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Impact Assessment and Loss Evaluation of Climate Change on the Economic Growth of Thailand's Agricultural Sector

Itthirit Wongchai[a], Kittipat Santaveesuk[b] and Wittawat Kadthan[c,*]

[a,c] School of Economics and Investment, Bangkok University, Thailand
[b] Faculty of Business, Economics and Communications, Naresuan University, Thailand

* Corresponding author e-mail: wittawat.k@bu.ac.th Tel. 668 84 259 7937

Abstract

This study investigates the impact of climate change on Thailand's agricultural sector, one of the very vital areas in the Thai economy. Using time series data from 1993 to 2023 and employing an Autoregressive Distributed Lag model, this study examines the relationship between climate variables-temperature and rainfall-and agricultural GDP. The findings indicate that there was a significant threat from climate change to agricultural productivity in Thailand. Specifically, a 1% rise in temperature reduces agricultural GDP growth by 1.58% in the short run and 1.23% in the long run, while an increase in rainfall variability by 1% reduces the growth in the short run by 0.15% and also declines in the long run by an equal magnitude of 0.14%. The study also analyzes other variables that affect the sector, including fertilizer application and agricultural employment. Increased fertilizer use is found to have a negative effect on agricultural GDP growth, reflecting potential inefficiencies in its application. Similarly, increased agricultural-labor employment does not result in a proportional increase in output. The combined estimated effect of climate change and the additional factors mentioned above on agricultural GDP could result in an annual contraction of 1.72%. Looking ahead, this would translate into a drop of 15 percent in agricultural GDP by 2027, based on no adaptation measures and thus huge economic losses. The key findings of this paper highlights the importance of resilience strategies to address climate changes via investments in climate-smart agriculture, enhancements in water management techniques, and sustainable farming through which these negative impacts can be mitigated or reduced.

Keywords: Climate Change, Agricultural GDP, Adaptive Strategies.

1. Introduction

Climate change is a critical issue impacting various sectors globally, particularly the agricultural sector, which is one of the most vulnerable to climate variability. Thailand's economy has long relied heavily on agriculture as a source of income and employment, especially for rural populations. Key agricultural products, including rice, sugarcane, rubber, and various fruits, are crucial export commodities, significantly contributing to the national income and employment. In 2020, Thailand's agricultural sector accounted for approximately 8.6% of the country's GDP and employed around 30% of the total labor force (Waqas, Naseem, Humphries, & Hlaing, 2024), underscoring its economic significance.

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However, climate change presents substantial challenges to agriculture. Changes in temperature and rainfall patterns negatively affect crop growth and yield. Rising temperatures can inhibit the growth of certain crops, droughts can lead to crop wilting and reduced yields, and floods can damage agricultural land, resulting in income losses for farmers (Boonwichai, Shrestha, Babel, & Shrestha, 2018). Additionally, the increasing unpredictability of rainfall patterns exacerbates both floods and droughts, posing serious threats to agricultural regions. For instance, rice, a staple crop in Thailand, is particularly sensitive to these climatic shifts (Arunrat, Pumijumnong, & Sereenonchai, 2020).

Examining the impacts of climate change on agriculture is essential to develop adaptive strategies that mitigate its adverse effects. Analyzing the relationship between climatic variables and economic growth in Thailand's agricultural sector will provide valuable insights into the problem's scale, enabling sustainable agricultural development planning. Assessing the positive and negative impacts of climate change will inform the formulation and implementation of adaptive strategies to withstand evolving climatic conditions (Pipitpukdee, Attavanich, & Bejranonda, 2020). These findings can also serve as a foundation for public policy aimed at strengthening and securing the agricultural system to promote food security and economic stability (Attavanich, 2013).

This study utilizes an Autoregressive Distributed Lag (ARDL) model to examine the relationship between climate variables (temperature and rainfall) and agricultural GDP in Thailand using time series data from 1993 to 2023. The ARDL approach was chosen for its ability to handle variables with different orders of integration and provide both short-run and long-run estimates. Additionally, we employ a Total Factor Productivity (TFP) analysis to assess the efficiency of agricultural production factors. The combination of these methodologies allows for a comprehensive assessment of climate change impacts while controlling for other relevant economic factors.

2. Literature Reviews

2.1 Thailand's Agricultural Gross Domestic Product (GDP)

Thailand's agricultural sector has long been a cornerstone of its economy, significantly influencing the nation's Gross Domestic Product (GDP) and providing employment for a substantial portion of the population. As of 2020, the agricultural sector accounted for approximately 8.6% of Thailand's GDP and employed around 30% of the labor force, underscoring its importance in both economic and social contexts (Sampaothong & Attavanich, 2021; Mata et al., 2021). The agricultural GDP includes a diverse range of products, notably rice, sugarcane, rubber, and various fruits, which not only support domestic food security but also contribute significantly to export revenues, thus enhancing the balance of trade (Sampaothong & Attavanich, 2021).

The dynamics of Thailand's agricultural GDP are influenced by several critical factors, including land use, productivity enhancements, and technological advancements. For instance, the country's focus on export-oriented agricultural policies has led to an emphasis on high-value crops, which has, in turn, driven productivity improvements within the sector (Sampaothong & Attavanich, 2021). Furthermore, the integration of sustainable agricultural practices has gained traction, as local NGOs and

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government initiatives aim to empower small-scale farmers and promote agroecological principles (Amekawa, 2010). Despite the sector's declining share in the overall GDP due to industrialization and urbanization, agriculture remains vital for rural economies and is increasingly recognized as a key area for development and sustainability initiatives (Amekawa, 2010).

Moreover, the agricultural sector's contribution to GDP is not merely a reflection of its output but is also intertwined with broader economic trends, including urbanization and industrial growth. Research indicates that while agriculture's share of GDP may be diminishing, its role in supporting rural livelihoods and food security remains critical (Mata et al., 2021). The sector's resilience is further tested by challenges such as climate change and water resource management, which necessitate adaptive strategies to ensure sustainable agricultural practices (Jitanugoon, 2021). As Thailand continues to navigate these complexities, the agricultural sector's ability to innovate and adapt will be crucial for maintaining its economic significance and supporting the livelihoods of millions.

