WATER'S ROLE IN ENSURING FOOD SECURITY: AN ANALYSIS OF MALAYSIA FROM 1991 TO 2020

BY

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DECLARATION

We hereby declare that:

(1) This undergraduate FYP is the end result of our own work and that due acknowledgement has been given in the references to ALL sources of information be they printed, electronic, or personal.

(2) No portion of this FYP has been submitted in support of any application for any other degree or qualification of this or any other university, or other institutes of learning.

(3) Equal contribution has been made by each group member in completing the FYP.

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey Fuller
ARDL	Autoregressive Distributed Lag Model
CEO	Chief Executive Officer
CO2	Carbon Dioxide
CUSUM	Cumulative Sum of recursive residuals test
ECM	Error Correction Model
GDP	Gross Domestic Product
GFSI	Global Food Security Index
MADA	Muda Agricultural Development Authority
MT	Metric Tons
NGO	Non-profitable Organization
O2	Oxygen Gas
OLS	Ordinary Least Square
SSL	Self-Sufficiency Level

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PREFACE

Food security being the most prominent element is shaping the well-being of individuals, communities, and nations. Food insecurity poses a multitude of challenges ranging from malnutrition, which particularly affects children to intensify health risks such as diabetes and obesity. Moreover, food insecurity has economic consequences, reducing productivity and income, and extending poverty cycles. It worsens social disparities, disproportionately affecting vulnerable groups, and increases existing inequalities. In addition, the stress of uncertain food availability also worsens mental health issues for affected individuals and families.

In Malaysia, this country celebrates a rich culture and vibrant heritage, the issue of food security holds particular significance. In the context of rapid urbanization, environmental pressures, and socio economic transformation, ensuring access to safe, nutritious, and sufficient food for all Malaysians emerges as a top priority. Providing that Malaysia is known for importing about 70% of food to meet domestic demand, as the country has rice self-insufficiency.

Water is undeniably one of the most critical resources for sustaining life on our planet. It is a vital component of ecosystems, and a fundamental necessity for human survival. Understanding the entangled relationship between water and food security has never been more crucial. At its core, this research seeks to go beyond surface-level assessments and delve into the other causes of food insecurity in Malaysia. By interrogating issues such as water resources with its diverse agricultural landscape and reliance on water for irrigation and production along with other factors such as carbon dioxide emission, population growth, and economic growth. Researchers in this study aimed to provide insights that can inform interventions aimed at strengthening Malaysia's food security system.

ABSTRACT

Food security has been a prominent economic issue in the world which is gradually gaining global attention, especially climate change, population growth and socio-economic disparities has been a global challenge these days. Undoubtedly food security has emerged as a pressing issue worldwide. The COVID-19 pandemic has further intensified existing vulnerabilities in food systems, highlighting the urgent need for resilient and sustainable approaches to ensure adequate food supply for all. This study aims to analyze the relationship between water resources, economic growth (economical aspect), population growth (social aspect), carbon dioxide emission (environmental aspect) and food security in Malaysia over the period from 1991 to 2020. Moreover, there are 3 prominent theories supporting our study, namely, Keynesian Theory, Neo-Malthusian Theory, and Photosynthesis Theory. Water resources will serve as our focus in this study. Data of all independent variables was collected from international sources - World Bank Data. Statistical analysis including Unit Root Test, ARDL Cointegration Bounds Test, Error Correction Model, ARCH Test, LM Test, CUSUM Test, VIF Test, and Normality Test was employed in this study. The findings indicate a significant positive correlation between water resources and food security indicators in Malaysia over the period of 1991 - 2020.

CHAPTER 1: RESEARCH OVERVIEW

1.0 Introduction

This chapter is divided into a few major sections. Started with the research background of food security which include the view of food security and 1991-2020 Malaysia's past 3 decades' food security issues. Followed by problem statements that are prompt to be addressed. In the continuous section, this chapter includes the research objectives and questions are included in the subsequent part. The significance study and scope of study of this research was also included. Lastly, the chapter ends with the organisation of the chapter.

1.1 Research Background

The concept of food security was introduced during the early 1970's in response to the global food crisis, the concept primarily emphasized on ensuring the availability of food as well as stabilizing its prices (Peng & Berry, 2019) due to scarcity of the global grain market leaving commodity prices at a volatile state, causing the disease of famine across nations in Asia and Africa (De Oliveira Veras et al., 2021). Since 2012, the introduction of the Sustainable Development Goals (SDGs) 2030 has incorporated the objective of eliminating hunger, achieving food security, and enhancing nutritional standards as the second goal, thereby recognizing the significance of food security (Echendu, 2022). According to the latest improved definition which has accepted and received approval from the 1996 World Food Summit (WFS); claims that food security requires a consistent enjoyable access to safe and nutritious food in order to foster individual's normal growth, development as well as a vibrant and healthy lifestyle as defined by the Food and Agriculture Organization of the United Nations (FAO) (1996). Food security's definition consists of the elements of food availability, food accessibility, utilization and stability of food as introduced by the World Food Summit in 1996, constitute the four pillars of food security (FAO, 1996). Hence, food security in this paper refers to the state where every individual, without exception, has consistent and unrestricted availability, affordability, and accessibility to a sufficient supply of safe, nutritious food that caters to their daily dietary requirements and personal food choices, ensuring their overall wellbeing and active lifestyle (Khoso, 2022).

Based on Statista (2022), there is a global food surplus with a 2.5 billion metric tonnes of food consumption per year with a 4 billion metric tonnes of food production per year in 2021. However, "UN Report: Global Hunger" (2022) reported that on an individual level, only 70% of the world population gained consistent access to food for basic energy needs, given a surplus of global food production. World Bank Group (2023) further added that 9.2% of the global population has experienced hunger. Baer-Nawrocka and Sadowski (2019) on the other hand stated that the domestic supply acquired to ensure food supply varies across nations. Wealthy countries like North America, Australia, Kazakhstan and New Zealand that have advantageous land for agriculture, domestic production is an important foundation for food security. Conversely, it has a higher production intensity in European countries that have relatively small areas of arable land per capita. In North Africa, several South America and Middle Eastern countries that are net importers of food products, their food security is ensured through international trading. Whereas in Sub-Saharan and Central Asia, these countries are badly affected by problematic food situations. Mahmood, Rajaram, & Guinto (2022) and Kakaei et al. (2022) added that developing countries that are highly dependent on food trade, their food security is more vulnerable to major world events such as the COVID-19 Pandemic.

Currently, the food security in Malaysia is not ensured with domestic production. It is evident that Malaysia's domestic food production is unable to meet the domestic food demand (Dardak, 2020). The insufficiency of food production is reflected by the rice Self-Sufficiency Level (<100%), given rice is the main staple diet in Malaysia (Firdaus et al., 2020). Omar et al. (2019) stated that Malaysia's Rice Self-Sufficiency Level (SSL) is reported at 69% which falls behind Philippines (93%), Indonesia (97%) [Figure 1]. At the same time, Vietnam, Thailand and Myanmar are experiencing a production surplus of more than 200% of SSL. In Malaysia, there is a significant increase in the consumption of rice since 2019; from 2.75 million MT to 2.9 million MT in 2022 (Dorairaj & Govender, 2023). However, the annual production of rice in 2021 is at 1.68 million MT (Statista, 2023; *Malaysia: Rice Production Volume | Statista*, 2023). In accordance with Clapp (2017), when a country is not able to achieve self-sufficiency due to low domestic production, trade is utilized to enhance food resources in order to meet domestic demand. As a result, around 30% of the rice consumed by Malaysia is imported from neighbouring countries (*Annual Rice Consumption in Malaysia 2019-2024*, 2023; *Malaysia: Rice Production Volume*, 2023).

Furthermore, over the time span of 28 years (1987 -2015), there is a significant increase in Malaysia's agricultural commodities import from 7.3% to 13.7% in order to meet domestic demand (Department of Statistic Malaysia, 2022). There is a report of RM51.4 billion of Malaysia's food imports in 2019, RM55.4 billion in 2020 and RM63.7 billion in 2021 (Department of Statistic Malaysia, 2022). In 2020, it is evident that Malaysia accounted for 60% of food imports, mainly fruits (Mango from Thailand; coconut from India), vegetables, livestock (mutton from Australia; beef from Indonesia) and fisheries products (Hazim, 2022).

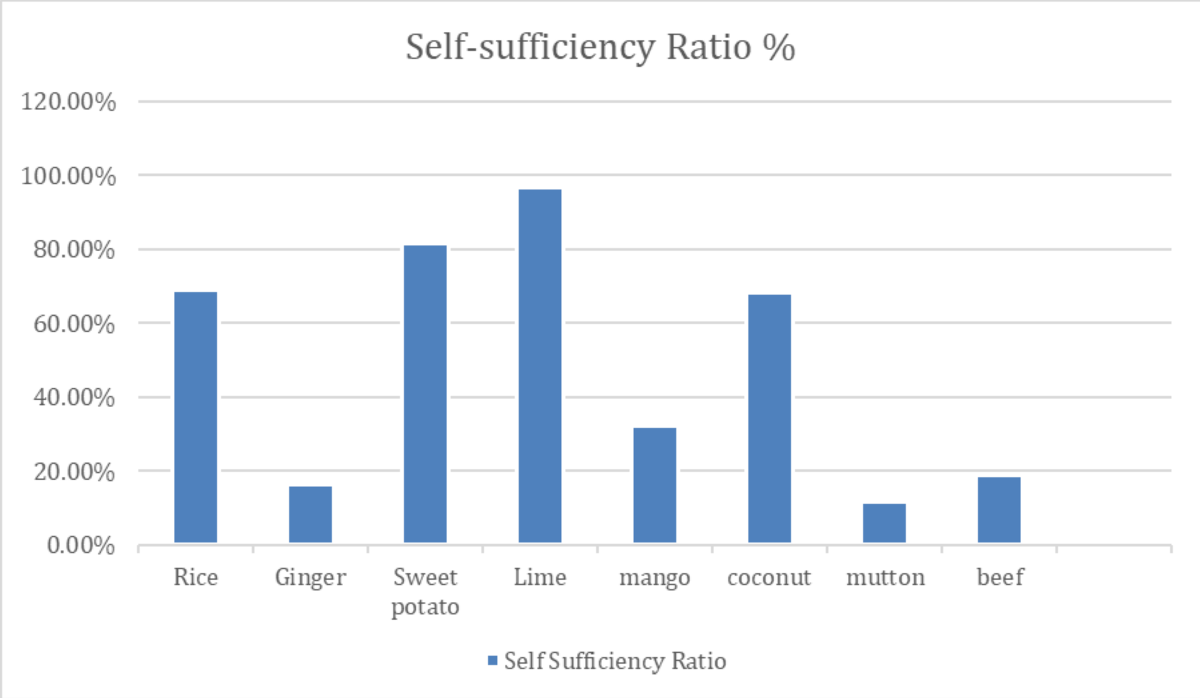


Figure 1: Malaysia Self Sufficiency Ratio in 2019

Source: Department of Statistics Malaysia (2020), Hanif (2023) and Amin (2022)

Population upsurge in many countries, particularly in the developing countries such as Malaysia, is posing a dire threat to food security (Husni, 2017). According to data from the United Nations, the total population of Malaysia has been increasing in the past three decades, from 1991 to 2020, from 18 million to 33 million (Malaysia Population Growth Rate 1950- 2023, 2024). Meanwhile, Malaysia's growth rate shows a downward trend from 2.86% in 1991 to 1.21% in 2020. The increase in total population is parallel with the demand and consumption of rice. Along with increasing population, we can only meet 70% of local demand for rice (Firdaus et al., 2020). Even with 36.3 billion (1980-2021) subsidies, paddy and rice continue to grow very slowly (Murni, 2023).

Malaysia's economic growth hit the lowest in nearly two years due to sliding exports and a global slowdown. The latest released data from the central bank shows that second-quarter annual growth in 2023 came in at 2.9% (Chu & Ananthalakshmi, 2023). The expansion was the slowest pace since the third quarter of 2021 when the economy contracted by 4.2% due to covid-19 pandemic and was lower than the 5.6% growth in the first quarter of the year (Chu & Ananthalakshmi, 2023).

Carbon footprint in Malaysia increased by 221% during the period from 1990 to 2004 and the country has been placed in the list of 30 biggest greenhouse gas emitters in the world (Alam et al., 2019). Recently, carbon footprint in Malaysia is increasing at an increasing rate in 2020, from existing 225.1 kilotons (2017) to 245.1 kilotons (2020). While carbon footprint is the major contributor to global warming, it has led to extreme weather. For instance, in 2023, Malaysia is reported experiencing drier weather than in recent years during the Southwest Monsoon season, which defines a technical heat wave, or level 2 alert, as temperatures of between 37 - 40 degree Celsius for at least three straight days (Cue, 2023).

Floods are common in Malaysia during the annual Northeast Monsoon season between October and March due to heavy rain (Harris & Hussain, 2023). Usually, during the northeast monsoon season, only the east coast of the peninsula will be impacted by heavy rain (Yusof, 2021). However, in 2021, the center and the west coast of the peninsula have also been severely affected and resulting in floods that happen once in a hundred years (Yusof, 2021). The number of flood incidents reported in 2021 was 1,057 between 2017 and 2021.

