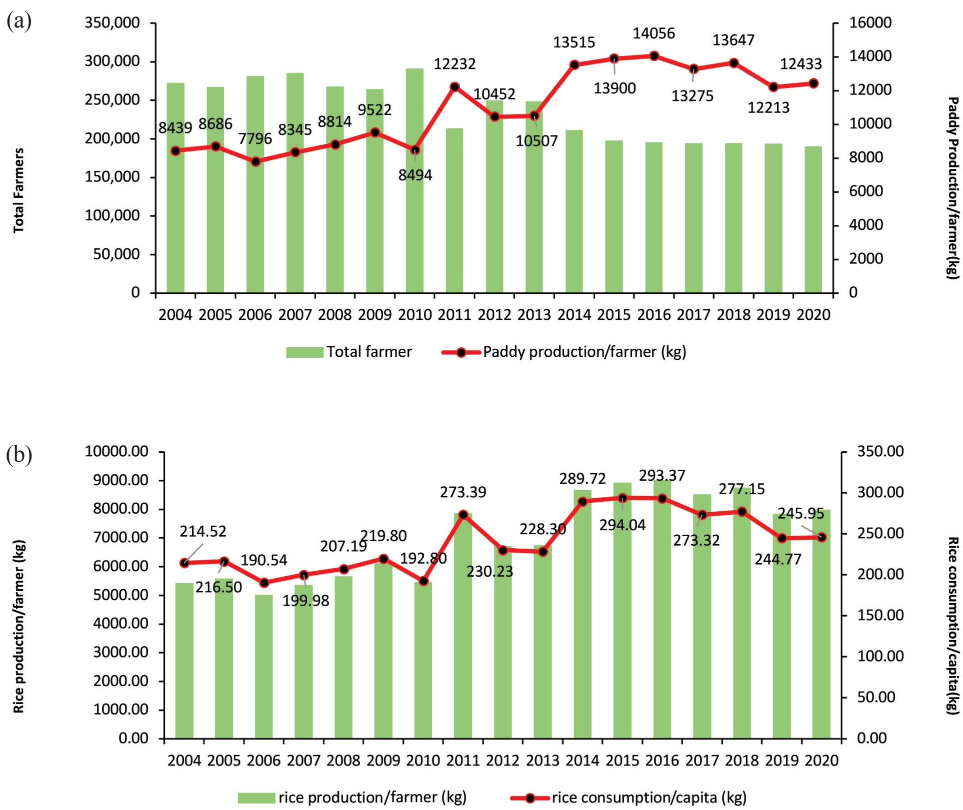


Figure 3: Performance of (a) paddy per farmer and (b) rice per capita

production in a given year is low due to several factors, including paddy diseases and other climate-related issues. In contrast, the rice production per farmer and rice consumption per capita indicated positive relationship from 2004 until 2020. The pattern depicting high production and consumption was influenced by rapid population growth in Malaysia which significantly contributed to the high demand of rice.

Time Series Forecasting Analysis

Time series analysis is a method for analysing a sequence of data points collected over time. Time series analysis helps researchers to understand the underlying causes of trends or systemic patterns over time. Therefore, time series analysis was applied in this study to investigate the trends and changes in the paddy and rice industry in Malaysia. The result depicted that the smoothing coefficient and error metrics were various. The smoothing coefficient is measured between 0 and 1. According to Nugus (2009), the value between 0.05 and 0.10 indicates a high degree of smoothing, while a high coefficient value results in less smoothing. The alpha value for paddy production, rice production, and waste husk indicated a high degree of smoothing, while rice consumption and rice import indicated a lower degree of smoothing (0.90). The Beta and Gamma values showed a high coefficient for trend and seasonality smoothing, with both values indicating 0.00 for each parameter, as displayed in Table 3.

The forecasting model was based on historical data which can be used as an indicator of the forecast accuracy. The forecasting model will indicate the accuracy value in percentage (%). The value close to 0% is considered highly accurate, while a value greater than 100% is defined as over forecasting. An error metric of the paddy and rice industry in Malaysia indicated that the model of Symmetric Mean Absolute Percentage Error (SMAPE) is significantly accurate compared to other models such as MASE, MAE, and RMSE. The SMAPE indicated value of paddy production as 0.07%, rice production (0.06%), rice consumption (0.13%), rice import (0.14%), and waste husk (0.08%). In contrast, the model of MAE and RMSE indicated value greater than 0% for all variables. The MAE of paddy production was indicated at 168.47%, rice production (97.31%), rice consumption (119.85%), rice import (119.93%), and waste husk (74.10%). The RMSE of paddy production was depicted at 202.43%, rice production (115.28%), rice consumption (140.50%), rice import (140.38%), and waste husk (97.87%).