In summary, Thailand's agricultural sector is a vital component of the national economy, contributing significantly to GDP and employment. While facing challenges from industrialization and climate change, the sector's focus on sustainability and productivity enhancements positions it as a key player in the country's economic landscape

2.2 Climate Change

Climate change refers to long-term alterations in temperature, precipitation patterns, and other atmospheric conditions, primarily caused by human activities such as deforestation, industrial emissions, and the burning of fossil fuels (Praveen & Sharma, 2019). These changes are evident through global warming, shifting weather patterns, and an increase in the frequency and severity of extreme weather events. Climate change poses substantial challenges to ecosystems, biodiversity, and human societies, impacting agriculture profoundly. Altered precipitation patterns can result in droughts or floods, affecting water availability and crop yields (Mahato, 2014). Rising temperatures stress crops, modify growing seasons, and heighten pest and disease pressures (Calzadilla et al., 2013). For nations like Thailand, where agriculture is a significant economic sector, understanding and addressing the impacts of climate change is essential to ensure food security, protect livelihoods, and sustain economic growth (Wiebe et al., 2015). Adaptation strategies, including the development of climate-resilient crops, improved water management, and enhanced agricultural practices, are crucial for addressing the challenges of a changing climate (Howden & Soussana, 2007).

2.3 Related Literature

Numerous studies have explored the impacts of climate change on agricultural production, offering critical insights into the vulnerabilities and adaptive capacities of various regions. For example, Lobell, Schlenker, and Costa-Roberts (2011) examined global crop production trends since 1980, revealing that rising temperatures and altered precipitation patterns have significantly decreased yields of staple crops such as wheat, maize, and rice, underscoring the urgent need for adaptive agricultural practices to protect food security. Similarly, a study by Xie, Zhang, and Wu (2018) in China demonstrated that technological advancements in agriculture, such as heat-resistant crop

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varieties and enhanced irrigation systems, effectively mitigate the adverse effects of climate variability on crop yields.

In the United States, Brown et al. (2019) emphasized the importance of water management in adapting to climate change. Their research indicated that precision irrigation and water-saving technologies could mitigate drought impacts significantly, ensuring more stable crop production amid fluctuating water availability. This approach is particularly relevant in regions facing severe water scarcity due to climate changes. Additionally, Adger et al. (2017) studied organic farming in Europe, finding that biodiversity- and soil-health-focused practices enhance agricultural resilience to climate variability. Organic farming not only increases yields but also contributes to long-term sustainability.

In the Southeast Asian context, Punyawardhana (2013) explored the impact of climate change on rice production in Thailand, highlighting the crop's sensitivity to temperature and rainfall variations. This study stresses the need for regional adaptation strategies, such as climate-resilient rice varieties and optimized water management practices, to safeguard rice production from climate-related challenges. Collectively, these studies provide a comprehensive understanding of how climate change affects agriculture globally and underscore the importance of tailored adaptation strategies to build resilience.

2.4 The Agricultural Situation in Thailand

Thailand's agricultural sector is a cornerstone of its economy, significantly contributing to GDP and providing employment for a large portion of the population. As of 2023, the agricultural sector accounted for approximately 5.995% of the country's real GDP (production approach, seasonal adjusted) (Office of the National Economic and Social Development Council, 2024) and employed around 30% of the total labor force (World Bank, 2023). Key agricultural products include rice, sugarcane, rubber, and a variety of fruits, all of which are crucial both for domestic consumption and export. Thailand is one of the world's leading rice exporters, with major rice-producing regions in the Central Plains, Northeast, and North of the country. Sugarcane, another significant crop, is primarily grown in the Central and Northeastern regions, positioning Thailand as one of the top sugar exporters globally. Rubber plantations, mostly found in the Southern region, make Thailand the world's largest producer and exporter of natural rubber. Additionally, Thailand is known for its diverse range of tropical fruits such as durian, mango, pineapple, and longan, which are major export commodities.

Despite its critical role, the sector faces several challenges, including the impacts of climate change, fluctuating market prices, and water resource management issues. Climate change, in particular, poses a significant threat by altering precipitation patterns and increasing the frequency of extreme weather events, leading to crop failures and reduced agricultural productivity. The following graph illustrates the trend in Thailand's agricultural GDP (% of real GDP [Production approach]) from 1993 to 2023, showing a general decline with some fluctuations, highlighting the sector's vulnerability to external shocks and the need for sustainable practices and technological advancements to ensure resilience.

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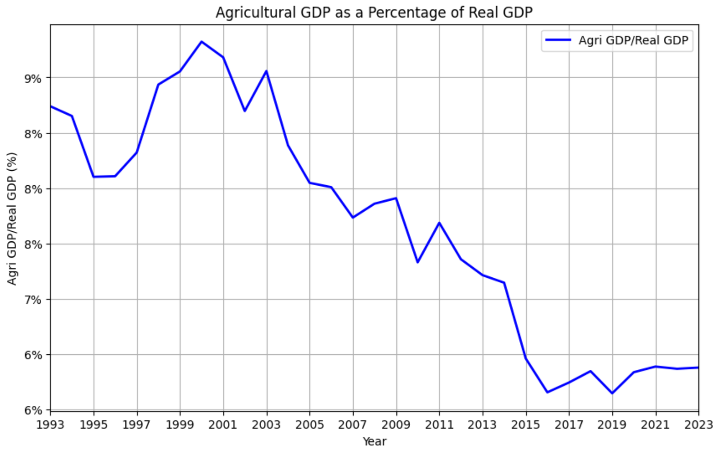

Figure 1 GDP in Agriculture sector (% of Real GDP [production approach]) in Thailand (1993-2023)

Source: Office of the National Economic and Social Development Council (2024)

2.5 Climate Change in Thailand: An Overview

Climate change has become an increasingly critical issue affecting Thailand's environment, economy, and society. According to the World Bank's Climate Knowledge Portal, Thailand has experienced significant climatic changes over the past decades, characterized by rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events. These changes pose substantial risks to various sectors, especially agriculture, which is highly sensitive to climatic variability.

Rising Temperatures

Thailand has observed a consistent increase in average temperatures. The data from the World Bank indicates that the annual mean temperature has risen by approximately 1-1.5°C over the past century. This increase in temperature contributes to several adverse effects, such as heat stress on crops, altered growing seasons, and increased evaporation rates, which can reduce water availability for irrigation.

Changing Precipitation Patterns

Precipitation patterns in Thailand have become more erratic, with some regions experiencing more intense rainfall while others face prolonged dry spells. This variability in rainfall poses significant challenges for water resource management and agricultural planning. Regions that depend heavily on consistent rainfall for crop production are particularly vulnerable to these changes.