Water resource is an essential component used in agriculture food production whereby approximately 70% of the total global freshwater withdrawals are allocated to irrigation, simultaneously supporting around 40% of the global food production (Zhang et al., 2022). According to Kazanci, (2021), Malaysia as a water-rich country, water sources mainly come from withdrawal of surface water (80.8%) which is mainly from rivers. However, data released by the Department of Environment (DoE) in 2017 showed that there were 579 rivers in 2008, but currently, there are only 477 rivers (Goi, 2020), indicating a reduce of water resource. Despite Malaysia's abundance of water resources (Kazanci, 2021), the country is facing the problem of the presence of severely polluted water, which rank at the highest level of agriculture water risk. In 2016, A total of 219 (46%) of the 477 supervised rivers were categorized as clean, 207 (43%) were slightly polluted and 51 (10%) were polluted (Goi, 2020).

As food security is interlinking with environmental, social and economic aspects. Therefore, this research will conduct a comprehensive analysis of factors affecting food security in Malaysia by considering all these three aspects. Thereby, this research can be a valuable reference to policymakers in strategies designations for the prevention and adaptation of the food security crisis as well as enhancing food security in Malaysia.

1.2 Problem Statement

Despite the prevalence of undernourishment rate among Malaysians declining (Ministry of Agriculture and Food Security Malaysia, 2023), the nation currently experienced a minor increment in Global Hunger Index (2022) from 10.9 (2014) to 12.5 (2022). Furthermore, there is evidence that shows an evident increase in the coexistence of child stunting and obesity. For instance, the percentage of children under 5 who were underweight and stunted went from 11.6 and 16.6%, respectively, in 2011 to 14.1 and 21.8%, respectively, in 2019 (Lee et al., 2022). Based on the 4 criteria of food security: Availability, Accessibility, Utilization, and Stability, Malaysia is in 41st rank on the Global Security Food Initiative, which is behind Singapore, which came in 28th (Hazim, 2022). The country scored poorly in "availability" dimension which is 59.5 out of 100 (*Global Food Security Index (GFSI)*, 2022). It is primarily because of the significantly low rating in one of its indicators, specifically food supply sufficiency, which only achieved a score of 27.2 out of 100 on the index (*Global Food Security Index (GFSI)*, 2022).

Malaysia's food production and supply is experiencing a significant decline that is caused by a severe climate change (Entezari et al., 2021). It is evident that carbon footprint causes extreme weather that leads to natural disasters such as flood and drought that often leads to food production disruption in Malaysia. The number of flood incidents reported in 2021 was 1,057 between 2017 and 2021, a total of 40,828.28 hectares of paddy fields nationwide were destroyed by floodwaters while another 9,336.45 hectares were damaged due to drought (Kamarudin & Said, 2021). Consequently, the actual farm yields of rice in Malaysia vary from 3-5 tons per hectare, where potential yield is 7.2 tons, indicating the inefficiency in rice production. Furthermore, according to Shukla et al. (2019) and FAO (2016), Malaysia as a tropical region, extreme weather caused by increasing carbon footprint can pose a significant impact on the agriculture and livestock production sectors, leading to food security issues.

Besides, it is evident that water resources serve as pivotal medium for the agricultural industry to cultivate food production. However, Malaysia's prospects for maintaining food security through its domestic agricultural production are becoming increasingly grim due to the escalating issue of water pollution within the country (Fazaniza, 2022). According to Global Food Security Index, the sustainability and adaptation dimension suffered from a low score (46.6/100) largely due to the inadequate rating of one of its indicators, specifically water resources, which only achieved a score of 27.6 out of 100 on the index. As reported by Goi (2020), there are 10% the river's water quality in Malaysia was categorized as polluted and 43% is slightly polluted. In accordance with CDC (2016), contaminated water used in crop production potentially transmit bacteria, viruses, and parasites to crops and livestock. This can possibly be threatening to human health as it has violated the food safety with the inclusion of contaminated residues in the crops. Hence, this has limited the safe and usable water resources that can be utilize for irrigation purpose. This issue has brought upon a plethora of past studies of water and food security in other countries namely, China (Wang et al., 2017; Wang et al., 2019), South Africa (Gulati et al., 2013; Ingutia & Sumelius, 2022; Boateng et al., 2022), Central Africa (Nounkeu et al., 2021). However, this variable is rarely added in the studies of food security issues in Malaysia, despite water being the paramount factor in addressing the food security issue.

Since rice is the staple food in Malaysia, its low production has reflected the insufficient food production in the country. The current rice production only able to satisfy only 70% of its population demand, where 30% of Malaysians rice consumption depends on imports (Firdaus et al., 2020). Based on Udmale et al (2020), insufficient local food production has turned a nation to be highly dependent on food import, exposing the country's vulnerability to global food supply chain disruption. Referring to the most recent global supply chain disruption which is the pandemic of Covid-19, various countries have imposed export restrictions on food in order to prevent the countries' local food shortage and insulate their domestic market from world market price volatility (Falkendal et al., 2021). For instance, Malaysia's main rice import country Vietnam and Thailand have imposed white rice export ban in response to the Covid-19

(Schmidt et al., 2021). Likewise, despite India's large rice stocks and no formal export ban, logistics challenges due to shelter-in-place policies to curb COVID-19 contagion substantially delayed rice shipments and supply chain logistics (Schmidt et al., 2021).

As a result, Malaysia's food availability is highly affected, caused the food price significantly increased. It is reported by Khalid (2022) that in 2021 post COVID-19, Malaysia has suffered from the increasing global food price which leads to 6.1% surged in Malaysia's food price. According to the survey conducted by the World Bank, 17 percent of low-income households were at risk of poor food security in 2021, mainly because global food inflation has reduced their food affordability (Financial Literacy for Youths (FLY), 2022). This phenomenon has caused many individuals to choose alternative food sources where the price is cheaper along with lower nutritional value, causing the health and nutritional value to further deteriorate. According to Tan et al. (2023), heavy reliance on agricultural imports in Malaysia is indeed not a sustainable measure to combat the potential upcoming health crisis.

Additionally, if the event of climate change pertains, or worsens, individuals who heavily relied on agricultural activities for their livelihoods would be affected the most by poverty, therefore, threatening their food security (Mahmood et al., 2022). Consequently, as more individuals will dwell into poverty, it is hardly possible that citizens are able to afford the basic necessities (Sundaram and Tan, 2019). On the other hand, the undernourishment rate will continue to spike with insufficient food produced to meet the demand of the population. In addition, Malaysia will once again become the next victim of the disruption of the international food supply chain, due to the heavy reliance on food imports.

This issue had brought the attention of government entities and the non-profitable organization (NGO) where policies concerning food supply were laid down to solve the food security issues and charity effort has been made. The government has made efforts to improve local food production by helping farmers with the adoption of agro-technology which aims to increase productivity (Natrah, 2023). For instance, RM200 million has been allocated under Agrobank to help provide financing facilities especially for the application of modern agricultural technology (Natrah, 2023). Apart from this, the government has built an infrastructure worth RM3 billion to improve the irrigation system in the areas of the Muda Agricultural Development Authority (MADA) in Kedah and Perlis to increase the productivity of rice production (Natrah, 2023). Besides the government's effort, non-profit organization (NGO) - Food Aid Foundation (Julian-Fa, 2023) and SESO Malaysia serves as the food bank step in to help the community. The total meal distribution by Food Aid Malaysia in 2022 is amounted to nearly 4 million meals with the value of RM23.5 million (Julian-Fa, 2023). However, even with 36.3 billion (1980-2021) subsidies, paddy and rice continue to grow very slowly (Murni, 2023).

Therefore, a deep analysis of the factors influencing food security in the country needs to be prioritized. Between 2019 and 2022, numerous factors, including population growth, economic growth, and carbon footprint, have been shown to have a significant relationship with food security in Malaysia (Siwar et al., 2022; Solaymani et al., 2019; Firdaus et al., 2020). However, there is a lack of studies that consider water resources as a potential factor. Water resources have been shown to be a significant factor affecting food security in China (Wang et al., 2017; Wang et al., 2019), South Africa (Ingutia & Sumelius, 2022; Boateng et al., 2022), and Central Africa (Nounkeu et al., 2021). Thus, we aim to examine whether water resources are an important factor influencing food security in Malaysia.

1.3 Research Objectives

1.3.1 General Objectives

The general objective of this study is to determine the factors that affect food security in Malaysia.

1.3.2 Specific Objectives

To achieve our general objective, the subsequent specific objectives are developed.

1. To examine whether there is a significant relationship between economic growth and food security in Malaysia.
2. To examine whether there is a significant relationship between population growth and food security in Malaysia.
3. To examine whether there is a significant relationship between carbon footprint and food security in Malaysia.
4. To examine whether there is a significant relationship between water resources and food security in Malaysia.

1.4 Research Question

To clarify the research direction in our study, the following research questions are developed.

1. Is there a significant relationship between economic growth and food security in Malaysia?
2. Is there a significant relationship between population growth and food security in Malaysia?
3. Is there a significant relationship between carbon footprint and food security in Malaysia?
4. Is there a significant relationship between water resources and food security in Malaysia?

1.5 Significance of Study

Food security has become a global concern after several unforeseen events including pandemics, wars, and natural disasters causes the food production and food supply distribution chain to be disrupted. According to the Department of Statistic Malaysia, the number of imported foods surged during the study period between 1991 - 2020, due to self-insufficiency. Moreover, it is noteworthy that Malaysia heavily relies on food import instead of domestic food production, thus posing a threat to Malaysia's food security. In this study, the past 3 decades (1991-2020) in Malaysia have been chosen. There were 3 major shock events during the period, namely, 1997-1998 Asian Financial Crisis, 2007-2008 Global Financial Crisis, and 2019 Global Pandemic COVID-19 outbreak. Based on Davis et al. (2020), environmental variability and shock events can be affected by economic, political, and infrastructural elements along food supply systems, it is essential to understand these procedures to lower the risk of recurring food scarcities, price spikes as well as food quality degradation.

Moreover, this study is necessary to be conducted because it sheds light on the urgency of addressing climate change as a central component of food security efforts. As food security not only ensures the survival of humanity but also crucial in nourishing the physical and cognitive wellbeing of individuals. The significance of food security is intertwined with the fundamental right to sufficient nutrition, as it has a direct impact on health, growth, and overall quality of life of human beings. In addition, food security plays an important role in terms of improving the health of the citizens, translating into a more productive and skilled citizen which could have a positive impact on a nation's economic growth (Silvia & Bowo, 2023).

Primarily, water resources serve as our research gap variable owing to lack of study of water resources in Malaysia. Majority of researchers and scholars have been focused on climate change (Solaymani, 2017; Alam et al., 2017; Xiang & Solaymani, 2022) as well as economic growth that affects food security in Malaysia. Agriculture in general is highly dependent on water for cultivation, alongside Malaysia's highly polluted water (Fazaniza, 2022), it is certain that this will assist in shifting the focus from the factor hindering Malaysia to achieve sustainable food production. This study can determine whether water resources are one of the main factors that affect food security in terms of hindering food production. Therefore, the government and authorities would be required to find solutions such as ways to conserve clean water, minimize water losses, and/or adopt a new technology to purify the water used.

Nonetheless, economic growth plays a pivotal role in fostering the food security issues in a nation. When a nation is experiencing an economic expansion, it will increase the citizen's purchasing power as well as employment rate, which in turn allows the citizens to purchase and have access to nutritious food in the market. Besides, to foster a healthy economic growth in a nation is closely related to the government's decision on both fiscal and monetary policy. Ever since the Malaysian government shifted their focus from agricultural industry to manufacturing industry, the production of agriculture in Malaysia has gradually declined (Lockard et al., 2024). It is prominent that government intervention has an effect on the later found food security issue in Malaysia. The effect of shifting focus in between industries depletes agricultural land which results in declining crop yield (Ayele & Tarekegn, 2020). Therefore, this study includes the Keynesian Theory in explaining the relationship between economic growth and food security issues in Malaysia. This could contribute an in-depth understanding to the Malaysian government in making informed decisions in the future intervention.

The exponential growth of population in Malaysia is significant alongside with the shortage of food supply that causes a food security issue in the nation. This study includes population growth as independent variables on food security in view of the fact that population growth increased the demand for food. This variable is pivotal for the government to look into the matter of efficient allocation of resources to ensure all citizens are able to consume enough and nutritious food.

Moreover, the factor of carbon footprint has also taken in as an independent variable to food security in Malaysia. There is an inconsistent finding in this variable, Lobell & Field (2008) stated that high carbon footprint is able to prompt the crop growth, whereas, in Loladze (2014) findings, excessive carbon footprint could deprive the nutrients in the crop yield. Therefore, this study includes Photosynthesis Theory in explaining how carbon footprint is important to Malaysia's food security. This can provide clearer insights to the government to leverage their role into addressing carbon footprint and encourage environmentalists to find ways to manage their impact on food security.

This study provides a broader viewpoint by combining this study with 3 different perspectives namely, environmental concerns (carbon footprint; water resources), social factors (population growth), and economic factors (economic growth) altogether to address the complexity of factors affecting food security. In the Malaysian context, the food security issue has gained attention over the decades. This issue has a close relation to the underlying lack of focus on agriculture industry due to overly emphasized industrial yield (Wong et al., 2023), according to the Department of Statistic Malaysia, the country is highly dependent on food imports. In the long run, our food supply will be jeopardized by any changes in the world food supply chain. Hence, this study can contribute a broader viewpoint to policymakers, and authorities to make adequate policy amendments.