Historical data covering the whole period of 2004-2020 were first divided into two distinct subsets to enable an out-of-sample assessment of forecast accuracy. The training set comprised observations from 2004 to 2016, which were used to estimate the model parameters and generate forecasts for paddy and rice production. The validation (or hold-out) set consisted of the subsequent observations from 2017 to 2020,

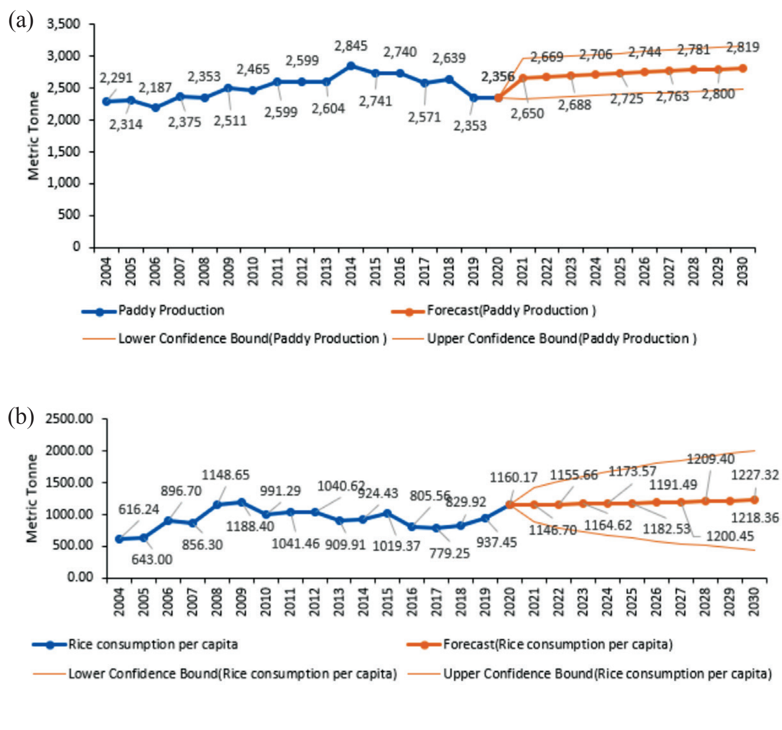
Table 3: Forecasting analysis of paddy and rice in Malaysia

Statistics	Paddy Production	Rice Production	Rice Consumption	Rice Import	Waste Husk
Alpha	0.10	0.10	0.90	0.90	0.10
Beta	0.00	0.00	0.00	0.00	0.00
Gamma	0.00	0.00	0.00	0.00	0.00
MASE	1.78	1.55	1.15	1.15	2.35
SMAPE	0.07	0.06	0.13	0.14	0.08
MAE	168.47	97.31	119.85	119.93	74.19
RMSE	202.43	115.28	140.50	140.38	97.87

which were not included in the model fitting process and were used exclusively to evaluate predictive performance.

Using these hold-out years, forecast accuracy was assessed with several standard error metrics. Among these, the SMAPE proved the most reliable, with values close to zero for paddy production (0.07%), rice production (0.06%), rice consumption (0.13%), rice import (0.14%), and waste husk (0.08%), indicating very high predictive accuracy. In contrast, the MAE and RMSE recorded substantially higher percentage values for all variables (e.g., MAE of paddy production 168.47% and RMSE 202.43%), suggesting that these metrics are less suitable for evaluating percentage-based forecast performance in this context. The use of a hold-out validation period (2017 to 2020), therefore, provides a robust empirical basis for concluding that the SMAPE statistic offers the most meaningful measure of the model's forecasting accuracy for Malaysia's paddy and rice industry.

Meanwhile, paddy production in Malaysia is anticipated to increase 19.65% from 2020 to 2030, with the highest production at 2,819 metric tonnes, as shown in Figure 4 (a). In the same period, rice production is also expected to increase by 14.77% with the highest production linearly recorded in 2030 compared to other years [Figure 4 (c)]. Rice imports are also anticipated to increase slowly at pace 6.38% from 2020 until 2030 [Figure 4 (d)]. The slow increase is likely influenced by technological advancements and a steady rise in paddy and rice production. Furthermore, rice consumption is also expected to increase due to high population, particularly in urban regions, slowly. The rice consumption is anticipated to achieve a level of 1,227.32 metric tonnes with an increment of about 5.78% from 2020 to 2030 [Figure 4 (b)]. The waste husk is also expected to increase in line with paddy and rice production in Malaysia steadily. The waste husk is expected to generate about 954.40 metric tonnes in 2030 with an increase of about 30.3% from 2020 to 2030 [Figure 4 (e)].