Increased Frequency of Extreme Weather Events

The frequency and intensity of extreme weather events, including floods, droughts, and tropical storms, have increased in Thailand. These events can cause severe damage to infrastructure, disrupt agricultural activities, and lead to substantial economic losses. For instance, the devastating floods in 2011 affected large parts of the country, resulting in significant damage to agricultural lands and a considerable decline in crop yields.

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2.6 The impacts of climate change on agriculture

The impacts of climate change on agriculture are multifaceted and extensive, affecting crop yields, soil health, water availability, and pest dynamics. Various studies have provided in-depth analyses of these impacts, highlighting the urgent need for adaptive strategies to ensure food security and sustainable agricultural practices.

Crop Yields and Productivity

Climate change has a direct impact on crop yields and productivity. Increasing temperatures and changing precipitation patterns can reduce the growth period of crops, alter flowering times, and affect the overall biomass. Lobell et al. (2011) found that global warming has significantly reduced yields of major crops such as wheat, maize, and rice, with some regions experiencing up to a 10% decline in productivity. In Thailand, rice production is particularly vulnerable, with studies showing that higher temperatures during the growing season can reduce yields by as much as 15% (Punyawardhana, 2013).

Soil Health

Soil health is another critical factor influenced by climate change. Increased temperatures can accelerate soil organic matter decomposition, leading to reduced soil fertility. Additionally, erratic rainfall and extreme weather events can cause soil erosion and loss of arable land. Lal (2004) emphasized that soil degradation due to climate change poses a significant threat to global food security, requiring urgent measures to improve soil management practices.

Water Availability

Water availability is a major concern in the context of climate change. Changes in precipitation patterns can lead to water scarcity or flooding, both of which negatively impact agricultural activities. Brown et al. (2019) highlighted that effective water management strategies, such as precision irrigation and the use of drought-resistant crop varieties, are essential to mitigate the impacts of water variability on agriculture. In Thailand, the increasing frequency of droughts has led to significant reductions in crop yields and agricultural productivity (FAO, 2020).

Pest and Disease Dynamics

Climate change also affects pest and disease dynamics, which can have severe implications for agriculture. Rising temperatures and changing humidity levels can expand the range and lifecycle of pests and pathogens, leading to increased crop damage. Chakraborty and Newton (2011) noted that climate change could exacerbate pest and disease outbreaks, making it more challenging to protect crops. In Thailand, the spread of pests such as the brown planthopper has been linked to changing climatic conditions, resulting in substantial losses in rice production (Horgan, 2017).

Extreme Weather Events

The increasing frequency and intensity of extreme weather events, such as floods, droughts, and storms, pose significant risks to agriculture. These events can destroy crops, disrupt planting and harvesting schedules, and cause long-term damage to agricultural infrastructure. The devastating floods in Thailand in 2011 serve as a stark

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reminder of the vulnerability of the agricultural sector to extreme weather, with losses estimated at over $40 billion, affecting millions of hectares of farmland (World Bank, 2012).

Adaptive Strategies

Given the extensive impacts of climate change on agriculture, adaptive strategies are crucial to enhancing the resilience of the sector. These strategies include developing climate-resilient crop varieties, improving water management systems, adopting sustainable farming practices, and enhancing soil health through conservation agriculture. Liu et al. (2018) demonstrated that technological advancements in agriculture, such as precision farming and the use of climate-smart technologies, can significantly mitigate the adverse effects of climate change and improve agricultural productivity.

3. Materials and Methods

3.1 Materials

The time series data used in this study were sourced from various institutions and ranged from 1993 to 2023. A summary of the variables used in the analysis, together with their definitions, units, and sources, is shown in Table 1.

Table 1 Summary of the variables, definitions, units, and sources

Variables	Definition/ Unit	Source
GDP_AGRI	Real GDP (production approach) in the Agriculture Sector, in Thai Million THB	Office of the National Economic and Social Development Council, Thailand
Climate variable		
Temperature	Country Average in Celsius	Thai Meteorological Department
Rain	Yearly Mean Rainfall in Thailand (mm)	Hydro Data Science Section, Hydro Informatics Institute, Thailand
Economic Variables in Agriculture		
NB_AGRI	Thai National Budget in the Agriculture Sector, in Thai Million THB	Budget Bureau, Thailand
CS_AGRI	Country Average Net Capital Stock in the Agriculture Sector, in Thai Thousand THB	Food and Agriculture Organization of the United Nations (FAO)
Agricultural Resources		
AGRI_land	Land Used in the Agriculture Sector, in Thousand Rai	World bank and the Office of Agricultural Economics (OAE), Thailand
Fertilizer	Country Average Fertilizer Use (Kilograms per Hectare of Arable	World Bank

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Variables	Definition/ Unit	Source
	Land)	
Production Variables		
Cereal_production	Thousand Metric Tons	World Bank
Crop_PI	Crop Production Index	World Bank
Livestock_PI	Livestock Production Index	World Bank
Labor Variables		
Employed_ AGRI	Thousand Persons Employed in the Agriculture Sector)	World Bank and The Office of Permanent Secretary, Ministry of Labour, Thailand

Notes: 1) The GDP_AGRI variable represents the gross domestic product (production approach) in chain volume measures, with the reference year set to 2002 (seasonally adjusted).

2) Capital_stock_AGRI represents the value in "local currency, 2015 prices."

3) All data from World Bank (2024) are available from World Bank Open Data, Website: https://data.worldbank.org/

3.2 Data Preprocessing

3.2.1 Data Cleansing

Collected data are cleaned to handle issues concerning quality-inaccurate, inconsistent, and missing values. Missing entries are filled using the values derived from a linear regression equation or estimated based on percentages, if available from other sources for the same period. This approach was undertaken to minimize bias and ensure data integrity that is to be used for reliable analyzing.

3.2.2 Data Preparation

1) Log Transformation or Log – Linearity Model: in order to stabilize the variance and handle any exponential growth tendencies in the data.
2) Stationarity Check or Unit Root Test: using the Augmented Dickey-Fuller Test at a 5% Significance Level. If not stationary, make the series stationary through differencing to make the mean and variance constant throughout a time series. The results are shown as table 2.

Table 2 Stationary Check Results

Variable	ADF Statistic (Before)	p-value (Before)	ADF Statistic (After)	p-value (After)
LGDP_AGRI	-2.852	0.051	-4.889	0.000
LTemperature	-1.578	0.495	-6.236	0.000
LRain	-5.850	0.000	-2.887	0.047
LNB_AGRI	-1.194	0.676	-6.850	0.000
LCS_AGRI	-1.228	0.661	-3.274	0.016
LAGRI_land	-1.127	0.704	-6.454	0.000

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LFertilizer	-0.999	0.754	-6.508	0.000
LCereal_production	-2.571	0.099	-5.286	0.000
LCrop_PI	-2.622	0.088	-3.992	0.001
LLivestock_PI	-0.378	0.914	-6.186	0.000
LEmployed _AGRI	-1.112	0.710	-3.220	0.019

Note: 1) All variables are in the stationary condition.