1.6 Scope of Study

The purpose of this study is to study the factors that affect the food security in Malaysia based on the past 3 decades data 1991-2020, mainly obtained from World Bank, and Food and Agriculture Organisation (FAO). Primarily this study focuses on a macro level, environmental issues such as Water Resources, Carbon Footprint, Population growth and Economic Growth affecting food security in Malaysia. Nevertheless, in order to improve the current issue of food security in Malaysia, a few recommendations of policy amendments will be provided at the end of the study.

1.7 Organisation of Chapter

This thesis encompasses 5 chapters. Chapter 1 presents the background research of the study, problem identifying, hence research objective, research questions, and significance of study are generated accordingly. The scope of study can also be found at the end of Chapter 1.

The following Chapter 2 attended the past concept and theories that anchors the food security issue. Later on, the chapter reviewed past empirical study to identify the research gaps and present hypothesis development. The chapter also includes research frameworks; both conceptual and theoretical.

Chapter 3 focuses on methodology to conduct the study, it includes data preparation, constructing econometric models, then proceeding to empirical tests. Diagnostic checking of models is included at the end of this chapter.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter reviews literature on food security issues and other selected constructs which are relevant to this research. This chapter begins with a theoretical review of the relationship between dependent variables (food security issues) and independent variables (economic growth, population growth, carbon footprint and water resources). The following section includes the review of literature based on previous studies. Lastly, this chapter ends with a research gap analysis.

2.1 Theoretical Review

2.1.1 Keynesian Theory

Keynesian economics, also known as the Keynesian Theory, was introduced by John Mynard Keynes, a British economist born in 1883. This concept of this theory is introduced in the book "The General Theory of Employment, Interest, and Money" published in 1936. The Keynesian economy simply portrays a concept of the overall expenditure also known as aggregate demand within the nation and its impact on output and inflation (Blinder, 2002). In the short run, the central concept of the Keynesian Theory is that government intervention serves as an economic tool in manipulating the economic activities, namely recessionary and inflationary gaps in a country, ultimately stabilizing the economy. (Wheelock, 2008, Selvanathan et al., 2021, Stockhammer, 2022).

For instance, during the infamous Great Depression in the United States in between 1929 - 1932, where the economy took a downturn, causing a sharp decline in aggregate demand, where businesses are hesitant to invest and consumers are cutting down their expenses. Subsequently, businesses experienced declining sales due to low aggregate demand, where the employer laying off employees to cut costs, gradually led to high unemployment rate (Blinder, 2002). In accordance with Keynes' economic theory, during an economic downturn, the theory suggested the government to intervene. For instance, implementing fiscal policy such as reducing income taxes to increase the purchasing power of consumers, or spending more on private sectors in order to revive and kickstart the economy (Blinder, 2002). This concept can be further explained by the underlying multiplier effect by Keynesian. The multiplier effect focused on the concept of one mans’ spending equals the other man’s earning, where government spending can stimulate other’s earning, which creates a repeating cycle of spending that benefited the economy as a whole (Allen et al., 2013, Jahan et al., 2014).

There are few nations that adhere to the Keynesian theory by implementing a vast array of policies in fine-tuning their nation’s economy and economic boost. Soko et al. (2023) found that institutional quality plays a vital role in influencing one nation’s economic growth. In addition, finding of Fan and Zhang (2008) on “Public Expenditure, Growth, and Poverty Reduction in Uganda” shows that investing in public spending has a direct impact on boosting both farmer’s income and productivity. Besides, according to the research done by Soko et al. (2023) on cereal production in Sub-Saharan Africa and Asia, an increase in cereal production is positively influenced by both per capita public agricultural spending and the share of public agricultural expenditure. An increase in food production is one of the remedies in addressing the food security issue (Hanif, 2024), hence, it is clear that government intervention has a significant impact on addressing economic issues such as food security (Soko et al., 2023).

2.1.2 Neo Malthusian Theory

This study utilizes Thomas Robert Malthus’s theory to explain the impact of population growth on food security. In his book, “An Essay on the Principle of Population", asserted that population grows exponentially while food production grows arithmetically (Agarwal, 2022). These concepts further supported the hunger theory introduced in 1798, which suggests that the food demand of a population growing exponentially cannot be adequately met by the linear growth of food supply (Abdelhedi & Zouari, 2018).

According to (Rahut et al., 2022), if population growth exceeds food production growth, available food might not be sufficient to feed the population, it could lead to higher food prices (Abdelhedi & Zouari, 2018), thus, there will be a risk to food security and ultimately starvation. Malthus also highlighted that many people will die from the shortage of food as there will be a higher population than the availability of food (Agarwal, 2022), this phenomenon is generally referred to as ‘'population trap”. The Food and Agriculture Organization (FAO) estimates that by 2050, around 60% more food will be needed to nourish a global population of 9.3 billion (United Nations, 2024).

Subsequently, Neo-Malthusian derived from Malthusian theory by environmentalists, published in the report for the Club of Rome, during the 20th century (Abdelhedi & Zouari, 2018). Neo-Malthusian theory concerned that out-of-control population growth would deplete resources and lead to widespread famine (Abdelhedi & Zouari, 2018). This can be illustrated by the fact that the supply of natural resources, especially land, remains unchanged while the population grows, leading to decline in agricultural productivity (Pawlak & Kołodziejczak, 2020). For instance, Schneider et al. (2011) indicates that at current rates of population growth, agriculture would demand an area equivalent to a half and two-third of the current terrestrial land area by 2030 and 2070, respectively, in order to maintain current food consumption levels per capita.

However, Malthus's theory faced strong critique, with arguments suggesting that technological advancement complemented food production growth without requiring the acquisition of additional land resources. These contradicting claims are subsequently supported by the fact that, most of the time, the food supply consistently increased faster than the population growth since the 18th century. Nevertheless, only around 70% of people around the world have consistent access to food to satisfy their energy needs in 2021 ("UN Report: Global Hunger" 2022). Thereby, it has been discovered that the food production has outpaced the world's population, predominantly in developed countries (Pawlak & Kołodziejczak, 2020). This suggests that developing countries that lack technological advancement are at higher risk of falling into the population trap compared to developed countries. Thus, the Neo-Malthusian theory is utilized to study the impact of population growth on food security in Malaysia, a developing country.

This neo-Malthusian theory is also widely used in existing studies related to food security. For instance, Ojiya et al. (2022) examine the population growth and food security nexus in Nigeria based on the neo-Malthusian theory. Similarly, Obinna (2021) uses neo-Malthusian to examine the impact of agricultural land area on food security in Nigeria. Furthermore, Khor et al., (2023) applied Neo-Malthusian theory to examine the impact of fertility rate on food security in Malaysia.

2.1.3 Photosynthesis Theory

This study utilizes the Photosynthesis Theory to reinforce the idea that carbon dioxide and water resources play a crucial role in influencing food security. Jan Ingenhousz established the Photosynthesis Theory in the late 17th century. It explains how plants, as autotrophs, produce their own food through photosynthesis (National Geographic Society, 2024). This process involves the conversion of water, sunlight, and carbon dioxide into oxygen and simple sugars that plants use as fuel (National Geographic Society, 2024).

The majority of life on Earth heavily relies on photosynthesis, as it enables plants to serve as primary producers, forming the foundation of ecosystems and providing energy for higher trophic levels (National Geographic Society, 2024). Through photosynthesis, green plants and various organisms capture water, sunlight and carbon dioxide to generate oxygen (O2) and chemical energy stored in glucose. This energy is then transferred through the food chain, with herbivores consuming plants and carnivores feeding on herbivores (National Geographic Society, 2024). Human, as omnivore, obtain energy by consuming both plants and animals, highlighting photosynthesis as the primary source of food and energy for human beings (Blankenship, 2010). If photosynthesis were to cease, the availability of food and organic matter on Earth would rapidly diminish (Lambers & Bassham, 2024).

Carbon dioxide serves two important functions in the process of photosynthesis. Firstly, it acts as a producer of glucose molecules when combined with light energy (National Geographic Society, 2024). These glucose molecules are crucial for storing food. Secondly, carbon dioxide regulates the rate of photosynthesis ("Carbon Dioxide Is Essential for Photosynthesis", 2023). This increased availability of carbon dioxide leads to a significant production of oxygen during photosynthesis.

For photosynthesis to occur, water is essential. Water serves three main functions in the photosynthesis process. Firstly, it acts as an oxygen supplier (Charmaine, 2018). During photosynthesis, six molecules of carbon dioxide and six molecules of water combine in the presence of sunlight to produce one glucose molecule and six oxygen molecules (Charmaine, 2018). Water's role is to release oxygen from the water molecule into the atmosphere as oxygen gas (O2). Secondly, water acts as an electron feeder (Charmaine, 2018). In photosynthesis, water provides the electron necessary to bind the hydrogen atom (from a water molecule) to carbon (from carbon dioxide), forming sugar (glucose). Lastly, water undergoes photolysis, serving as a reducing agent by providing H+ ions that convert NADP to NADPH (Charmaine, 2018).

In summary, recognizing that photosynthesis is the foundation of our food supply and understanding the crucial role of water in facilitating this process, the theory of photosynthesis strongly supports the notion that water resources are a critical factor in ensuring food security. Without adequate water resources, plants cannot thrive, leading to a ripple effect where animals that depend on these plants for sustenance also suffer. This ultimately results in decreased agricultural productivity and food supply, thereby posing a significant threat to food security.

2.2 Empirical Review

2.2.1 Economic Growth and Food Security

Many studies have focused on the relationship between economic growth and food security issues in many countries. The relationship between economic growth and food security is well established. It is theorized by numerous researchers that efficiency in economic growth can positively affect food security (Manap & Ismail,2019). Manap and Ismail (2019) further claim that famine, poverty, and undernourishment can be eliminated through a nations' economic growth and hence achieve food security. Owing to the fact that the overall economic growth will give rise in income per capita that enhances the poor households' food accessibility through affordability (Suryanto et al., 2023; Swietlik, 2018). Analysis by Herforth & Ahmed (2015) concluded that an increase in income can lessen hidden hunger.

In an era of rapidly growing global rivalry, many countries are seizing the chance for foreign investment by raising their economy, which enables them to improve the overall quality of life for the citizens as well as to satisfy their needs and wants. Several empirical studies have focused on economic growth and food security issues in developing countries (Mottaleb et al., 2022; Kamenya et al., 2022) as well as in Malaysia (Siwar et al., 2022; Solaymani et al., 2019). Besides, according to Barrios et al. (2008), countries with a larger GDP per capita have better access to food economically.

Based on the claim of Fauziyyah & Duasa (2021), using Fixed Effect Models (FEM), real gross domestic product (RGDP) has positively affected food production across 9 Southeast Asia countries within the period of 2006-2016. Indeed, the result of Fusco (2022) Random Effects Model (REM) shows a positive relationship between GDP per capita and food security level in Northern and Eastern African Regions with the test statistical value 0.001 lesser than the p- value. Besides, a meta-regression analysis is also utilized by Poudel & Gopinath (2021) based on a sample of 2479 data from across 139 countries, the result concludes that prevalence of undernourishment can be diminished by 0.77 percent for every increase in percentage point of GDP per capita.

Furthermore, Kamenya et al. (2022) utilized the Fixed-Effect Generalized Least Square Model just to obtain the consistent result as Fauziyyah & Duasa (2021) with a different approach where Kamenya et al. (2022) found that between 2000 and 2016, a one unit increase in public agriculture spending was linked to a 0.2% decrease in undernourishment and an enhanced average dietary energy supply sufficiency in 9 ECOWAS countries. Moreover, the Nonlinear Auto-Regressive Distributed Lag-Model (NARDL) shows that as the economy improves, malnutrition among South African children has significantly reduced (Gillani et al., 2022).

In accordance with past empirical review, majority results highlight the importance of economic growth on affecting the food security level in a nation where economic growth reflects the increase of overall income per capita. As economic growth increases, subsequently it also increases the average income level of each individual. As a result, the food accessibility of the poor individuals would be enhanced with higher income. Thereby, economic growth is suitable to be added in our research of food security in Malaysia as it links with one of the four pillars of food security - accessibility of food.

2.2.2 Population Growth and Food Security

Population growth is one of our variables as we aim to study the impact of population growth on food security in Malaysia. Population growth is an important driver of increased food demand (UNDESA, 2021), which aligns with the Malthusian Theory stating that population grows exponentially while food production grows arithmetically (Agarwal, 2022). According to Pawlak & Kolodziejczak (2020), it is predicted that the demand of food will rise around 59% - 102% in 2050 along with an estimated 9.2 billion population. In order to meet the demand for food, food production needs to double up by 2050 (Pawlak & Kołodziejczak, 2020). Agarwal (2022) further highlights that there is a high possibility of the phenomenon of food shortage due to a higher population growth and a lower availability of food. Consequently, it poses a threat to food availability, where there is insufficient food for the growing population (Rahut et al., 2022). Therefore, population growth is considered as a factor affecting food security through food availability from a demand side.