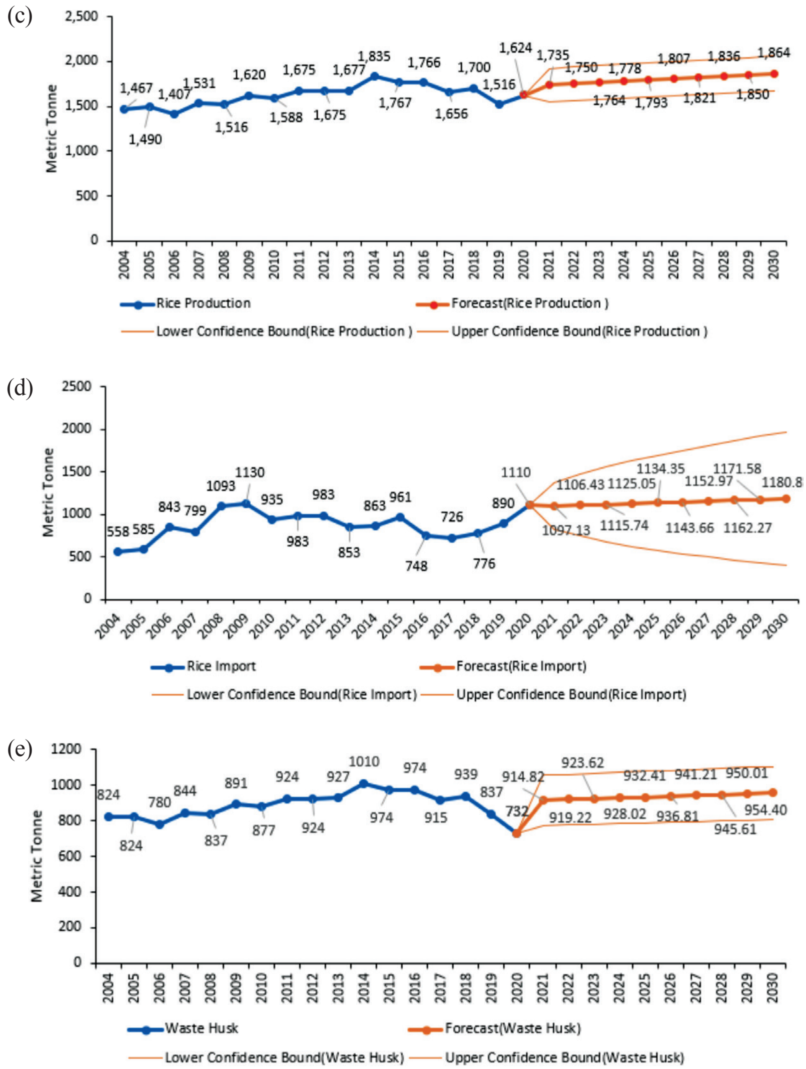


Figure 4: Forecast analysis of paddy and rice industry in Malaysia

Material Flow Analysis (MFA)

The MFA analysis revealed that total paddy production in 2004 to 2020 was about 57,379 metric tonnes, comprising 74.1% from the granary area and 25.8% from imports. Rice production comprises 27,510 metric tonnes or 64.6% and waste generated (husk) comprising 35.3%, as displayed in Figure 5. The study divided MFA into three phases. The study revealed that Phase 2 (2010 to 2015) has indicated high performance (10,217 metric tonnes of rice, 5,636 metric tonnes husk) followed by Phase 1 (2004 to 2009) with 9,031 metric tonnes of rice and 5,000 metric tonnes of husk, while Phase 3 (2016 to 2020) indicated the lowest performance of rice and husk with 8,262 metric tonnes and 4,397 metric tonnes, respectively.

The study also predicted the performance of paddy and rice production from 2021 until 2030 and revealed that total production is expected to be at a level of 38,735.06 metric tonnes. Based on this figure, paddy production from the granary area will achieve 42,543 metric tonnes (70.5%) while imports will settle at 11,390.06 (29.4%). In the same period, rice production is expected to achieve at 17,999 metric tonnes (65.8%) while waste husk will be produced at 9,346.13 metric tonnes (34.1%). From 2012 to 2015 (Phase 4), the performance of rice production will be settled at 8,820 metric tonnes while waste husk will be generated at 4,618.09 metric tonnes. At the last phase (2026 to 2030), the performance of rice production is expected to reach 9,179 metric tonnes and 4,728.04 metric tonnes of rice husk will be generated.