2) The "L" before all variables indicates the natural logarithm from the log transformation step.

3.3 Model Specification and Data Processing

The first step before determining an appropriate ARDL equation for the model is to find the optimal lag length of the equation. The researcher chose the lag length for y (dependent variable) = 0, x (Independent variables) = 0, because of lowest AIC (-134.948), BIC (-117.740), and HQIC (-129.339) values.

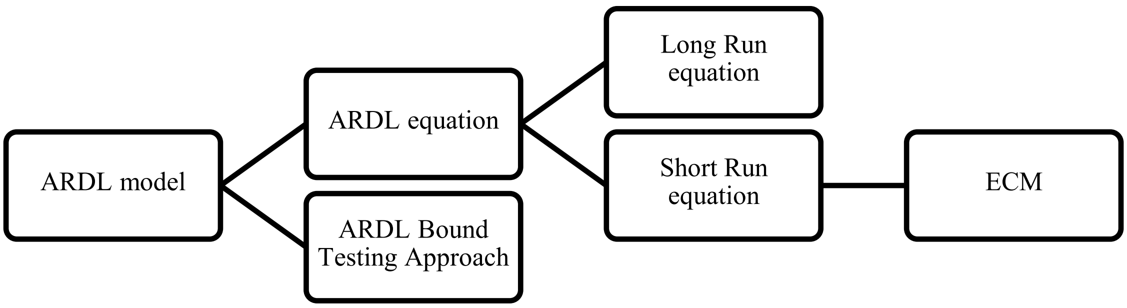

Figure 2 Elements of ARDL Model
Source: Swasdimongkol & Suksak (2018)

We will obtain the ARDL equation, consisting of two equations: the Long-Run equation and the Short-Run equation, as shown below:

$$\begin{aligned}\Delta LGDP\_AGRI_t = {} & \alpha_0 + \delta_1 \Delta LTemperature_t + \varepsilon_1 \Delta LRain_t + \sigma_1 \Delta LNB\_AGRI_t \\ & + \omega_1 \Delta LCS\_AGRI_t + \cdots + \partial_1 \Delta LEmployed\_AGRI_t + \lambda_1 LTemperature_t \\ & + \lambda_2 LRain_t + \lambda_3 LNB_{AGRI_t} + \lambda_4 LCS_{AGRI_t} + \ldots + \lambda_{10} LEmployed\_AGRI_t \\ & + u_t\end{aligned}$$

Where L = Natural Log

t = time t

0 = No Lagged Value

α_0 = Constant

$\beta_1, \delta_1, \varepsilon_1, \sigma_1, \omega_1, \ldots, \partial_1$ = Coefficient of variables in Short Run

$\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \ldots, \lambda_{10}$ = Coefficient of variables in Long Run

u_t = Error term

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1. Long-Run Relationship Analysis: it analyzes the long-run relationship of AGRI_GDP and various variables such as climate variables, economic variables in agriculture, agricultural resources, production variables, and labor variables through the **ARDL equation** with the application of an **ARDL Bound Testing Approach**. The model is specified as follows:

$$\Delta LGDP\_AGRI_t = \alpha_0 + \lambda_1 LTemperature_{t-1} + \lambda_2 LRain_{t-1} + \lambda_3 LNB_{AGRI_{t-1}} + \lambda_4 LCS_{AGRI_{t-1}} + \ldots + \lambda_{10} LEmployed\_ AGRI_{t-1} + u_t$$

2.0Then, after estimating the long-term relationships of the variables and testing the hypotheses above, the researcher will take the F-statistic derived from model-estimated after testing for Cointegration-and compare with UCB and LCB in the Bound Testing table by Pesaran et al. (2001). The method of analyzing long-term relationships that will be employed here is called **the ARDL Bound Testing Approach**.

In table 3, If the F-statistic falls between the LCB and UCB [LCB < F-statistic < UCB], one cannot conclude whether or not the variable of interest has a long-run equilibrium relationship. If the F-statistic is below the LCB [LCB > F-statistic], one can conclude there is no long-run equilibrium relationship. However, if the F-statistic is above the UCB [F-statistic > UCB], one can deduce there exists a long-run relationship.

Table 3 ARDL Bound Testing Approach Table (Unrestricted intercept and no trend)

K	10%		5%		1%	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0	6.58	6.58	8.21	8.21	11.79	11.79
1	4.04	4.78	4.94	5.73	6.84	7.84
2	3.17	4.14	3.79	4.85	5.15	6.36
3	2.72	3.77	3.23	4.35	4.29	5.61
4	2.45	3.52	2.86	4.01	3.74	5.06
5	2.26	3.35	2.62	3.79	3.41	4.68
6	2.12	3.23	2.45	3.61	3.15	4.43
7	2.03	3.13	2.32	3.5	2.96	4.26
8	1.95	3.06	2.22	3.39	2.79	4.1
9	1.88	2.99	2.14	3.3	2.65	3.97
10	1.83	2.94	2.06	3.24	2.54	3.86

Source: Pesaran et al. (2001)

Notes: 1) K represents the number of independent variables in your ARDL model (excluding the constant term)
2) 10%, 5%, 1% represent the statistical significance levels

2. Short-Run Relationship Analysis: The objective is, therefore, to examine the short-run relationship since, in the long-run under **ECM**, it explains the short-run adjustments of the variables. The equation is shown as below:

$$\Delta LGDP\_AGRI_t = \alpha_0 + \delta_1 \Delta LTemperature_t + \varepsilon_1 \Delta LRain_t + \sigma_1 \Delta LNB\_AGRI_t + \omega_1 \Delta LCS\_AGRI_t + \cdots + \partial_1 \Delta LEmployed\_ AGRI_t + \eta ECM_t + u_t$$

Where ECM_t = Error Correction Term, which is calculated from $ECM_t = \alpha_0 +$

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$\lambda_2 \text{LTemperature}_t + \lambda_3 \text{LRain}_t + \lambda_4 \text{LNB}_{\text{AGRI}_t} +$
$\lambda_5 \text{LCS}_{\text{AGRI}_t} + \ldots + \lambda_{11} \text{LEmployed\_ AGRI}_t$

3. Stability of the ARDL Model Test: The procedure involves testing the stability of the ARDL model by conducting tests, among other diagnostic checks such as serial correlation, heteroskedasticity, and model misspecification.