In the past research of Molotoks et al. (2020) finds that rapid population growth tends to experience a greater impact on food security; also population growth are the dominant determinants in the change of prevalence of undernourishment, by applying the FEEDME (Food Estimation and Export for Diet and Malnutrition Evaluation) modeling framework. Thereby, Obinna (2021) shows a negative relationship between population growth and food security in the short run in Nigeria, by using the Autoregressive Distributed Lag (ARDL) model. In accordance with Obinna (2021) study, by using both Granger Causality Approach and ARDL model, Ceesay and Ndiaye (2022) found that population growth have a negative influence on food security which 1 unit growth in population lead to 41% drop in the rate of growth of food security in Gambia. This study indicates that higher population growth, higher demand for food which is closely related to less food availability. In the study of Januarti et al. (2022) utilizing multiple linear regression shows a positive relationship between population growth and rice consumption and production in South Sumatra region. Similarly, in the study of Maja & Ayano (2021); it is stated that population growth led to overexploitation of natural resources resulting in intensive farming as well as demolished land eventually deplete the quality and quantity of natural resources as a result causing a drop in arable land hence, reducing the food production and threatening food security.

Contrariwise, there are insignificant results of population growth and food security. For instance, Abdelhed & Zouar (2018) obtained an insignificant result using Fixed Effect Model (FEM) in the study of North Africa namely; Tusnia, Morocco, Algeria, and Egypt to examine the impact of agriculture on food security, and population growth (independent variable).

In accordance with past empirical review, majority results highlight the importance of population growth on affecting the food security level in a nation where population growth leads to the increase of food demand. Because total food consumption increases followed by increases of total population. Hence, population growth is suitable to be added in our study of food security issues in Malaysia as it links with one of the four pillars of food security - availability of food.

2.2.3 Carbon Footprint and Food Security

Carbon footprint as one of the independent variables is added in our study to investigate the relationship between carbon footprint and food security. According to Lobell & Field (2008), increased levels of carbon footprint are widely recognized to have an impact on plant photosynthesis and growth which can potentially lead to crop productivity. However, an excess carbon dioxide concentration as a result of climate change will affect the conditions for farmers to cultivate crop productions (Ebi & Ziska, 2018). It has piqued the interest of many scholars and researchers to look into how carbon footprint affects global food supply. Brown et al. (2015) claims that progress of food security can be jeopardized by climate change as it leads to disruptions in food production.

The prevalence of impactful articles portraying the decline of local food production, predominantly attributed to the adverse effects of climate change which is caused by excessive carbon footprint (Rosegrant & Ringler, 2000; Mishra & Ramapal, 2020; Alexander et al., 2017). Carbon dioxide is vital to accelerate plant growth as carbon dioxide is the main element for photosynthesis of plants other than sunlight and water ((National Geographic Society, 2024). Lobell & Field (2008) explains that an increase in carbon dioxide concentration is widely acknowledged to facilitate plant growth and photosynthesis to encourage crop yield. However, excessive carbon footprint leads to climate change related to changes in temperature and rainfall pattern (Trenberth, 2011), which would disrupt agriculture production. Godde et al. (2022) and Ebi & Ziska, (2018) stated that climate change has contributed to low crop yield (Desk, 2022) causing shortage in local food availability resulting in high import dependency. This put local household stability to access to food vulnerable to global food supply chain disruption (Hellegers, 2022). Thus, carbon footprint is deemed to be a factor affecting food security through food availability, food stability and food utilization in terms of food quality.

In the past research of Ozdemir (2022) found that CO2 emission is significant in addressing agricultural productivity and food security in the short-run using dynamic and asymmetric panel autoregressive distributed lag models. In accordance with the findings of Obina (2021) which utilizes the Autoregressive Distributed Lag Model (ADRL), carbon dioxide emission has significantly affected the food production on Nigeria’s agricultural food production, on average 1 unit change in carbon dioxide emissions, affect 0.00017 unit of increase in food security. Furthermore, the result of FMOLS techniques in investigating the relationship between carbon dioxide emissions and crop production shows a positive relationship in Africa (Ejemeyovwi et al., 2018). In addition, Ainsworth & Long (2020) using meta-analysis found that under non- stressed conditions, there will be approximately 18% increase in crop yield along with 200 ppm increase in CO_2 emission; which the results are align with the findings of Obina (2021) and Ejemeyovwi et al. (2018). Besides, Chansdio et al. (2020) utilizing Johansen cointegration test together with ADRL found that CO_2 emissions have a significant effect on agriculture production in both long-run and short-run in China.

In the research of Firdaus et al. (2020), using Mann-Kendall and Sen's slope in the study of the impacts of climate change on paddy, rice and food security in Malaysia found a negative relationship between CO_2 emissions and food security. Such findings correspond with Tang (2019) finding a 3.44% decline in paddy output in Malaysia as a result of 1% increase in temperature caused by increased concentration of CO_2 emissions. On the other hand, by integrating the ADRL approach and Granger causality test, Warsame et al. (2021) found that there is no significant relationship between CO_2 emissions and crop production in Somalia. In Malaysia, rice is considered as the nation's staple food, consequently, any decrease in rice production will have a severe impact on Malaysia's self-sufficiency which indirectly has an impact on food security issues. Lee et al. (2019) studies results using Vector Error Correction Model revealed that CO_2 emission is insignificant to have an impact on rice production in Malaysia.

To recapitulate, previous study produces a mixed result of the significance between carbon footprint and food security, with minor studies obtaining insignificant results. Hence, it is pivotal to be added in our study as it is found that Malaysia is having a noticeable high carbon footprint to determine whether carbon footprints significantly affect Malaysia's food security.

2.2.4 Water Resources and Food Security

In agricultural production, water assumes a vital role; absence of water renders farmers unable to cultivate crops and sustain livestock. During drought, proper irrigation systems can effectively mitigate the impact of reduced rainfall (Alam et al., 2019), which utilize freshwater from rivers, lakes, and aquifers to nourish plants (The World Bank, 2024). In addition, irrigated agriculture generally yields at least double the productivity per unit of land compared to rainfed agriculture, providing greater opportunities for increasing production intensity and diversifying crops (The World Bank, 2022). Approximately 70% of the total global freshwater withdrawals are allocated to irrigation, simultaneously supporting around 40% of the global food production (Zhang et al., 2022). Furthermore, at household level, water security is complementing food security because it affects the availability of clean water to prepare food (ie, wash and boil food) for safe consumption and the ability of households to produce food for their own consumption, or to generate income that can be used to purchase food (Brewis et al., 2019). This underscores the critical role of water resources in maintaining food security. As polluted water leads to a reduction in available freshwater resources suitable for agricultural uses, there is a potential threat of compromising food security due to decreased crop yields (Asibi et al., 2019).

The impact of water availability on global crop production and food security has been examined across the globe in Nechifor & Winning (2018) study, by using a global computable general equilibrium (CGE) model. The result of the study shows that water availability positively impacts crop production with some differences across crop types. For instance, rice and wheat are affected the most by insufficient water availability with decreases in output of over 15% in India; the same crops drop by more than 20% in South Asia, whereas, other crops, fiber plants and wheat can have a decrease of more than 30% in the Middle East. Northern Africa is less affected with only other crops having a marked decrease next to 10%. This finding is consistent with Qureshi et al. (2013)'s study which proved that agricultural output, export and global food supply are positively affected by water availability in

Australia, by using hydro-economic stochastic modeling approach. For instance, low water availability leads to reduction of staple food production such as rice and its ability to export resulting in the rise in food prices onto markets and consumers in developing countries.

Furthermore, the impact of water resources on food security at household level proved to be similar results. For instance, in Hadush, (2018) study, it is found that the water availability positively affects household food security through affecting livestock production in Tigrai, Ethiopia, by using a two-stage least square approach. This is consistent with the studies of Bethancourt et al. (2022) and Brewis et al. (2019), both studies' findings show there is a strong positive association between household water security and household food security in northern Kenya and low middle-income countries. Even Though both studies employed different analysis models (multiple linear regression model in Bethancourt et al.(2022) study; multilevel generalized linear mixed-effect model in Brewis et al. (2019) study) to examine the relationship between Household Water Insecurity Experiences score and Household Food Insecurity Access Scalescore, both studies showed similar results of household water security positively impacting household food security.

Hence, as for developing countries such as Malaysia, when the quality and safety of food is not achieved, self-sufficiency level will be hindered and the food security issues on the brink (Christoforidou et al., 2022). Thus, in accordance with Kamal (2021) water resources should be taken into account when addressing food security issues in Malaysia.

2.3 Research Gap

The highlight of this study is to address the importance of water in the food system. There are a plethora of past studies of water and food security in other countries namely, China (Wang et al., 2017; Wang et al., 2019), South Africa (Gulati et al., 2013; Ingutia & Sumelius, 2022; Boateng et al., 2022), Central

Africa (Nounkeu et al., 2021). However, this variable is rarely added in the studies of food security issues in Malaysia, despite water being the paramount factor in addressing the food security issue.

Given the situation, it has piqued the interest among researchers and scholars whereby there is a plethora of studies on the factors influencing food security. However, these studies targeted on global food security such as Daniel (2020), Carthy et al. (2018), Udmale et al. (2020), and Lenaerts et al. (2019) has conducted research on food security on a global scale, without targeting any specific country or any particular timeline. Whereas, some researchers focus on the importance of food security in the aspect of food production on a national level such as Yaqoob et al. (2022), Abbas et al. (2022), and Chandio et al. (2021) carried out their research focusing on Pakistan; whereas, Liu & Zhou (2021), Pu & Zhong, (2020), and Wang et al. (2019) in China and Kumar & Sharma (2020), Qaim (2020), Yaqoob et al. (2022), and Roy et al. (2022) in India.

There are also researchers that studied food security in Malaysia. In the research of Firdaus et al. (2020) and Xiang & Solaymani (2022), found that paddy yield in Malaysia will be affected by severe climate change. Moreover, Akhtar et al. (2022) analyses climate change affects the food production in the aspect of economic, social and environmental based on farmer's perspective in Kedah, Malaysia. However, there are only limited studies on food security that consist of all 3 aspects namely environmental factors, social factors and economic factors in Malaysia. Okpala et al. (2021), focuses on all 3 aspects in Nigeria. Therefore, there is still a need to further address the food security in Malaysia from all 3 different aspects. It is also crucial to include the years that experienced event shocks to reflect the sufficiency of food supply in a country to meet their demands in a desperate state where the economy drops. Therefore, the objective of this study is to examine the factors that affect food security in Malaysia from 1991 - 2020 (3 decades).

2.4 Chapter Summary

In this chapter, theoretical review is stated in the first section which includes Keynesian Theory, Photosynthesis Theory and Photosynthesis Theory. Subsequently, the review of literature on all independent variables including economic growth, carbon footprint, and water resources. Lastly, the research gap is included in the last part of this chapter.

CHAPTER 3: METHODOLOGY

3.0 Introduction

The objective of this research is to examine Economic Growth, Population Growth, Carbon Footprint and Water Resources that affect food security in Malaysia. A vast array of information is collected from Empirical Review in Chapter 2 to aid in econometric model construction in this chapter. Chapter 3 will be discussing the chosen econometric model, the procedure of empirical testing as well as diagnostic checking for accuracy.

3.1 Definition of Variables

3.1.1 Food Security (DV)

Food security is defined as every individual, without exception, has a consistent and unrestricted availability, affordability, accessibility and utilization of sufficient safe and nutritious food supply that caters to their daily dietary requirements and personal food choice in ensuring an individual's overall well-being and active lifestyle (Khoso, 2022; FAO, 1996). Food Security is generally constituted by four pillars namely, Food Availability; Food Accessibility; Food Stability; as well as Food Utilization by FAO (1996). Thus, any improvement or disruption in either one pillar will affect food security.

3.1.2 Economic Growth (IV)

Economic Growth refers to economic goods and services production of a nation increasing from one period to another (Roser, 2023). Economic growth is often measured by the movement in Gross Domestic Product (GDP). GDP reflects a nation's economic status in terms of reflecting the nation's total value of produced goods and services in a specific time period (Fernando, 2023). Normally it is recorded annually. Besides, the output and economic activity is measured by a nation’s GDP. Therefore, GDP (constant LCU) is employed as an indicator of economic growth in this research.

3.1.2 Population Growth (IV)

Population growth is defined as the growing number of humans in Malaysia annually. The growth rate can be determined by the birth rate, mortality rate, immigration and emigration of the population (Harvey, 2008). Population growth is believed to have an impact on the food demand, where food security can be affected given insufficient food production in a nation. (Pawlak & Kołodziejczak, 2020)

3.1.3 Carbon Footprint (IV)

Carbon Footprint, also known as carbon dioxide is an odorless gas exhaled by humans and animals, or the gas released by burning organic natural resources in the process of energy production, including burning fossil fuels (Muro, 2023). According to prior studies' findings, excess levels of carbon dioxide concentration in the atmosphere has a significant impact on the nutritional quality of cultivated crop productions (Ebi & Ziska, 2018). Hence, it is clear that this phenomenon has an effect on "food utilization", one of the pillars of food security in terms of food quality.

