A Review of the Impact of Climate Change on Food Security and Co-Benefits of Adaptation and Mitigation Options in Thailand

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ABSTRACT

This paper aims to review previous studies exploring the impact of climate change on Thailand's food security and measure the co-benefits of climate change adaptation and mitigation options. For the impact of climate change, most of the studies focused on crop production. They are mainly important cash crops such as paddy rice, cassava, and maize. Overall, climate change is projected to have a negative impact on the production of these crops. As a result, Thailand's food security will not only be negatively affected by climate change, but global food security will also be sensitive to reductions in Thai crop production because Thailand is the world's major exporter of these food crops. To reduce the impact of climate change, there are limited past studies that assessed cost of production and benefits of adaptation and mitigation options. Some options require temporary government support to encourage farmers to change their practices because it provides enormous co-benefit to society and environment. Several policies have been proposed to reduce the impact of climate change and promote adaptation and mitigation options across the country.

Keywords: Climate change, Food security, Co-benefit, Impact, Adaptation, Mitigation

INTRODUCTION

Recent studies including the recent Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) revealed that climate change have reduced food security, hindering efforts to meet Sustainable Development Goals with high confidence (e.g., Brown *et al*., 2015; Brown *et al*., 2017; IPCC, 2022). Among economic sectors, agriculture is the most sensitive sector to climate change. Globally, climate change has slowed the productivity growth over the past 50 years (IPCC, 2022). Thailand is an upper-middle income country that agricultural sector has played a significant role in several aspects. For example, there are 12.40 million agricultural workers accounting for 31.34% of total labor force (National Statistical Office (NSO), 2022). Moreover, Thailand is a major producer and exporter of agricultural and food products in the world's market creating export revenue US$267 billion (Trademap, 2022).

Past evidences revealed that the Thai agriculture is very vulnerable to climate change in several dimensions. First, the agriculture has faced an aging society at an accelerated rate and above the national average. Second, young workers are also leaving the agricultural sector at an accelerated rate. Third, approximately 80% of all farm households are smallholders with less than or equal to 3.2 hectares of farmlands. Fourth, only 26% of farm households have access to irrigation systems. According to the recent global food security index 2022 reported by The Economist Group (2022), Thailand's global ranking dropped from 51st in 2021 to 64th in 2022 out of 113 countries. For the food availability aspect, Thailand's global ranking dropped from 59th to 77th and for the aspect of sustainability and adaptation, Thailand ranked 69th.

While agricultural and food sectors have provided important contributions to the Thai economy, studies exploring the impact of climate change, and appropriate mitigation and adaptation options are limited. The objectives of this study, therefore, are to: review and analyze the impact of climate change on Thailand's food security and; assess climate change mitigation and adaptation options. The following session analyzes the impact of climate change on Thailand's food security; and synthesizes climate change adaptation and mitigation options and corresponding co-benefits.

IMPACT OF CLIMATE CHANGE ON THAILAND'S FOOD SECURITY

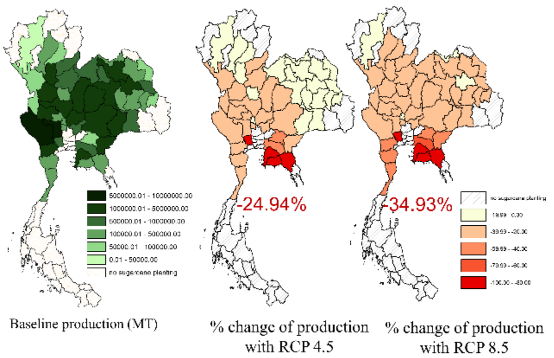
According to UN-FAO World Food Summit, the food security exists when all people, at all times, have physical, economic and social access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life (World

Food Summit, 1996). There are four dimensions of food security including: food availability; food access; food utilization; and stability of the previous three dimensions. As discussed in the previous section, food availability and its stability in Thailand are more vulnerable to climate change than other aspects of food security. This section, then, reviews previous studies and analyzes the impact of climate change on agricultural production and risks. Overall, previous studies exploring the impact of climate change on agricultural production is limited. They largely investigated the impact of climate change on crop production and focused only on major cash crops such as rice, maize, sugarcane, cassava, rubber and oil palm.