3.4 Total Factor Productivity (TFP) in Agriculture sector

The most important indicators used in the evaluation of production efficiency in an economy or industry are variables of total factor productivity. TFP refers to output not produced directly from inputs like labor and capital, but rather as enhanced productive capacity from knowledge, technology, or other factors that better enhance efficiency in the production process (Office of the National Economic and Social Development Council., 2007). TFP can be calculated using the equation below:

$$\text{FTP} = \frac{dY}{Y} - \alpha \frac{dK}{K} - \beta \frac{dL}{L} - \delta \frac{dN}{N}$$

Where

$$d = the\ difference\ between\ the\ value\ at\ time\ t\ and\ value\ at\ time\ t-1$$

$$\alpha, \beta, \delta = the\ ratio\ of\ each\ factor\ to\ TFP$$

$$Y = GDP, K = Capital, L = Labor, N = Land$$

Reformulating this equation to fit our variables, we obtain:

$$\text{TFP} = \frac{dGDP\_AGRI}{GDP\_AGRI} - \alpha \frac{d\text{CS\_AGRI}}{\text{CS\_AGRI}} - \beta \frac{d\text{Employed \_AGRI}}{\text{Employed \_AGRI}} - \delta \frac{d\text{AGRI\_land}}{\text{AGRI\_land}}$$

The researcher used the following values for the parameters: $\alpha = 0.6, \beta = 0.3, and\ \delta = 0.2$ values.

3.5 Economic losses

The results from ARDL model were used to evaluate the **economic losses** attributable to climate change. Projected changes in climate variables were applied to the estimated coefficients to quantify potential losses in agricultural GDP, providing a monetary valuation of the impact of climate change on Thailand's agricultural sector.

Calculate the Economic Loss

Determine the Baseline GDP: Identify the baseline GDP for the agricultural sector from reliable sources such as the World Bank.

Apply the Loss Rate: Use the estimated coefficient (loss rate) from the econometric model to calculate the economic loss. The formula for calculating the economic loss is:

$$Economic\ loss = Baseline\ GDP \times \left(\frac{Percentage\ Change\ in\ Climate\ Variable}{100}\right) \times Loss\ Rate$$

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4. Results

This study is divided into three parts: the first part is the statistical-descriptive analysis, the second part shows ADRL result, and the third part is ECM result. The details are shown as below:

4.1 Descriptive Statistics before data processing

Table 4 Descriptive Statistics before data processing

Variables	Mean	Minimum	Maximum	Standard Deviation
Dependent variable				
GDP_AGRI	567,474.84	379,366.00	693,834.00	96,678.55
Independent variables				
Climate variables				
Temperature	27.40	26.70	28.10	0.41
Rain	1,495.42	1,218.00	1,848.00	161.19
Economic variable in Agriculture				
NB_AGRI	111,042.89	33,952.58	206,810.10	59,939.24
CS_AGRI	2,230.76	1,471.64	2,996.14	470.20
Agricultural resources				
AGRI_land	143,444.13	133,359.54	152,936.15	6,306.40
Fertilizer	119.89	79.63	167.15	27.38
Production variables				
Cereal_production	34,640.66	22,017.63	43,447.71	5,571.22
Crop_PI	86.98	55.77	113.92	17.10
Livestock_PI	86.13	67.65	105.38	12.68
Labor variables				
Employed_AGRI	14,556.29	11,746.60	18,083.72	2,212.53

Notes: 1) The data covers a 30-year period from 1993 to 2023.
2) GDP_AGRI = Real GDP (production approach) in the Agriculture Sector, in Thai Million THB
3) Temperature, Country Average in Celsius, Rain, Country Average in mm
4) NB_AGRI = National budget in AGRI, unit in Thai Million THB
5) CB_AGRI = Capital_stock_AGRI, Country Average Net Capital Stock in the Agriculture Sector, in Thai Thousand THB
6) AGRI_land, Land Used in the Agriculture Sector, in Thousand Rai
7) Fertilizer, unit in Kilograms per Hectare of Arable Land
8) Cereal_production, unit in Thousand Metric Tons
9) Crop_PI = Crop production index, Livestock_PI = Livestock_produciton_index
10) Employed_AGRI, Thousand Persons Employed in the Agriculture Sector

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4.2 Short-Run Relationship Analysis Result

Performing the Cointegration test by using both the ARDL equation and the ARDL Bound Testing Approach, the methods presented the same result: that the variables tested have a long-run equilibrium relationship or coherence. With this identified relationship, it is possible to evaluate short-term adjustments or short-term relationships.

Table 5 Short-Run Relationship Analysis Result

Dependent Variable = $\Delta LGDPGRI_t$				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
α_0	0.0108	0.008	1.425	0.172
$\Delta \text{LTemperature}_t$	-1.5834	0.532	-2.975	0.008***
ΔLRain_t	-0.1491	0.079	-1.897	0.075*
$\Delta \text{LNB\_AGRI}_t$	-0.0548	0.038	-1.459	0.163
$\Delta \text{LCS\_AGRI}_t$	0.0294	0.22	0.133	0.895
$\Delta \text{LAGRI\_land}_t$	0.0708	0.354	0.2	0.844
$\Delta L\text{Fertilizer}_t$	-0.0218	0.061	-0.358	0.725
$\Delta \text{LCereal\_production}_t$	0.0689	0.143	0.481	0.637
$\Delta \text{LCrop\_PI}_t$	0.3797	0.158	2.406	0.028**
$\Delta \text{LLivestock\_PI}_t$	0.1435	0.127	1.127	0.275
$\Delta L\text{LEmployed \_AGRI}_t$	-0.0453	0.103	-0.439	0.666
ECM_t	-0.2695	0.339	-0.795	0.438
R-squared	0.724			
Adjusted R-squared	0.545			

Notes: * indicates statistical significance at the 0.10 level (90% confidence level)
** indicates statistical significance at the 0.05 level (95% confidence level)
*** indicates statistical significance at the 0.01 level (99% confidence level)

Table 5, the **Temperature** shows a negative significant impact on agricultural GDP growth at 1% with a coefficient of -1.5834. This infers that for every 1% increase in temperature, the agricultural GDP growth decreases by 1.5834%. The **Rain**, on the other hand, is significant at 10% with a coefficient of -0.1491, hence explaining that for every 1 percent increases in Rain, there will be a 0.1491% decrease in GDP growth. Other regression variables like **National Budget for Agriculture**, and **Agricultural Land** were not significant in the short run. Results show an R-square of 0.724 but an adjusted R-square of 0.545, showing variability in the short-run relationships.