3.1.4 Water Resources (IV)

Water resources are the source of water that are widely used for living organisms (Kılıç, 2020). However, humans can only use freshwater for most needs (drinking, watering animals and crops, hydroelectric plants, etc.). Freshwater refers to surface water (rivers, lakes and reservoirs) and groundwater (aquifers) with low concentration of salt (containing less than 1000 milligrams per liter of dissolved salt). According to (Zahoor et al., 2023), freshwater makes up only around 3% of the total water on Earth. Only 1.2% of it can be used for drinking and irrigation; the remainder is trapped beneath the earth or in glaciers, ice caps, and permafrost. Thus, water resources refer to the 1.2% of freshwater available for consumption in this research. Clean or unpolluted water resources has become a prerequisite for the food production mainly agricultural sector in Malaysia to flourish (Him-Gonzalez, 2009). According to Kazanci, (2021), Malaysia as a water-rich country, water sources mainly come from withdrawal of surface water (80.8%) which is mainly from rivers. Thus, annual freshwater withdrawal serves as an indicator of the sufficiency of useful water resources in Malaysia.

3.2 Data Description

Time series analysis is obtained to examine the relationship between Economic Growth, Population Growth, Carbon Footprint and Water Resources on Malaysia's food security for the past 3 decades (1991 - 2020). Table 3.2 exhibits the variable used and source of data:

Table 3.2: List of Variables and Source of Data

	Abbreviation	Variable	Source	Cite from
Food Security	InFOOD	Food production index (2014-2016 =100)	The World Bank	Ceesay & Ndiaye. (2022)
Economic Growth	InGDP	GDP (constant LCU)	The World Bank	Fusco (2022)
Population Growth	InPOPULATION	Population Growth (annual %)	The World Bank	Januarti, Junaidi, & Purbiyanti (2022)
Carbon Footprint	InCO2	CO2 emissions (kg per PPP $ of GDP)	The World Bank	Khor et al. (2023)
Water Resource	InWATER	Annual Freshwater Withdrawals, total (billion cubic meters)	World Development Indicators	Putra et al. (2020)

3.3 Econometric Model

3.3.1 Basic Model

This study suggests an econometric model that establishes the association between the Economic Growth and Food Security in Malaysia. In our research, we used Malaysia's Food Production Index as a proxy of Food Security. To conduct this research, we used the data from 1991 to 2020.

Food Security = f (Economic growth)

$$LnFOOD_t = \beta_0 + \beta_1 LnGDP_t + \varepsilon_t$$

Equation 3.1

Where,

$LnFOOD_t$ = Food production index (2014-2016=100)

β_0 = Intercept at time t

$LnGDP_t$ = GDP (constant LCU) at time t

ε_t = Error term at time t

Our basic model in this study is constructed as above. This model is adopted from Khor et al. (2023). The research has investigated the relationship between Gross Domestic Production growth and food security in Malaysia. In the research, it has been found that there is a significant positive relationship between variables. Moreover, we have extended the model by including three additional variables namely Population Growth, Carbon Footprint and Water Resources.

3.3.2 Extension Model

Carbon Footprint and Water Resources were included into the basic model (equation 3.1) for comparation purposes. This extension model examines the long run relationship between food security and these three variables.

Food Security = f (Economic Growth, Population Growth, Carbon Footprint, Water Resources)

$$LnFOOD_t = \beta_0 + \beta_1 LnGDP_t + \beta_2 LnPOPULATION_t + \beta_3 LnCO2_t + \beta_4 LnWATER_t + \varepsilon_t$$

Equation 3.2

Where,

$LnFOOD_t$ = Food production index (2014-2016=100)

β_0 = Intercept at time t

$LnGDP_t$ = GDP (constant LCU) at time t

$LnPOPULATION_t$ = Population Growth (annual %) at time t

$LnCO2_t$ = CO2 emissions (kg per PPP $ of GDP)

$LnWATER_t$ = Annual Freshwater Withdrawals, total (billion cubic meters) at time t

ε_t = Error term at time t

3.4 Empirical Testing Procedures

3.4.1 Unit Root Test

Unit root test is the first test to be applied in this study to evaluate the stationarity of the variables as well as the sequence of integration that is required. It is pivotal to establish a stationary variable to ensure the result does not contain any spurious regression problem; whereas non-stationary variables have a risk of obtaining a spurious regression problem that will lead to inaccurate findings. There are a few conditions that suggest the result might be spurious, namely, an extremely large t-distribution, value of R-squares is greater than Durbin-Watson (DW) Test, and the relationship between two variables does not make sense. There are 2 types of models - constant without trend and constant with linear trend is utilized in examining unit root test.

Constant without trend:

$$\Delta Y_t = a + \gamma Y_{t-1} + \sum_{i=1}^{k} \Delta Y_{t-1} + e_t$$

Constant with linear trend:

$$\Delta Y_t = \propto + \beta_t + Y_{t-1} + \sum_{i=1}^{k} \theta_j \Delta Y_{t-1} + e_t$$

3.4.1.1 Augmented Dickey-Fuller (ADF) Test

Augmented Dickey-Fuller (ADF) Test is utilized to examine the presence of unit root (stationarity) in a time series data. ADF Test is known as to be advantageous and an effective tool in diagnosing the stationarity of time series data. In terms of handling a complex model Augmented Dickey-Fuller Test is comparatively more efficient than Dickey-Fuller Test. The null hypothesis states that there is a unit root in the variables whereas the alternative hypothesis states otherwise.

H_0: There is a unit root (non-stationary)

H_1: There is no unit root (stationary)

Decision rules for the ADF test are stated as rejecting the null hypothesis if the p-value is smaller than the significance level at 1%, 5%, and 10%, otherwise do not reject the null hypothesis. Rejecting null hypothesis indicates that the variables are stationary, conversely if null hypothesis is not rejected, it indicates that the variables are non-stationary. In accordance with Seddighi, Lawler & Katos (2000) number of lag lengths used will be determined by the Akaike Info Criterion (AIC) and Schwarz Info Criterion (SIC).

3.4.2 Model Estimation

3.4.2.1 Autoregressive Distributed Lag (ARDL) Model Bounds Cointegration Test

After obtaining the stationarity of the time series data, the Autoregressive Lag Model (ARDL) Bounds Cointegration Test is applied as the second test for the examination of the long-run relationship between dependent variable and independent variables. During the past decades, examining the levels of cointegration of variables has piqued the interest of many researchers. In the conditions of small sample size, and variables that are integrated in different orders I(0), I(1) or a combination of both, ARDL model is preferable as it is reliable when there is only one long-run relationship between the underlying variables (Nikoro and Uko, 2016). The primary objective utilizing ARDL is to test whether the included variables have a long-term relationship through F-test where the significance of each variable's lag level coefficient is integrated (Nkoro & Uko, 2016).

Autoregressive Distributed Lag Model (ARDL) Bounds Cointegration Test hypothesis:

H_0: There is no cointegration relationship between DV and IV.

H_1: There is a cointegration relationship between DV and IV.

Decision rules are stated as reject null hypothesis (H0), if the F-Statistic is greater than the upper critical value I (1), otherwise, do not reject null hypothesis. However, if the F-Statistic is in between the crucial range, the test is said to be ambiguous and meaningless.

The ARDL bounds cointegration test model is expressed as below:

Basic model:

$$LnFOOD_t = a + \sum_{i=1}^{p} \beta_0 \, LnFOOD_{t-1} + \sum_{i=0}^{q} \beta_1 \, LnGDP_{t-i} + u_t$$

Extension model:

$$\begin{aligned} LnFOOD_t = a &+ \sum_{i=1}^{p} \beta_0 \, LnFOOD_{t-1} + \sum_{i=0}^{q} \beta_1 \, LnGDP_{t-i} \\ &+ \sum_{i=0}^{r} \beta_2 \, LnPOPULATION_{t-i} + \sum_{i=0}^{r} \beta_3 \, LnCO2_{t-i} \\ &+ \sum_{i=0}^{s} \beta_4 \, LnWATER_{t-i} + u_t \end{aligned}$$

Where,

$LnFOOD_{t-1}$ = first lagged of Food production index (2014-2016=100)

a = Intercept of the model

$LnGDP_{t-i}$ = lagged of GDP growth (Annual %) at time t

$LnPOPULATION_{t-i}$ = lagged of Population Growth (annual %) at time t

$LnCO2_{t-i}$ = lagged of CO2 emissions (kg per PPP $ of GDP) at time t

$LnWATER_{t-i}$ = lagged of Annual Freshwater Withdrawals, total (billion cubic meters) at time t

u_t = Error term at time t

3.4.2.2 Error Correction Model (ECM)

The following test after the ARDL model would be the Error Correction Model (ECM). In time series data, ECM is employed in examining both long-run and short-run relationships between the selected independent variables and dependent variables at the time the variables are cointegrated which indicates that both DV and IVs shared stable long-run relationships over a period of time. Based on Alogoskoufis and Smith (1991), ECM reproduces the process of the variables returning to the long run equilibrium after a short-term deviation from shock events.

If the ECM coefficient is statistically significant (different from zero), it indicates that there is a strong and significant short-term relationship between the variables. Otherwise, there may not be a strong short-term relationship. If the ECM coefficient is negative and statistically significant, it indicates that the variables are adjusting towards equilibrium in the long run after a deviation from equilibrium in the short run. If the ECM coefficient is positive, it suggests that the adjustment towards equilibrium after a shock or deviation from equilibrium in the short run is in the opposite direction of the long-run equilibrium. In other words, the variables are diverging further away from each other in the short run rather than converging towards their long-run equilibrium values.

During the period of 1991-2020, 3 shock events occurred, namely, 1997-1998 – Asian Financial Crisis; 2008 – Global Financial Crisis; and 2019 – Global Covid-19 Pandemic. Thus, ECM is important to be utilized in this particular research to examine whether the short-term deviation will return back to long run equilibrium. If yes, it further reinforces the validity of the cointegration result obtained from the ARDL bounds test. This is because the variables adjust towards their long-run equilibrium values over time, which is consistent with the concept of cointegration.

The ECM model is expressed as below:

Basic model:

$$\Delta LnFOOD_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \, \Delta LnFOOD_{t-1} + \sum_{i=0}^{q} \beta_2 \, \Delta LnGDP_{t-i} + \lambda U_{t-1} + e_t$$

Extension model:

$$\Delta LnFOOD_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \, \Delta LnFOOD_{t-1} + \sum_{i=0}^{q} \beta_2 \, \Delta LnGDP_{t-i} + \sum_{i=0}^{r} \beta_3 \, \Delta LnPOPULATION_{t-i} + \sum_{i=0}^{s} \beta_4 \, \Delta LnCO2_{t-i} + \sum_{i=0}^{t} \beta_5 \, \Delta LnWATER_{t-i} + \lambda U_{t-i} + e_t$$

$Ut-1$ refers as error correction term which included into the equation to construct the ECM model. The coefficient of the error correction term (λ) indicates the speed of adjustment of short-run deviation returning to long run equilibrium (J. Kim et al., 2007).

3.5 Diagnostic Checking

In chapter 3, diagnostic checking serves as the pivotal phase to ensure obtained time series data is accurate and unbiased. In this phase, a series of statistical tests is involved in order to run through the calibrated model, to check for heteroskedasticity, autocorrelation, incorrect functional form specification and other problems that need to be avoided to ensure the results are accurate, reliable, efficient, and consistent. The included diagnostic tests are Autoregressive Conditional Heteroskedasticity (ARCH) test, Breusch-Godfrey Serial Correlation LM Test, and CUSUM Test.

3.5.1 Autoregressive Conditional Heteroskedasticity (ARCH) Test

H_0: There is homoscedasticity.

H_1: There is heteroscedasticity.

Heteroscedasticity occurs when the standard deviations of a regression model deviate away from the previous data or it is inconsistent throughout the range of independent variable values. For instance, the correlation between consumption and income serves as an illustration of heteroscedasticity. The consumption will be limited if an individual's income earned is lessee. individuals who earn more will eventually spend more with a higher income as they are not limited with the amount of capital. In Ordinary Least Square (OLS) regression it is assumed that the population's residuals come with a constant variance. Heteroskedasticity can be detected using the ARCH Test in this study. The null hypothesis (H_0) will be rejected if the P-value for X square is less than the significance level at 1%, 5%, and 10%.

3.5.2 Breusch-Godfrey Serial Correlation LM Test

H_0: There is no serial correlation.

H_1: There is a serial correlation.

The Breusch-Godfrey Serial Correlation LM Test is implemented to test whether the variables suffer from a serial correlation. A serial correlation problem in time series investigation is known as the effect of historical data from the previous period can affect the data of the upcoming period. The prediction variances of the coefficient regression will be skewed due to the serial correlation problem; hence the validity of the hypothesis might be questionable. The t-statistic will seem to be more important than it is. Hence, the serial correlation problem in this study can be detected by using the Breusch-Godfrey Serial Correlation LM Test. The null hypothesis (H_0) will be rejected if the P-value for X square is less than the significance level at 5%.

3.5.3 CUSUM Test

The stability of the ARDL bounds test parameter can be tested by Cumulative sum of recursive residuals test (CUSUM). The CUSUM test is a statistical method used to detect shifts in the mean level of a time series data. If the CUSUM statistic falls within the range of the critical bounds at a specified significance level (e.g., 5%), this indicates that there is no statistically significant evidence of a shift in the mean level of the time series data. The ARDL parameters are stable and the null hypothesis of no change is not rejected. Conversely, if the CUSUM statistic exceeds the critical bounds, this suggests that there has been a statistically significant shift in the mean level of the time series data. The null hypothesis is rejected in favor of the alternative hypothesis, indicating a change.