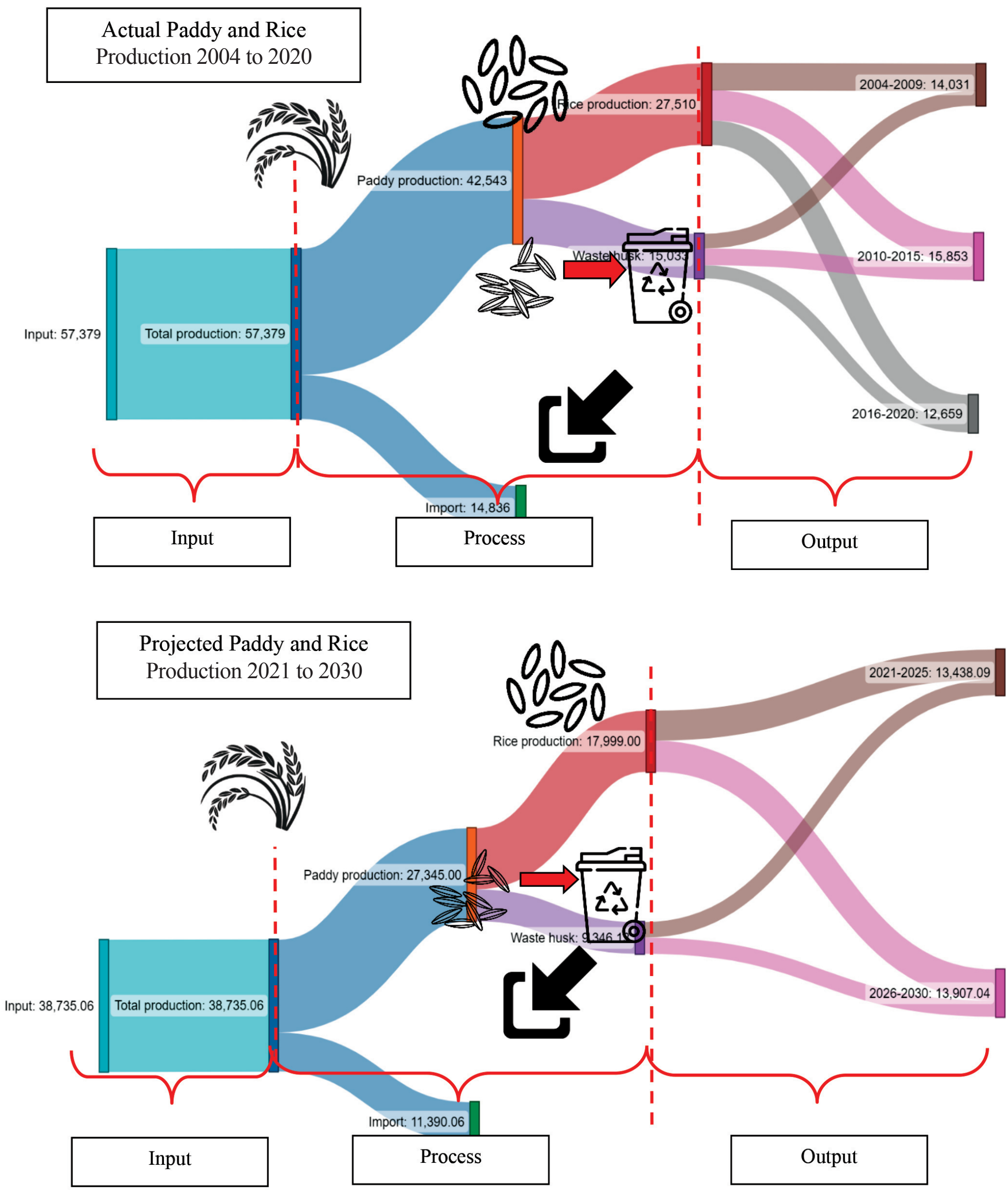


Figure 5: SankeyMATIC diagram of paddy and rice production 2004 to 2030

Discussion

The present forecast analysis projects that Malaysia's paddy production must increase by 14.77% by 2030 to sustain a national rice Self-Sufficiency Level (SSL) of about 70%, with the remaining 6.38% of consumption continuing to be met through imports during 2020 to 2030. These findings are broadly consistent with earlier national policy targets and independent research. For instance, the Ministry of Agriculture and Food Security (MAFS, 2021) set an SSL target of 75% by 2025 under the National Agro-food Policy 2.0 (NAP 2.0), while the Food and Agriculture Organization (FAO, 2021) similarly highlighted Malaysia's need to reduce reliance on imports to safeguard food security.