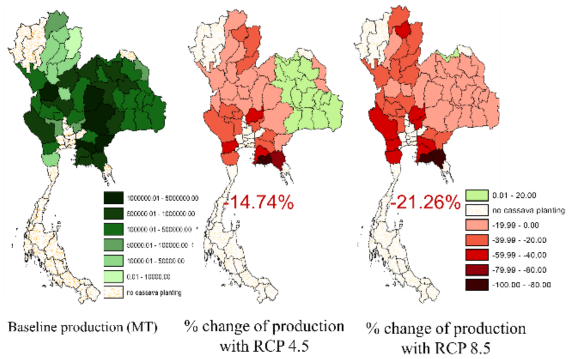
Considering rice production, most studies revealed that climate change will adversely affect overall rice production in Thailand. For example, Amnuaylojaroen *et al*. (2021) used the Decision Support System for the Transfer of Agrotechnology (DSSAT) modeling system and predicted rice yield and its corresponding production risks during the years 2020–2029 in the northern region of Thailand. Their study revealed that the production of rainfed rice is projected to decline by 5% and have a low risk of low production. Sinnarong *et al*. (2022) revealed similar findings. Their study used a panel data of economic crop production and weather at the provincial level from 1989 to 2017 and found that increase in the variance of rainfall decreased the mean of rice yield in the northeastern region.

Unlike other studies, Pipitpukdee (2020) estimated the effect of climate change on the yield, harvested area, and production of rice across all provinces of Thailand from 1981–2016 using new fine-scale weather outcomes and the instrumental variable (IV) approach together with the generalized method of moment (GMM). The study broke down rice into three types based on irrigation system and growing period to differentiate climate change impacts as suggested by literature. Pipitpukdee (2020) found that the total rice yield was projected to decrease by 10.34-14.42% from the baseline. The total rice harvested area was anticipated to slightly increase, ranging from 0.18-1.27% from the baseline. After multiplying the rice yield by its harvested area, the study revealed that the production of in-season rice in the rainfed area will have the largest reduction of 31.99-42.26%. The production of in-season rice in the irrigated area was predicted to increase by 25.71-34.36% from the baseline. Therefore, the future total rice production was predicted to decrease 10.18-13.33% from the baseline (Figure 1c). The provinces in the northeastern and upper section of southern regions are expected to have the largest impact of climate change.

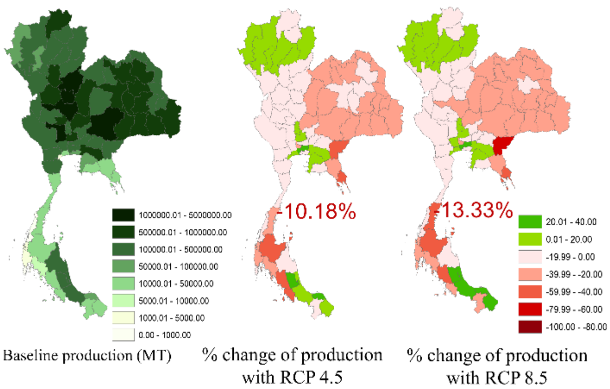
For sugarcane production, Pipitpukdee, Attavanich, & Bejranonda (2020a) used similar approach of Pipitpukdee (2020) and projected that the national sugarcane yield was projected to decrease by 23.95% under RCP4.5 and 33.26% under RCP8.5 from the baseline and found that the national harvested area of sugarcane was projected to slightly decline, ranging from 1.29-2.49% from the baseline. By multiplying yield and the corresponding harvested area, national sugarcane production was forecasted to decrease by 24.94-34.93% from the baseline without the CO_2 fertilization effect. Considering the distributional impacts of climate change at the provincial level, our findings revealed a reduction in the yield of sugarcane in all provinces ranging from 12.23-30.53% under RCP4.5 and 16.06-43.80% under RCP8.5 from the baseline. The sugarcane production was projected to decline in all provinces. The largest decline was predicted in the eastern and lower sections of the central regions (Figure 1a).