3.5.4 Variance Inflation Factor Test (VIF)

Variance Inflation Factor (VIF) Test is used to test multicollinearity in a regression analysis as well as how this matter increases the variance of the predicted regression coefficients (Vatcheva et al., 2016). Multicollinearity happens when two or more variables in a regression model are highly correlated with each other, which violates the assumption of OLS to obtain an accurate result. For instance, the estimated regression coefficient is said to be unreliable as two variables are correlated with one another which makes it difficult to accurately quantify the impact of each predictor on the dependent variable.

In the model with multiple predictors, the variance of the coefficient estimate is divided by the variance of the coefficient estimate in a model with a single predictor.

VIF formula:

$$VIF = \frac{1}{1-R_i^2}$$

Multicollinearity can be found when the result of VIF is approximate or greater than 5, otherwise there is no multicollinearity problem (Kim, 2019).

3.5.5 Normality Test

Eviews will be utilized to run normality tests for all independent variables and dependent variables. Normality test is a procedure that aids in determining whether a dataset is normally distributed. P. Mishra et al. (2019) states that there are several alternative ways of performing normality tests. For example, Shapiro–Wilk test and Kolmogorov–Smirnov test.

H_0: Data is normally distributed.

H_1: Data is not normally distributed.

The decision rule is stated as - reject null hypothesis (H_0), if the t-statistical value is lesser than the significance level, otherwise do not reject null hypothesis. If the null hypothesis is rejected, this indicates that data are not normally distributed, and vice versa.

3.6 Chapter Summary

The Autoregressive Distributed Lag (ARDL) Model being the chosen econometric model in this chapter due to it is proven to be the best cointegration test techniques to utilize in the context of data with different order of integration; either I(0) (no differencing) or I(1) (first differencing) or it can be used for combination of both, also it is suitable for small sample size (Pesaran & Shin, 2012; Nkoro & Uko, 2016). Besides, the objective of this research is to test whether all included IVs (Economic Growth, Population Growth, Carbon Footprint and Water Resources) have an impact on DV (Food Security in Malaysia) in the long run. Hence, the Augmented Dickey Fuller (ADF) test is included in the empirical testing procedure to determine the sequence of integration based on the stationarity of the variables' data to avoid a spurious regression (Rehal & Rehal, 2023). Moreover, the Error Correction Model (ECM) is employed to examine the speed of adjustment needed for short run deviation return to the long-run equilibrium after shock events during 1991-2020 (Mishra, 2011). Furthermore, Granger Causality Test is added into the empirical testing of both short-run and long run causal relationships between DV and IVs (Wei, 2013).

The following section of this Chapter 3 would be "Diagnostic Checking" to evaluate the multiple linear regression models in accordance with the Ordinary Least Square (OLS)'s 10 regression assumptions to ensure the obtained result is accurate, reliable, efficient, and consistent to avoid biases (Jenkins-Smith et al., 2017). Therefore, ARCH test, Breusch-Godfrey Serial Correlation LM Test, CUSUM Test, Variance Inflation Factor Test (VIF), and Normality Test (Jarque-Bera) are added.

In brief, ARCH test is to ensure parameter is homoscedasticity (Engle, 1982); Breusch-Godfrey Serial Correlation LM Test is added to ensure no serial correlation problem; CUSUM test is to test the stability of ARDL Model used; VIF is used to ensure there are no multicollinearity problem; and Normality Test is to ensure the error terms are normally distributed.

CHAPTER 4: EMPIRICAL RESULTS

4.0 Introduction

In this chapter, we will run the diagnostic checking and examine the relationship between the food security and all the independent variables by using E-views 12. This chapter will include a summary of all the results while the appendices will display the outputs. Each model's complete outputs, which are listed in the appendices, are listed below with their respective numbers.

4.1 Unit Root Test

All independent variables have undergone both an interaction-free and interaction-based unit root test. The sustainability of the research's variables will be assessed using the ADF test. Table 4.1 presents the findings of all variables without interaction. Each variable can move on to the next stage for more research, such as ARDL, to examine the long-term link between the dependent variable and independent factors after it reaches stationary behavior in the first difference. Otherwise, it will produce a biased and invalid result.

Table 4.1: Results of Augmented Dickey Fuller Test

Augmented Dickey Fuller Test				
Variables	**Constant Level (p-value)**	**First Difference (p-value)**	**Constant Level (p-value)**	**First Difference (p-value)**
	Intercept without trend		**Intercept with trend**	
Ln FOOD	-0.246547 (0.9213)	-3.751803 (0.0086)**	-2.041734 (0.5542)	-3.714756 (0.0379)**

Ln GDP	-4.906471 (0.0005)**	-7.320619 (0.0000)**	-5.225347 (0.0011)**	-7.149222 (0.0000)**
Ln POPULATION	1.400432 (0.9985)	-2.865538 (0.0623)**	-2.073763 (0.5373)	-4.078071 (0.0178)**
Ln CO2	-0.323160 (0.9096)	-5.518439 (0.0001)**	-1.635703 (0.7534)	-5.580140 (0.0005)**
Ln WATER	-3.531779 (0.0142)**	-5.198590 (0.0002)**	-3.019221 (0.1449)	-3.60933 (0.0481)**

Remarks: All variables had been changed to natural logs while (**) indicates that variables are statistically significant at 5%

As mentioned earlier in our previous chapter, we reject null hypothesis if the p-value is smaller than the significance level of 5%. Otherwise, we do not reject the null hypothesis. For intercept without trend, LnGDP and LnWATER are stationary at both level form and first difference; LnFOOD, Ln POPULATION and LnCO2 are stationary at first difference only. Besides, for intercept with trend, LnGDP are stationary at both level form and first different; LnFOOD, LnPOPULATION, LNCO2 and LnWATER are stationary at first difference only. In conclusion, all data is stationary or does not have a unit root at first differencing (at significant level of 5%), hence, spurious regression problem should not be worried.

4.2 Model Estimation

4.2.1 ARDL Cointegration Bounds Test

The ARDL Cointegration Bounds Test has been used as the first test in model estimation to examine the long run relationship between the dependent and independent variables. The value of F-statistics will be used to compare with the critical value at I(0) and I(1) to see if there is any cointegration between variables.

Table 4.2.1: Results of ARDL Bounds Test for Extension Model

TEST STATISTICS	VALUE	SIGNIFICANT LEVEL	I(0)	I(1)
F STATISTIC	7.718516	1%	3.29	4.47
K	4	5%	2.56	3.49
		10%	2.2	3.09
CONCLUSION	Cointegrated			

Remarks: All variables had been changed to natural logs while (**) indicates that variables are statistically significant at 5%.

Based on the hypothesis of ARDL Cointegration Bounds Test mentioned in Chapter 3, reject null hypothesis (H0), if the F statistic is greater than the upper critical value I (1), Otherwise, do not reject. From table above, the value of F-statistic is 7.718516 which is greater than upper critical value of 3.49 at the significant level of 5%. Therefore, we reject H0 and draw a conclusion that there is cointegration and Economic Growth (lnGDP), Population Growth (InPopulation), Carbon Dioxide Emissions (InCO2) and Water Resources (InWater) do exist long run effect on food security.

Economic growth facilitates long-term improvements in food security by boosting income levels and purchasing power. As economies expand, people experience rising incomes enabling them to afford sufficient and nutritious food (Suryanto et al., 2023; Swietlik, 2018).

According to Maja & Ayano (2021), population growth has lasting impacts on food security by placing sustained pressure on resources. Rapid population growth over time strains natural resources, reduces arable land, and increases competition for food. These dynamics persistently influence food security outcomes, demanding proactive measures to address the adverse effects of demographic expansion on food availability, access, and utilization.

Besides, the enduring relationship between carbon dioxide emissions and food security arises from the persistent alterations in climatic patterns and agricultural productivity induced by anthropogenic greenhouse gas emissions (Khor et al., 2023). Over time, escalating carbon dioxide levels exacerbate climate change impacts, including shifts in precipitation patterns, temperature extremes, and disruptions to ecosystems (Trenberth, 2011). These long-term environmental changes place enduring pressures on agricultural yields, crop distribution, and food production systems, underscoring the enduring interdependence between carbon emissions and food security.

Water resources have a long run relationship with food security owing to their indispensable role in supporting agricultural productivity. Over time, access to sufficent water resources remains critical for ensuring food security, as water is crucial for photosynthesis – the fundamental process driving food production (Blankenship, 2010). During drought, water resources are important for irrigation (Alam et al., 2019). Adequate water availability directly influences crop yields and quality. Therefore, water scarcity threatens to food security by compromising photosynthesis, jeopardizing agricultural output, livestock production, and overall food systems resilience.

Table 4.2.1.1: Results of Long Run Coefficient for Extension Model

Variables	Coefficient	T-statistic	P-value	Standard Error
InGDP	1.015345	3.296084	0.0064**	0.308046
InPOPULATION	-1.296823	-3.327703	0.0060**	0.449807
InCO2	1.876049	3.573414	0.0038**	0.525002
InWATER	0.494251	3.151762	0.0083**	0.156817
C	-0.036209	-1.767667	0.1025	0.020484

Remarks: All variables had been changed to natural logs while (**) indicates that variables are statistically significant at 5%.

Based on the table 4.2.1.1 shown above, the p-value for GDP, 0.0064 is smaller than 5% significant level. Thereby, we have sufficient evidence to conclude that there is a relationship between economic growth and food security in the long run. On average, food security will increase by 1.015345 if economic grows by 1%. The result is consistent with the study conducted by Fauziyyah & Duasa (2021) on 9 Southeast Asia countries which indiactes that real gross domestic product made positive impact on food production. Additionally, Poudel & Gopinath (2021) and Gillani et al. (2022) studys' also proves that increase in economic growth leads to decrease in prevelance of undernourishment and children malnutrition.

Secondly, Population has p-value of 0.0060 which is lower than 5% significant level proves that population has significant impact on food security. There is sufficient evidence to conclude that there are significant negative relationship between food security and population. For every 1% growth of population leads to 1.296823 decreases in food security. This results is consistent with Malthusian Theory, it claims that higher population growth, higher demand for food then lower food availability. Therefore, food security decline as population increases. Obinna (2021) and Ndiaye & Gambia (2022) also found similar results in Nigeria and Gambia respectively.

Thirdly, the p-value for CO2 is 0.0038 which is lower than 5% siginifcant level. Therefore, we could conclude that CO2 also have significant impact on food security. If CO2 increases by 1%, food security will increase by 1.876049%.

The positive relationship between carbon dioxide and food security is consistent the Photosynthesis Theory which claims that plants needs carbon dioxide to grows. Accoring to Lobell & Field, an increase in carbon dioxide concentration is widely acknowledged to facilitate plant growth and photosynthesis to encourage crop yield. Similar results also found in Africa (Ejemeyovwi et al., 2018) and Asian countries (Ozdemir., 2022).

Lastly, the p-value for the gap variables, water resources is 0.0083 is lower than 5% significant level indicates that water resources is significantly affects food security in Malaysia. If water resources increase by 1%, food security will increase by 0.494251%. This positive relationship indicates that water resources is required to produce more food in order to enhance food security. In Qureshi et al. (2013) study found that water resources availability have positively affected agricultural output, export and global food supply. Besides, Brewis et al. (2019) also claims that water availability could affect households food security as water is required to process and prepare food.

4.2.2 Error Correction Model

Table 4.2.2: Results of ECM for Extension Model

Extension Model	
Variables	GDP, Population, CO2, Water Resources
ECM Coefficient	-0.878298
P-value	0.0000**
T-Statistics	-8.099839
Standard Error	0.108434

Remarks: All variables had been changed to natural logs while (**) indicates that variables are statistically significant at 5%.

Based on the information provided in the ECM (Error Correction Model) table 4.2.2, it is evident that the ECM coefficient is statistically significant, as indicated by a p-value (0.0000) at the 5% significance level. The ECM coefficients for the extension model is -0.878298 which has fallen within the range of 0 and -1. The value of -0.878298 indicates that approximately 87.83% of any deviation from the long-term equilibrium relationship among the variables is corrected within one year. Beside, the magnitude of the coefficient (0.878298) is relatively high, suggesting a fast adjustment speed. This implies that if there is a shock or any deviation from the long-term equilibrium, the model predicts that a significant portion of this disequilibrium will be adjusted in the next year. The negative value of the ECM coefficient further reinforces the validity of the cointegration result obtained from the ARDL bounds test. This is because the negative coefficient indicates that the variables adjust towards their long-run equilibrium values over time, which is consistent with the concept of cointegration.