4.3 Long-Run Relationship Analysis Result

The ARDL model estimations using OLS contain the F-statistic value of 3.668 and the P-value of 0.00719, which means there is a significant long-term equilibrium relationship at 1%. This result has been further authenticated through the ARDL Bound Testing Approach because the F-statistic was above the Upper Bound at the 5% level of significance, as shown in Table 3. This therefore confirms the presence of a long-run relationship between the variables.

Thereafter, we utilized the Conditional MLE method with log-linear data (L) in analyzing the change of temperature, precipitation, agricultural capital stock, land area, fertilizer use, and cereal production upon the economic output of the agricultural sector.

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The results can be viewed in Table 6.

Table 6 Long-Run Relationship Analysis Result

Dependent Variable = $\Delta LGDPGRI_t$				
Variable	**Coefficient**	**Std. Error**	**z**	**Prob.**
α_0	11.7389	4.159	2.823	0.011
$\mathrm{LTemperature}_t$	-1.2317	0.573	-2.15	0.044**
LRain_t	-0.1398	0.075	-1.853	0.079*
$\mathrm{LNB\_AGRI}_t$	-0.0236	0.041	-0.568	0.576
$\mathrm{LCS\_AGRI}_t$	0.1215	0.117	1.04	0.311
$\mathrm{LAGRI\_land}_t$	0.2199	0.337	0.652	0.522
$L\mathrm{Fertilizer}_t$	-0.1141	0.055	-2.089	0.05*
$\mathrm{LCereal\_production}_t$	0.3456	0.129	2.683	0.014**
$\mathrm{LCrop\_PI}_t$	0.4942	0.137	3.602	0.002***
$\mathrm{LLivestock\_PI}_t$	0.0576	0.112	0.516	0.612
$L\mathrm{LEmployed\ \_AGRI}_t$	-0.2297	0.078	-2.937	0.008***
Log Likelihood	79.474			

Notes: 1) * indicates statistical significance at the 0.10 level (90% confidence level)
** indicates statistical significance at the 0.05 level (95% confidence level)
*** indicates statistical significance at the 0.01 level (99% confidence level)

2) For these data, using Conditional MLE method with log-linear data (L) gives the best result compared to OLS method with differenced log-linear data (ΔL).

From table 6, The Conditional MLE method was applied to analyze the long-run relationship of factors affecting agricultural GDP growth. From the results obtained, the following important features are identified:

Temperature inversely relates to agricultural GDP growth. Hence, a 1% rise in temperature leads to a decrease of 1.23% in growth.

Rainfall was found to have a negative effect at 10% significance level, where with a 1% increase in rain, 0.14% inhibiting occurs in GDP growth.

Fertilizer use again has an inhibiting effect, suggesting the inefficiencies of its use since a 1 percent increase in the use of fertilizer leads to a 0.11 percent decrease in agricultural GDP growth.

Cereal production is positive and significant in influencing agricultural GDP: a 1 percent increase in cereal production leads to a 0.35 percent increase in GDP growth.

The crop production index is very significant, as a 1 percent increase in the index results in the growth of agricultural GDP by 0.49 percent.

Agricultural employment is negatively linked, as 1% increase in employment results in the growth of agricultural GDP by -0.23%.

Other factors like national budget share allotted to agriculture and livestock production were insignificant. This means that crop production enhancement and control over climatic factors of temperature and rainfall might provide the key to sustainable agricultural growth.

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After that, we tested stability of the ARDL Model by conducting tests, among other diagnostic checks such as serial correlation, heteroskedasticity, and model misspecification. We found that there is no any problem and the model is quite stability for most period at 90% confidence interval.

4.4 Total Factor Productivity (TFP) in Agriculture sector

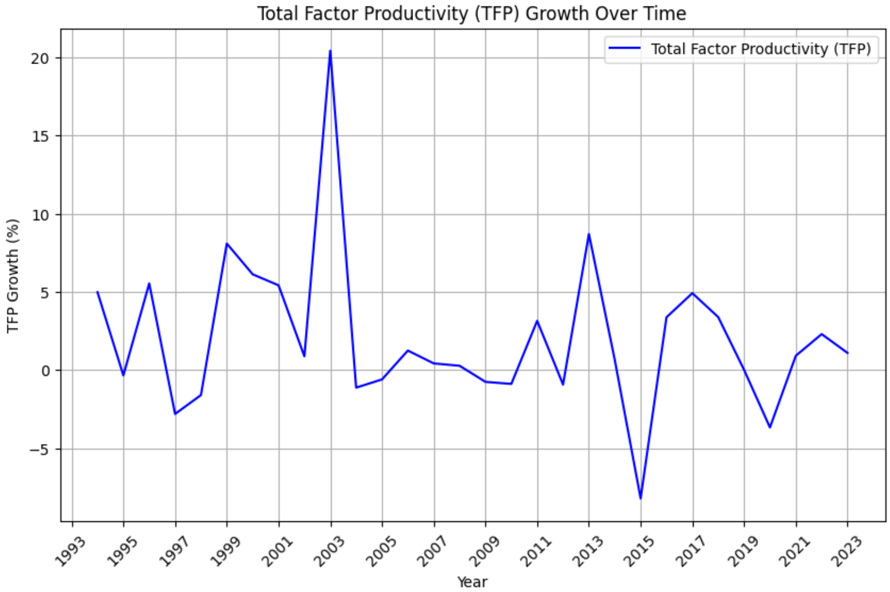

Figure 3 Total Factor Productivity (TFP) in Agriculture sector (1994-2023)

Table 7 GDP growth, Capital Growth, Labor growth, Land Use growth and TFP growth in Agriculture sector (1994-2023)

Unit: Percentage

Year	GDP_growth	Capital	Labor	Land	TFP
1993	-	-	-	-	-
1994	6.875	2.751	0.137	0.044	3.943
1995	1.244	10.807	-0.418	0.044	-9.188
1996	5.753	2.913	-0.153	0.043	2.950
1997	-0.147	1.749	0.327	0.043	-2.266
1998	-0.863	0.724	0.071	0.043	-1.700
1999	6.026	0.012	-0.351	0.043	6.323
2000	7.559	-0.278	0.250	0.043	7.544
2001	1.865	-0.279	-0.581	0.042	2.683
2002	0.533	0.205	-0.077	0.042	0.363
2003	11.611	1.022	-1.538	0.042	12.084
2004	-1.604	1.448	-0.177	0.042	-2.916
2005	-0.014	1.653	-0.012	0.042	-1.696
2006	4.468	1.978	0.406	0.042	2.042
2007	1.851	2.168	0.096	0.041	-0.454
2008	3.431	2.464	0.275	0.585	0.107