a. Sugarcane



b. Cassava



c. Paddy Rice

Figure 1. Projected impact of climate change on production of sugarcane, cassava and paddy rice in Thai agriculture

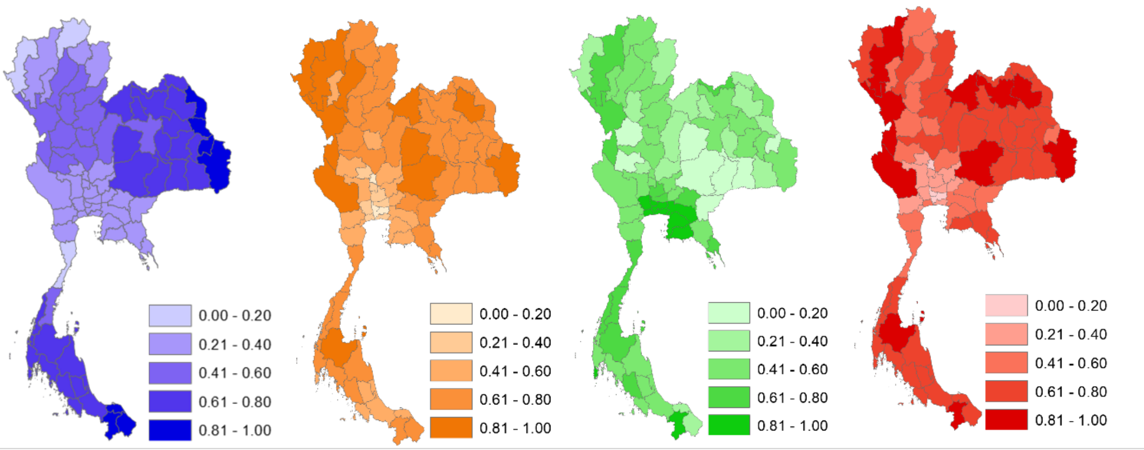
Source: Pipitpukdee, Attavanich, & Bejranonda (2020a; 2020b) and Pipitpukdee (2020)

For cassava production, the national cassava yield was projected to decline by 2.57% under RCP4.5 and 6.22% under RCP8.5 from the baseline. The harvested area of cassava was also projected to decline by 12.49% under RCP4.5 and 16.05% under RCP8.5 from the baseline. Moreover, this study revealed that the cassava production was predicted to decrease by 14.74% under RCP4.5 and 21.26% under RCP8.5 from the baseline without the CO_2 fertilization effect. Considering the disaggregated impacts of climate change, their findings revealed that the cassava production in the northeastern regions was forecasted to increase by 0.55-6.74%, while its production in other regions was projected to decline under RCP4.5. We also observed that cassava production was projected to decrease in all provinces (except for Nong Kai) under RCP8.5 as shown in Figure 1b (Pipitpukdee, Attavanich, & Bejranonda, 2020b).

For other remaining crops, Amnuaylojaroen *et al*. (2021) projected maize yield and its corresponding production risks during the years 2020–2029. Their study revealed that maize production is projected to decline by 4% and maize production is at a high risk of low production in the northern region. For rubber production, Sinnarong *et al*. (2022) estimated that average temperature and total rainfall negatively affected the yield of rubber in the southern region. Oil palm production in the southern region was negatively affected by the average and variance of temperature and rainfall.