4.3 Diagnostic Checking

4.3.1 ARCH Test and LM Test

Table 4.3.1: Results of ARCH Test and LM Test

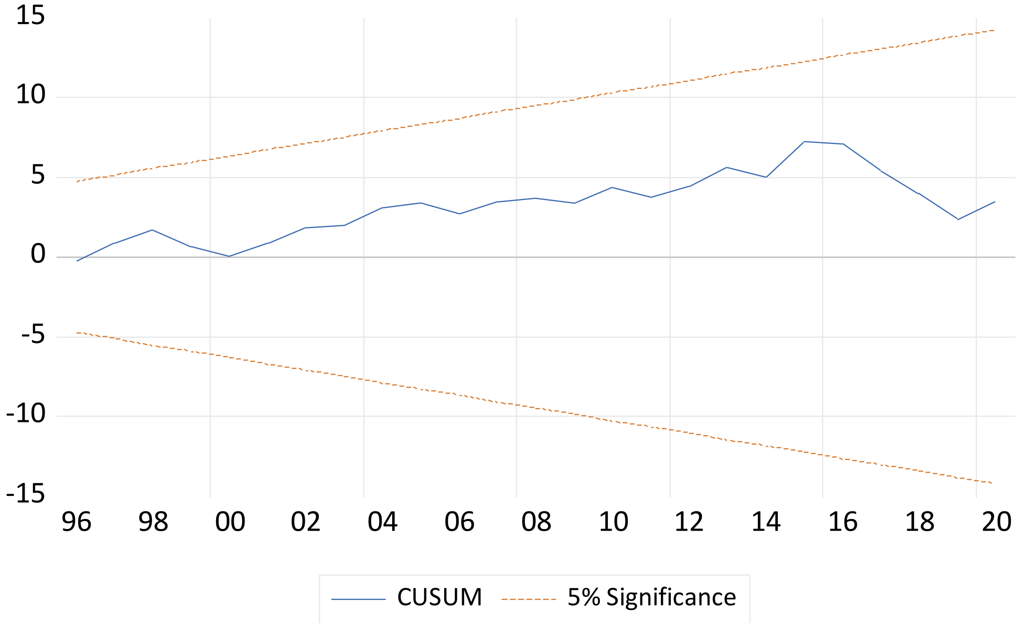
Diagnostic Testing	Chi-Square/P-value	Conclusion
Extension Model		
ARCH Test	0.6006	No Heteroskedasticity
Serial Correlation LM Test	0.4473	No serial correlation

Remarks: All variables had been changed to natural logs while (**) indicates that variables are statistically siginificant at 5%

Based on the outcomes presented in the table 4.3.1, the extended model exhibits no econometric issues. The p-value for the ARCH test is 0.6006, and for the serial correlation LM test, it is 0.4473, both of which exceed the 5% significance level. Consequently, we do not reject the null hypotheses, indicating the absence of both heteroscedasticity and autocorrelation issues within the model.

4.3.2 CUSUM Test

Figure 4.3.2: Results of CUSUM Test



Based on the e-views output, it shows that the CUSUM statistic fall within the critical bound at 5% significant level. Hence, we do not reject the null hypothesis and conclude that the ARDL parameters are stable.

4.3.3 Variance Inflation Factor (VIF)

Table 4.3.3: Results of Variance Inflation Factor

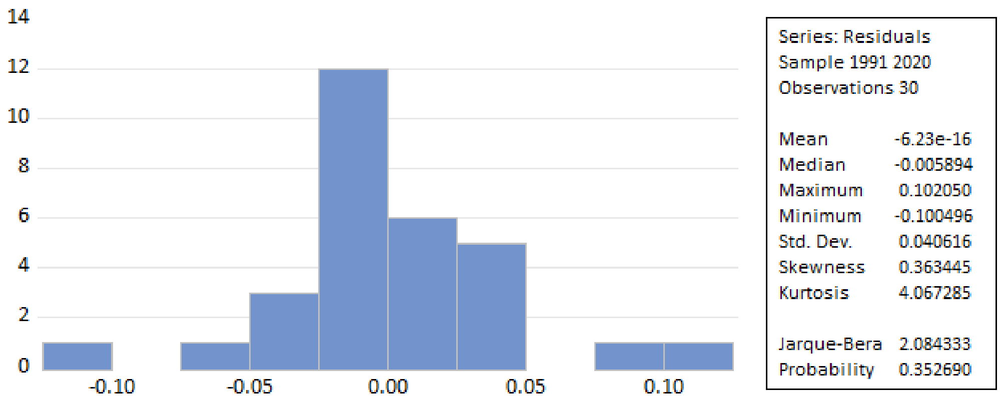
Extension Model	Multicollinearity	
	VIF	Yes/No
LnGDP	1.192396	No
LnPOPULATION	1.092087	No
LnCO2	1.119700	No
LnWATER	1.142283	No

Based on the table 4.3.3 above, VIF for GDP, population, CO_2 and water is 1.192396, 1.092087, 1.119700 and 1.142283 respectively. According to Kim (2019), collinearity is deemed present in a variable if its Variance Inflation Factor (VIF) approaches or exceeds 5. Conversely, if the VIF value falls below 5, it indicates the absence of multicollinearity issues within the model. Since VIF for all variables are lesser than 5, we could conclude that there is no multicollinearity problem within the model. Therefore, the model's estimation should be reliable and trustworthy.

4.3.4 Normality Test

Output for Normality Test

Figure 4.3.4.1: Results of Normality Test



The outcome of the normality test conducted on the model indicates that we do not reject the null hypothesis, as evidenced by a p-value of 0.352690, surpassing the 5% significance level. Therefore, it can be inferred that the time series data adheres to a normal distribution.

4.4 Chapter Summary

In this chapter, several tests have been conducted to test for the long run relationship between Food Security, Economic Growth, Population Growth, Carbon Footprint and Water Resources in Malaysia from year 1991 to 2020. The first test we performed is Unit Root Test to examine the time series data stationarity. We computed Augmented Dickey Fuller (SDF) test to examine the level of integration of each time series data set to achieve stationary. The test shows that Food Production Index, Population Growth and CO2 Emission achieve stationary at first differencing (intercept without trend & intercept with trend) while GDP achieve stationary at both level and first differencing (intercept without trend & intercept with trend). Water resources achieve stationary at both level and first differencing when include intercept without trend and achieve stationary at first differencing when include intercept with trend.

Next, ARDL Cointegration Bounds Test have been conducted to examine the exist of long run relationship between variables. The results shows that all independent variables namely Economic Growth, Population Growth, Carbon Footprint and Water Resources have long run relationships with Food Security. Given that there is long run relationship between variables, the ECM test has been conducted to examine the speed of adjustment of the short-term deviation move back towards the long run equilibrium. The result shows a relative high speed which is 0.878298.

Subsequently, diagnostic checking has been conducted. ARCH test has been conducted and the results proves that there have no heteroscedasticity problems in the model. LM test has been conducted and the results indicates the absence of serial correlation problems. CUSUM test has been conducted and the results indicates that the parameters are stable. Variance Inflation Factor (VIF) has conducted, and the results indicates the absence of multicollinearity problem. Lastly, normality test has been conducted and the results indicate all variables are normally distributed.

CHAPTER 5: DISCUSSION, CONCLUSION AND IMPLICATIONS

5.0 Chapter Summary

The discussion about policy implications, limitations, and recommendations are included in this chapter and serves as a conclusion for this study. The data was being analyzed and discussed to draw a conclusion on whether there is acceptance of rejection of the hypotheses in this study. The recapitulation of this study will be presented, followed by implications of several solutions on the issues found. Besides, there are a few imperfections in this particular study that will be stated followed by suggestions for future researchers that are interested in carrying out similar topics.

5.1 Summary of Major Findings

This research aims to study factors that influence food security in Malaysia. A total of 4 independent variables namely economic growth, population growth, carbon footprint, and water resources had been identified to investigate their relationship with food security in Malaysia from 1991-2020.

Primarily, the study found that economic growth (Gross Domestic Product GDP) is significantly correlated to food security in Malaysia. With a coefficient of 1.015345, economic growth has a positive impact on food security issues. On average, food security will increase by 1.015345 if economic grows by 1%. Therefore, the finding is consistent with the Keynesian Theory. The result of our finding is in tune with numerous researchers that theorized economic growth can positively affect food security (Manap & Ismail,2019). As the wellbeing of the nation will improve according to the improvement of the economy, according to Gillani et al. (2022), the results show a significant reduction of malnutrition among the South African children as the economy improves. Furthermore, the past studies of Kamenya et al. (2022) demonstrated that government intervention in improving economic growth has a positive effect on food security issues, the result shows that in 9 ECOWAS countries there is a 0.2% decrease in undernourishment and an enhanced average dietary energy supply sufficiency with 1 unit increase in public agricultural spending in between 2000 - 2016. As a result, economic growth has a positive impact on food security issues.

Secondly, the study found that population growth has an adverse relationship with food security with a coefficient value of -1.296823. For every 1% growth of population leads to 1.296823 decreases in food security. The result was consistent with the Neo-Malthusian Theory, where population growth has an adverse relationship with food security. Agarwal (2022) and Kousar et al. (2021) both stated that as the food production grows arithmetically while population grows exponentially, which population grows is crucial in causing the heightened demand for food (UNDESA, 2021). Our results are consistent with many of the past research. Obinna (2021) conducted research between the population growth and food security in Nigeria, it was resulted as a negative relationship. Moreover, Ceesay and Ndiaye (2022) also obtained a consistent result. Population growth leads to overexploitation of land and natural resources, leading to a drop of arable land eventually reducing the food production and threatening food security (Maja & Ayano, 2021). Consequently, a rise in population growth significantly decreases the food security in a nation.

Thirdly, the result of carbon dioxide emission with a coefficient value of 1.876049 has a positive relationship with food security. If CO2 increases by 1%, food security will increase by 1.876049%. The finding is however consistent with the Photosynthesis Theory stating that agricultural growth relies on carbon dioxide. Carbon dioxide is one of the vital elements to facilitate the photosynthesis process. This finding of our study is in sync with much past research stating that carbon dioxide emission has a positive impact on food security (Lobell & Field, 2008, Ejemeyovwi et al., 2018, Ainsworth & Long, 2020, and Chansdio et al., 2020). In accordance with the research of Ejemeyovwi et al. (2018), the study obtained a positive relationship between

CO_2 emission and crop production in Africa. Besides, Chansdio et al. (2020) has also obtained the positive relationship between CO_2 emission and agriculture production in China in both short-run and long-run. Therefore, this proof that carbon dioxide (CO_2) emission will positively affect food security by prompting crop productions through photosynthesis.

Lastly, our fourth objective - water resources is too consistent with the Photosynthesis Theory where water has a positive impact on food security in Malaysia in terms of prompting crops production. If water resources increase by 1%, food security will increase by 0.494251%. Water is the vital element in agricultural production in terms of nourishing the crops and promotes photosynthesis to increase crop yields. In the finding of Asibi et al. (2019), polluted water resources pose a potential threat to food security as it will reduce the crop yields. According to Qureshi et al. (2013), lower water availability in a nation will adversely affect the overall food production, resulting in insufficient food supply, and a spike in food price in the agricultural market. Besides, Hadush (2018) stated in his research in Tigrai, Ethiopia, it is found that water availability has a positive impact on household food security through livestock production. Hence, increasing water resources will increase food production, gradually improving food security issues in Malaysia.

5.2 Implications of Study

5.2.1 Smart Farming

To meet the demands of a population that continues to expand and to foster economic growth with finite natural resources, it is essential to prioritize achieving higher crop yields and utilizing natural resources efficiently. Smart farming encompasses the utilization of modern information and communication technologies to effectively manage agricultural operations, with the aim of increasing both the quantity and quality of products while simultaneously optimizing resource utilization (Sciforce, 2023). The technologies utilized in smart farming include sensors, big data analytics, drones, satellites, robots, and the Internet of Things (IoT).

According to Javaid et al., 2022, implementation of Smart Farming can enhance farmers' working hours by enabling remote handling of numerous tasks. The integration of sensors, drones, satellite imagery, and meteorological data creates a comprehensive information ecosystem that allows for remote monitoring. Sensors play a pivotal role in facilitating real-time monitoring of both environmental conditions and field parameters (Cherlinka, 2023). It can be utilized by farmers to gather data on diverse metrics, encompassing light, temperature, soil quality, humidity, CO2 levels, and insect infestations, across various microclimates and ecosystems within the field (Javaid et al., 2022). Drones and satellites equipped with cameras provides updated imagery enable growers remotely monitor their land, identify and address issues efficiently without the necessity of physically visiting the field (Cherlinka, 2023). Furthermore, the incorporation of Internet of Things (IoT) technology fosters seamless connectivity among diverse farm devices and systems, empowering farm managers to remotely monitor agricultural conditions via smartphone or desktop computer interfaces (Javaid et al., 2022).

According to Sciforce (2023), smart farming facilitates precision agriculture, a method that enhances control and accuracy in farming. Precision farming allows decisions to be made on a per square meter or even per plant/animal basis, which is in contrast to the traditional approach of making decisions at the field level (Sciforce, 2023). In essence, precision agriculture ensures that plants and livestock receive customized treatment, determined by highly accurate machines. Precision farming is essential because conditions within fields can vary, requiring different approaches (The Top Ten Benefits of Smart Farming, 2021). Factors such as soil composition and terrain can differ even within a single field, affecting the amount of spray or fertilizer needed. To address this variability, farmers utilize big data analytics to analyze extensive agricultural data. This helps them determine the precise amounts of water, fertilizer, and pesticides required for their crops (Javaid et al., 2022). For example, Variable Rate Application which is a technology enables automated application of agricultural input (Igor, 2018), automatically adjusts the flow of spray according to prescribed plans making sure exactly the right amount of application is delivered to the right location (The Top Ten Benefits of Smart Farming, 2021).

Traditional farming methods frequently lead to both under and over-application of sprays (The Top Ten Benefits of Smart Farming, 2021). Smart farming empowers farmers to respond appropriately after receiving comprehensive digital analyses of their crops in real-time, eliminating the necessity for unnecessary application of pesticides, fertilizers, and irrigation (Javaid et al., 2022). For example, smart farming technologies can decrease over-spraying by automatically shutting off sections of the sprayer when the tractor reaches the end of a field (The Top Ten Benefits of Smart Farming, 2021). It could save on average 5-10% of fertilizer costs by reducing overlaps to 0%. Moreover, the utilization of Smart Farming during drilling eliminates the issue of over-seeding. (The Top Ten Benefits of Smart Farming, 2021).