Compared with historical analyses, the current projection of a 14.77% production increase is moderately higher than the 10% to 12% production growth projected by Arshad and Shamsudin (2014) for the decade ending 2025. This difference may reflect recent policy reforms and the accelerated adoption of digital technologies, precision farming, and irrigation innovations, which have been identified as key drivers of yield improvement (Ali *et al.*, 2020; Hashim *et al.*, 2022). Moreover, the finding that imports will remain necessary, albeit at a low 6.38% echoes the conclusion of Hassan and Kam (2022) that Malaysia's domestic production alone is unlikely to meet total demand given land constraints and climate variability.

The MFA conducted in this study complements these forecasts by tracing the balance of inputs and outputs across the paddy supply chain. This approach highlights where inefficiencies and post-harvest losses occur, strengthening the argument of Ben Hassen and El Bilali (2022) that reducing systemic losses is as critical as expanding cultivated area in improving national food security. Together, these results underscore that while Malaysia's food-production transformation has achieved notable progress, sustained investments in technology, irrigation efficiency, and climate-resilient practices remain essential to achieve the long-term SSL targets beyond 2030.

However, changes in rainfall patterns, especially extreme weather events such as droughts and floods have a significant long-term impact on paddy production in Malaysia. The temperature and rainfall trends reported by the Malaysian Meteorological Department (2025) show apparent long-term climate shifts that directly affect paddy production in Malaysia. Mean temperatures in Sarawak, Peninsular Malaysia, and Sabah have been rising steadily by 0.013°C to 0.024°C per year, creating hotter conditions that increase evapotranspiration, reduce soil moisture, and shorten the grain-filling period, ultimately lowering rice yield and quality. Higher temperatures, especially above 33°C during the flowering stage, also increase the risk of heat stress and spikelet sterility. Rainfall patterns, meanwhile, show an overall increase but with high variability, including intense rainfall peaks, inconsistent distribution, and occasional dry spells. These fluctuations can cause flooding, delays in land preparation, seedling damage, and reduced irrigation water availability, especially in reservoir-dependent granary areas such as MADA, IADA Kerian, and KADA.

Combined, the warming climate and unstable rainfall patterns are amplifying production risks, disrupting established cropping calendars, and increasing pest and disease outbreaks across major rice-growing regions. If not addressed, these climate-induced stresses will undermine Malaysia's rice self-sufficiency goals and threaten farmers' livelihoods. Therefore, adaptive strategies such as adopting heat- and flood-tolerant rice varieties, upgrading irrigation and drainage systems, and using climate-informed planting schedules are essential to safeguard the long-term sustainability and resilience of the national paddy sector.

Droughts can lead to water scarcity and impact the growth and development of paddy crops, while floods can cause significant damage to crops and infrastructure, disrupting the entire agricultural ecosystem. The unpredictability of these events makes the already difficult task of rice cultivation even more complex, underscoring the need for farmers and policymakers to develop resilient strategies to mitigate their impacts.

Thus, Malaysia needs to prioritise research into and the introduction of new crop varieties resilient to changing environmental conditions. These new varieties could have traits such as heat tolerance, pest resistance, and efficient water utilisation, making them better suited to meet the challenges of climate change. Additionally, investments in sustainable agricultural practices such as precision agriculture and advanced water management techniques are crucial for mitigating the adverse effects of climate change on paddy production. Precision agriculture technologies enable optimised resource utilisation, increased productivity, and a reduced environmental footprint. At the same time, advanced water management techniques can help conserve water resources and enhance the resilience of rice cultivation amid changing rainfall patterns.

Conclusion

This study focused solely on paddy and rice production as key drivers of Malaysia's food security, but future research should expand to examine additional factors such as community attitudes, weather and cropping patterns, and trade dynamics, as these variables influence production and consumption in complex ways. Strengthening the paddy sector requires deeper analysis of climate-related challenges, particularly rising temperatures and inconsistent rainfall, alongside the development of adaptive strategies such as improved crop varieties and sustainable farming practices. Empowering farmers through training in crop management, pest control, and soil fertility, supported by policies that reduce input costs and incentivise environmentally friendly practices can further enhance productivity. At the same time, investments in rural infrastructure such as roads, storage, and market linkages are crucial to improving market access, minimising post-harvest losses, and raising farmer incomes. Overall, integrated efforts combining technology adoption, farmer capacity building, supportive policies, and infrastructure development are essential to strengthening paddy production and ensuring long-term national food security.

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Conflict of Interest Statement

The authors disclosed any conflict of interest.

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