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Year	GDP_growth	Capital	Labor	Land	TFP
2009	-0.063	1.937	-0.004	-0.007	-1.989
2010	-0.398	2.939	-0.099	-0.019	-3.220
2011	5.759	3.305	0.231	-0.011	2.234
2012	2.601	3.511	0.369	0.000	-1.279
2013	0.644	3.322	-1.549	0.000	-1.128
2014	0.035	2.154	-0.237	-0.001	-1.881
2015	-6.735	1.533	0.214	-0.390	-8.093
2016	-1.466	1.500	-0.968	0.408	-2.405
2017	5.679	1.542	0.031	0.000	4.107
2018	5.919	1.537	0.327	-0.001	4.056
2019	-1.087	1.552	-0.285	0.034	-2.387
2020	-3.234	1.412	-0.009	-0.041	-4.596
2021	2.469	1.336	0.182	-0.036	0.987
2022	2.193	1.296	-0.088	-0.058	1.044
2023	2.043	-0.167	0.110	0.353	1.748
Average	**2.098**	**1.935**	**-0.117**	**0.047**	**0.234**

Source: Calculated by researcher

Figure 3 and Table 7 illustrate the trends in GDP growth, capital growth, labor growth, land use growth, and TFP growth in the agricultural sector from 1994 to 2023. Summary of Findings is below:

The trend of GDP Growth stood at an average of 2.1%, reaching a maximum of 11.6% in the year 2003 due to recovering from the Asian financial crisis but fell to -3.2% in the year 2020 due to the effects brought forth by COVID-19.

The growth of Capital has steadily ranged between 1.9%, but in the years marking a crisis, it did fall-for instance, in the years 2008 and 2020-showing responsiveness to international economic conditions.

Labor Growth averaged -0.1%, reflecting labor migration away from agriculture and the negative impact it has on sustaining workforce levels, particularly during economic downturns.

TFP growth was modest, at 0.23% overall, but had surprisingly strong gains during recovery years, while it has declined in crisis years, underlining the contribution of TFP to sustaining productivity within a framework of technological and operational advancements.

4.5 Economic Loss Assessment from Climate Change and other factors in Thailand

The assessment of economic losses due to climate change and other negative effect factors in Thailand utilizes data from the World Bank, related studies, and analysis through the Dynamic Computable General Equilibrium (DCGE) model.

This model comprehensively and accurately analyzes the economic impacts of various variables in a complete economic system.

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4.5.1 Source of Data for Loss Calculation

The data sources for calculating the economic loss are derived from our own improved econometric model combined with results from previously conducted studies, such as those from the World Bank.

4.5.2 Economic Losses from Temperature Change

Climate change could even give rise to long-term agricultural GDP decline in Thailand. Every year, Thailand also suffers from economic losses linked to climate change, amounting to about 2.5% of agricultural GDP (World Bank, 2023). From this study, based on the coefficients derived from the ARDL model, a rise in the average temperature by 1 degree Celsius reduces agricultural GDP by approximately 1.5834% in the short run relationship and 1.2317% in the long run relationship. We shall consider both coefficients in calculating the economic loss from its short-run and long-run effects.

4.5.3 Economic Losses from Rainfall Variability

This implies that with every 1% increase in the variability of rainfall, there is a reduction in agricultural GDP by about 0.1491% in the short run relationship and 0.1398% in the long run relationship, using coefficients obtained from the ARDL model.

4.5.4 Economic Losses from Fertilizer Use

In the long run, 1% increase in fertilizer use per hectare of arable land, there will result in a reduction of agricultural GDP by approximately 0.1141%. Excessive fertilizer use can reduce agricultural GDP by degrading soil quality, increasing production costs, and causing inefficiencies in resource use, ultimately lowering productivity (Gomiero et al., 2011).

4.5.5 Economic Losses from Agricultural Labor Employment

In the long run, the ARDL model analysis indicates that a 1% increase in agricultural labor reduces the growth in GDP by 0.2297%. This would therefore mean that an increase in the labor of agriculture is not always proportionately increased with a rise in output concerning economic growth. Inefficiencies such as overstaffing, untrained labor, or lack of technological improvements may reduce productivity further. Labor, if complemented with neither improvement in technology nor improvement in resource management, may not effectively contribute towards GDP growth. (Schultz, 1964; Timmer, 2009)

4.5.6 Economic Losses from Climate Change

In the short run relationship

Considering both temperature increases and rainfall variability, it is found that Thailand's agricultural sector loses approximately 1.7325% (1.5834% + 0.1491%) of its GDP annually, which equates to approximately 12,020.67 million THB per year (based) on an agricultural real GDP (production approach) of about 693,834 million THB in 2023).

In the long run relationship (based on ARDL model)

Thailand's agricultural sector loses approximately 1.3715% (1.2317%+ 0.1398%) of its GDP annually, which equates to approximately 9,515.93 million THB per year.

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4.5.7 Overall Economic Losses

From the short-run relationship perspective, a 1% increase in climate change decreases the growth of agricultural GDP by about 1.7325%, which equates to approximately 9,515.93 million THB per year.

Based on the ARDL model, the long-term impact of climate change on agricultural GDP growth is around 1.3715%. With the addition of other negative factors such as fertilizer use and agricultural labor employment, these additional negative impacts will reduce agricultural GDP growth by about 0.3438% (0.1141% + 0.2297%). The combined factors' overall effect from a 1% increase would decrease the agricultural GDP growth by 1.7153% (1.3715% + 0.3438%), which equates to approximately 11,901.33 million THB per year of about 693,834 million THB in 2023) (Office of the National Economic and Social Development Council, 2024).

4.5.8 Long-Term Loss Assessment

The model also considered long-term impacts (by the year 2027), assuming the trend of climate change continues. The assessment found that the agricultural GDP could decline by up to 15% if no adaptive measures are taken to mitigate the impacts of climate change (World Bank, 2023). The total economic loss of the country could reach up to 104,075 Million THB[1] per year by 2027 if appropriate measures are not implemented (World Bank, 2023).