Smart Farming offers a practical advantage in ensuring food security by mitigating the risk of sudden food shortages caused by crop disease outbreaks. Through its preventive measures against crop diseases, Smart Farming also contributes to maintaining food safety. Precision livestock farming, made possible by Smart Farming technology, empowers farmers to monitor individual animal needs more effectively and adjust nutrition accordingly. This proactive approach reduces the likelihood of disease and enhances herd health (Sciforce, 2023). Additionally, the utilization of wireless IoT applications by large farm owners enables them to closely monitor the location, well-being, and health of their cattle. By swiftly identifying and isolating sick animals, farmers can prevent the spread of disease within the herd (Sciforce, 2023).

5.2.2 Water Resources Tax Scheme

China has introduced a comprehensive water resource tax system, consisting primarily of a water resource tax and a water pollution tax. The water pollution tax consists of taxes on industry output where the tax rate is based on the amount of pollution generated in producing that output—what economists call Pigovian taxes. The purpose of the water resource tax is to address resource scarcity by encouraging water conservation, while the water pollution tax aims to offset environmental damage caused by water usage and discourage the discharge of pollutants. These two taxes work together to form a cohesive system for managing water resources. It is suggested that the Malaysian government consider implementing a similar tax system to safeguard the nation's food security.

The water resource tax operates under the principle of "user pays," where those who withdraw water resources are responsible for paying the tax. This principle dictates that all costs associated with resource use should be factored into the prices of goods and services (SECT 11 Meaning of User Pays Principle, 2011). Consequently, the production of goods incurs the water resource tax when utilizing water resources.

On the other hand, the water pollution tax operates based on the "polluter pays" principle, where polluters bear the costs of pollution prevention and control measures mandated by public authorities (Guo et al., 2018; OECD, 2021). This tax is imposed in conjunction with the discharge of water pollutants during the production process. It encompasses taxes on industrial output, with the tax rate determined by the amount of pollution generated in producing the output—known as Pigovian taxes by economists (Xin et al., 2022). The purpose of this tax is to introduce price signals into the economic system, prompting consumers to consider the environmental impact of goods when making purchasing decisions (Guo et al., 2018).

According to Xin et al. (2022), the incorporation of water resources into production factors increases production costs, with producers bearing part of the tax burden. However, some of this burden is passed downstream, leading to higher prices for downstream commodities and ultimately reducing consumer demand. This, in turn, prompts producers to reduce output, resulting in a decrease in GDP. To enhance competitiveness, some producers may innovate to reduce costs, such as by decreasing water pollutant discharge and improving water resource efficiency. Consequently, the water tax system can restrain industries with high water consumption and pollution, encouraging a shift towards greener economic development.

In conclusion, China's water resource tax system has encouraged water conservation and pollution reduction. This taxation system could serve as a crucial instrument in controlling water resources to ensure sufficient supply for agricultural use. Malaysia could benefit from adopting a similar taxation system for addressing water management challenges and ensuring long-term food security.

5.2.3 Wastewater Recycling Policy

Israel utilizes wastewater for irrigation, with approximately half of the irrigation water coming from treated wastewater (Zach, 2017). This is made possible by Israel's wastewater recycling policy, which has led to the establishment of an advanced wastewater reuse system, enabling unlimited irrigation with treated effluent. This comprehensive policy is supported by legal foundation, technological, economic strategies and regulatory support aimed at maximizing the reuse of treated wastewater for agricultural purpose (Zach, 2017). It is highly advisable for the Malaysian government to consider implementing a similar policy to ensure an adequate water supply for the agricultural sector.

Israel's legal and regulatory foundation is a crucial component in the integrated water resource management. The establishment of The Water Law recognizing all water sources as public property, sets the stage for a centralized approach to water resource management (Zach, 2017). This foundation is further strengthened by the establishment of the national Water Authority, which accounted for overall responsibility for water, sewage, and water resources management policy (Zach, 2017). This centralized management is crucial for controlling and protecting Israel's water resources, enabling the implementation of wastewater recycling policy.

A key element of Israel's policy has been the substantial investment in wastewater treatment infrastructure. The transition from primary treatment standards to tertiary treatment ensuring the effluent quality is safe for irrigation of all agricultural crops, enabling the use of treated wastewater for unlimited irrigation (Zach, 2017). This was achieved through the adoption of advanced treatment technologies, including nitrogen and phosphorus reduction, filtration, and disinfection processes. The infrastructure development was not just about improving water quality; it was also a strategic move to increase the availability of water for agricultural use, thereby supporting the nation's food security.

Economic strategies are crucial for the success of Israel's wastewater recycling policy. The implementation of water tariffs has facilitated full cost recovery in the water sector, encompassing the expenses of wastewater treatment (Zach, 2017). Consequently, water prices have risen, with domestic consumers now paying around 2.5 Euro per cubic meter of potable water, while farmers pay only 0.4 Euro per cubic meter of treated effluent (Zach, 2017). This differential pricing incentivizes farmers, who are the primary beneficiaries of treated wastewater, by offering them significantly lower rates compared to potable water. This economic feasibility ensures the resilience and productivity of the agricultural sector, which is essential for the country's food security, particularly in the context of water scarcity challenges.

Regulatory support further bolsters the policy framework. The establishment of stricter quality criteria for treated wastewater has enabled its use in unlimited irrigation, ensuring that agricultural productivity is not compromised. Moreover, national policy advocates for gradually replacing freshwater allocations for agriculture with reclaimed effluents (Zach, 2017).

The impact of the wastewater policy is substantial. According to Zach (2017), treated wastewater accounts for approximately 21% of Israel's total water consumption and around 45% of agricultural usage. 97% of the sewage is collected and approximately 85% of it reused, the success of the wastewater recycling policy is evident. This underscores the importance of adopting a similar approach by the Malaysian government to safeguard water resources for the agricultural sector and bolster food security.

5.3 Limitations

This analysis presents certain limitations that should be acknowledged and considered by future researchers. Firstly, our study focused solely on one developing country - Malaysia. This was due to the unavailability of data from other developing nations. As suggested by Owen (2023), there are up to 51 countries struggling with food security difficulties that have yet to be thoroughly examined and addressed in this study. Consequently, the gap of this study lacked a comprehensive understanding of the food security issue in these neglected countries. Therefore, we strongly recommend that future researchers are able to dedicate their attention to these overlooked countries, to provide a more comprehensive perspective of food security issues on a global scale.

5.4 Recommendations

In our study, we refrained from including certain variables such as arable land for agriculture use, due to a lack of available data. However, we propose and strongly advocate for increased transparency in the release of previously researched data by governments and legal authorities. This transparency would not only enrich the pool of information available for future studies on food security issues but also enhance the precision and reliability of their test results. By making historical research data openly accessible, governments can empower researchers to conduct more comprehensive and nuanced analyses. This, in turn, facilitates a deeper understanding of the complexities surrounding food security, allowing policymakers to make more informed decisions that can effectively address and improve societal situations.

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Appendices

Appendix 1: Augmented Dickey Fuller Test (ADF)

Level Form: Intercept Without Trend

Null Hypothesis: LNFOOD has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.246547	0.9213
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	

Null Hypothesis: LNGDP has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.906471	0.0005
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	

Null Hypothesis: LNPOPULATION has a unit root
Exogenous: Constant
Lag Length: 2 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		1.400432	0.9985
Test critical values:	1% level	-3.699871	
	5% level	-2.976263	
	10% level	-2.627420	

Null Hypothesis: LNCO2 has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.323160	0.9096
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	

Null Hypothesis: LNWATER has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.531779	0.0142
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	

First Difference: Intercept Without Trend

Null Hypothesis: D(LNFOOD) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.751803	0.0086
Test critical values:	1% level	-3.689194	
	5% level	-2.971853	
	10% level	-2.625121	

Null Hypothesis: D(LNGDP) has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-7.320619	0.0000
Test critical values:	1% level	-3.699871	
	5% level	-2.976263	
	10% level	-2.627420	

Null Hypothesis: D(LNPOPULATION) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.865538	0.0623
Test critical values:	1% level	-3.689194	
	5% level	-2.971853	
	10% level	-2.625121	

Null Hypothesis: D(LNCO2) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.518439	0.0001
Test critical values:	1% level	-3.689194	
	5% level	-2.971853	
	10% level	-2.625121	

Null Hypothesis: D(LNWATER) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.198590	0.0002
Test critical values:	1% level	-3.689194	
	5% level	-2.971853	
	10% level	-2.625121	

Level Form: Intercept With Trend

Null Hypothesis: LNFOOD has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.041734	0.5542
Test critical values:	1% level	-4.323979	
	5% level	-3.580622	
	10% level	-3.225334	

Null Hypothesis: LNGDP has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.225347	0.0011
Test critical values:	1% level	-4.309824	
	5% level	-3.574244	
	10% level	-3.221728	

Null Hypothesis: LNPOPULATION has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.073763	0.5373
Test critical values:	1% level	-4.323979	
	5% level	-3.580622	
	10% level	-3.225334	

Null Hypothesis: LNCO2 has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.635703	0.7534
Test critical values:	1% level	-4.309824	
	5% level	-3.574244	
	10% level	-3.221728	

Null Hypothesis: LNWATER has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.019221	0.1449
Test critical values:	1% level	-4.323979	
	5% level	-3.580622	
	10% level	-3.225334	

First Difference: Intercept With Trend

Null Hypothesis: D(LNFOOD) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.714756	0.0379
Test critical values:	1% level	-4.323979	
	5% level	-3.580622	
	10% level	-3.225334	

Null Hypothesis: D(LNGDP) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-7.149222	0.0000
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

Null Hypothesis: D(LNPOPULATION) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.078071	0.0178
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

Null Hypothesis: D(LNCO2) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 0 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.580140	0.0005
Test critical values:	1% level	-4.323979	
	5% level	-3.580622	
	10% level	-3.225334	

Null Hypothesis: D(LNWATER) has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 1 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.606933	0.0481
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

Appendix 2: ARDL Cointegration Bounds Test

Extension Model

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LNFOOD)
Selected Model: ARDL(1, 1, 2, 2, 3)
Case 2: Restricted Constant and No Trend
Date: 03/05/24 Time: 01:43
Sample: 1991 2020
Included observations: 26

Levels Equation
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNGDP	1.015345	0.308046	3.296084	0.0064
LNPOPULATION	-1.496823	0.449807	-3.327703	0.0060
LNCO2	1.876049	0.525002	3.573414	0.0038
LNWATER	0.494251	0.156817	3.151762	0.0083
C	-0.036209	0.020484	-1.767667	0.1025

EC = LNFOOD - (1.0153*LNGDP -1.4968*LNPOPULATION + 1.8760
*LNCO2 + 0.4943*LNWATER - 0.0362)

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	7.718516	10%	2.2	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37
Actual Sample Size	26		Finite Sample: n=35	
		10%	2.46	3.46
		5%	2.947	4.088
		1%	4.093	5.532
			Finite Sample: n=30	
		10%	2.525	3.56
		5%	3.058	4.223
		1%	4.28	5.84

Appendix 3: Error Correction Model

ARDL Error Correction Regression
Dependent Variable: D(LNFOOD)
Selected Model: ARDL(1, 1, 2, 2, 3)
Case 2: Restricted Constant and No Trend
Date: 03/05/24 Time: 03:07
Sample: 1991 2020
Included observations: 26

ECM Regression
Case 2: Restricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNGDP)	0.465544	0.131703	3.534795	0.0041
D(LNPOPULATION)	-0.941726	0.175415	-5.368555	0.0002
D(LNPOPULATION(-1))	0.849005	0.186939	4.541620	0.0007
D(LNCO2)	0.232410	0.087834	2.646007	0.0213
D(LNCO2(-1))	-0.855276	0.108961	-7.849341	0.0000
D(LNWATER)	-0.034065	0.054853	-0.621017	0.5462
D(LNWATER(-1))	-0.445855	0.119919	-3.717968	0.0029
D(LNWATER(-2))	-0.263600	0.069916	-3.770213	0.0027
CointEq(-1)*	-0.878298	0.108434	-8.099839	0.0000

Appendix 4: ARCH Test

Heteroskedasticity Test: ARCH

F-statistic	0.257014	Prob. F(1,26)	0.6165
Obs*R-squared	0.274075	Prob. Chi-Square(1)	0.6006

Appendix 5: LM Test

Breusch-Godfrey Serial Correlation LM Test:
Null hypothesis: No serial correlation at up to 2 lags

F-statistic	0.675456	Prob. F(2,23)	0.5187
Obs*R-squared	1.608829	Prob. Chi-Square(2)	0.4473

Appendix 6: Variance Inflation Factor (VIF)

Variance Inflation Factors
Date: 03/05/24 Time: 04:00
Sample: 1991 2020
Included observations: 29

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	0.000164	4.181177	NA
LNGDP	0.030180	3.083642	1.192396
LNPOPULATION	0.056728	2.342201	1.092087
LNCO2	0.030205	1.394708	1.119700
LNWATER	0.010207	1.194370	1.142283