Table 8 Economic Loss Assessment from Climate Change and other factors in Thailand

Section	Description	Short Run Relationship	Long Run Relationship
Economic Losses from Climate Change	Annual loss due to climate change (percentage of agricultural GDP)	2.50%	2.50%
	Reduction in agricultural GDP per 1°C increase in temperature	1.5834%	1.2317%
Economic Losses from Rainfall Variability	Reduction in agricultural GDP per 1% increase in rainfall variability	0.1491%	0.1398%
Economic Losses from Fertilizer Use	Reduction in agricultural GDP per 1% increase in fertilizer use	-	0.1141%
Economic Losses from Climate Change	Annual reduction in agricultural GDP due to temperature and rainfall changes	1.7325%	1.3715%
	Annual economic loss in Million THB	12,020.67	9,515.93

[1] This amount of money is calculated from 15% × 693,834 million THB in 2023 (104,075 Million THB)

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Section	Description	Short Run Relationship	Long Run Relationship
Overall Economic Losses	Annual reduction in agricultural GDP due to climate changes and other negative effect factors	1.7325%	1.7153%
	Annual economic loss in Million THB	12,020.67	11,901.33
Long-Term Loss Assessment	Potential reduction in agricultural GDP by 2027 if no adaptive measures are taken	15%	15%
	Potential total economic loss in Million THB per year by 2027 if no adaptive measures are taken	104,075.1	104,075.1

Note: Calculated by researcher

5. Summary and Recommendations

5.1 Summary

The study shows that climate change and variability of rainfall have caused large economic losses in the agriculture sector of Thailand. It is estimated that climate change will lead to long-term agricultural GDP decline, and the estimated economic loss is 2.5% of agricultural GDP annually (World Bank, 2023). From the results of the ADRL model, it can be noticed that with a rise in average temperature by 1°C, the agricultural GDP decreased by 1.5834% in the short run and 1.2317% in the long run, thus showing the detrimental impact because of temperature rise. Similarly, from the results, it could be noticed that a 1% rise in rainfall variability results in a decline in agricultural GDP by 0.1491% in the short run and 0.1398% in the long run, thus reflecting the negative impact due to climate variability. All the factors combined reduce the estimation annually by 1.7325% in the short run and 1.3715% in the long run, which is approximately 12,020.67 and 9,515.93 million THB, respectively. Also, a 1% increase in agricultural labor leads to a decrease in GDP growth by 0.2297%, which may indicate that labor growth is not proportional to economic growth, possibly because of inefficiencies such as overstaffing and lack of technological advancement. Thus, enhancing labor skills and integrating machinery with labor could improve the GDP contribution. Without any adaptive measure, GDP in agriculture may decrease by up to 15% in 2027. The economic loss may reach 104,075.1 million THB annually.

5.2 Discussion

The findings of this study align with and extend several key works in the literature on climate change impacts in Thailand's agricultural sector. Our results showing that a 1% rise in temperature reduces agricultural GDP growth by 1.58% in the short run and 1.23% in the long run are consistent with Arunrat et al. (2020), who documented significant negative impacts of temperature increases on rice yields in Thailand. The observed 0.15% reduction in agricultural GDP growth from increased rainfall variability supports Boonwichai et al.'s (2018) findings on irrigation water requirements

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and crop water productivity changes in the Songkhram River Basin. Additionally, our economic loss projections indicating a potential 15% drop in agricultural GDP by 2027 align with World Bank (2023) assessments, while extending their work by providing more granular short-run and long-run impact coefficients. The negative relationship between increased fertilizer use and agricultural GDP growth (-0.11%) corroborates Gomiero et al.'s (2011) findings on the inefficiencies of intensive agricultural inputs, suggesting the need for more sustainable farming practices. Our results on agricultural labor's negative relationship with GDP growth (-0.23%) support classical development economics perspectives, as articulated by Schultz (1964) and Timmer (2009), regarding the need for technological advancement and improved resource management in agricultural transformation.

5.3 Recommendations

To reduce the negative impacts of climate change on Thailand's agricultural sector, adaptive strategies and policies should be enacted to make the sector resilient. The following recommendations are put forward:

5.3.1 Invest in Climate-Resilient Agriculture: This involves developing and deploying climate-resilient crop varieties that can sustain increased temperatures and rainfall variability. This investment in agricultural research and development is crucial for sustaining productivity.

5.3.2 Practice Water Management: Encourage efficient water management technologies, including precision irrigation and rainwater harvesting, as responsive strategies for shifting rainfall and as means to reduce risks of water scarcity and flooding.

5.3.3 Enhancing Agriculture Infrastructure: More investments in agricultural infrastructures like irrigation, storage, and transportation systems shall assist farmers in adapting to climate change for increased and sustained production.

5.3.4 Encourage Sustainable Farming Methods: Promote sustainable farming methods such as conservation agriculture, organic farming, and agroforestry that enhance soil health and biodiversity and reduce vulnerability to climate change within the agricultural sector.

5.3.5 Strengthen Early Warning Systems: Develop and improve early warning systems that enable the better forecasting of the timing and magnitude of extreme events such as floods and droughts to provide timely information to farmers that would enable them to take appropriate preventive measures against loss of crops and livelihoods.

5.3.6 Support Farmers' Adaptation: Support farmers both financially and technically in adopting adaptive practices and technologies, including subsidies for climate-resilient seeds, training in sustainable farming methods, and access to credit to undertake investments when required.

5.3.7 Policy and Institutional Framework: Improve policies and institutional frameworks that can favor climate adaptation in agriculture through the inclusion of the climate variable in agricultural policies, agency coordination, and stakeholder participation in decision-making.

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5.4 Limitations of the Study

5.4.1 Data Quality and Availability: The accuracy of the study's findings depends on the quality and availability of data. Some critical data, such as detailed climate projections and high-resolution agricultural output records, may not be available or may contain uncertainties that can affect the results.

5.4.2 Spatial and Temporal Variability: Climate change impacts can vary significantly across different regions within Thailand and over time. This study provides a national-level analysis, which may overlook region-specific factors and variations in vulnerability and resilience among different agricultural areas. Additionally, long-term projections carry inherent uncertainties due to the unpredictable nature of future socio-economic and environmental developments.

5.4.3 Exclusion of Non-Climatic Factors: While the study focuses on climate variables, other non-climatic factors such as market prices, technological advancements, and policy changes also play a critical role in determining agricultural productivity and economic outcomes. These factors were not comprehensively integrated into the analysis, which could influence the overall assessment of economic losses.

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