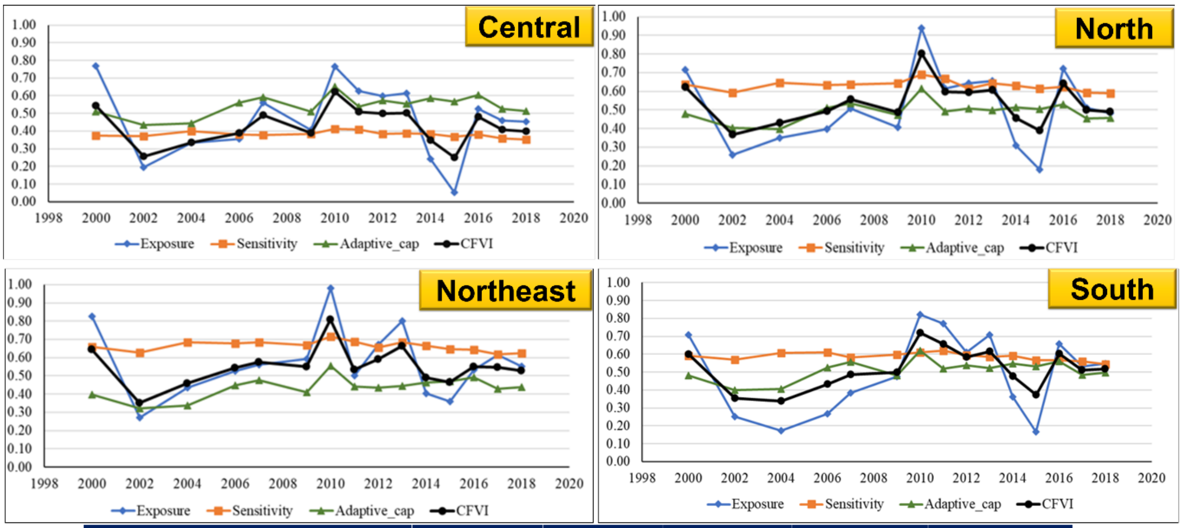
Besides the aspect of food availability, Pipitpukdee (2020) quantified the household-level vulnerability index of food security incorporating the role of climate change and evaluate the food insecurity status using the data from socio-economic survey from 2000-2018. For the exposure status (Figure 2), the average score of all provinces was 0.4956 reflecting the medium severity of exposure. Provinces located in the Southern and Northeastern regions had the highest exposure. The average sensitivity score of all provinces was 0.62 reflecting the high severity of sensitivity. The national adaptive capacity score was 0.50, which was in the medium adaptive capacity. After calculating the climate-induced food insecurity vulnerability index (CFVI) score at the provincial level in 2018, the national average was 0.60 meaning that, Thailand had medium to high levels of severity from climate-induced food insecurity vulnerability status. Highly vulnerable provinces were spread in the north, northeast and south. The top 5 provinces that had the highest CFVI score were Ubon Ratchathani, followed by Tak, Surat Thani, Nakhon Ratchasima, and Chiang Mai, respectively. These provinces have the provincial area at least two times higher than the national average and have the percent of access to irrigation system to total province area less than the national average making them more sensitive to food insecurity. There are also specific factors that affect food insecurity of each province. For example, Ubon Ratchathani province had a low level of gross provincial product per capita and high proportion of households having debt. Tak and Chiang Mai provinces low level of gross provincial product per capita, total household income per capita, and proportion of households who have high education.

At the regional level across time period, the study showed that the central region was exposed to climate impacts from very low to high severity, while it had low sensitivity scores and medium level of adaptive capacity. The sensitivity level was generally in the low level and the adaptive capacity level of the central region ranged from medium to high level. Overall, the level of CFVI in the central region ranged from 0.25- 0.62. In the case of the northern region, the exposure score was more severe than the central region. The sensitivity was also in the high level of severity, but the adaptive capacity was in the medium level. The CFVI of the northern region ranged from 0.37-0.80. The northeastern and southern regions had exposure scores from low level to the highest level. The highest score was in the very high severity of vulnerability level. The northeastern region had the adaptive capacity score lower than the southern region. Therefore, the CFVI of the northeastern region was higher than that of the southern region (Pipitpukdee, 2020).



a. Exposure b. Sensitivity c. Adaptive capacity d. Vulnerability

a. Status of climate-induced food insecurity vulnerability classified by province in 2018



Index	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
Severity of Vulnerability	Very low	Low	Medium	High	Very High

b. Status of climate-induced food insecurity vulnerability classified by region from 2000-2018.

Figure 2. Status of climate-induced food insecurity vulnerability

Source: Pipitpukdee (2020)

CLIMATE CHANGE ADAPTATION AND MITIGATION OPTIONS AND CORRESPONDING CO-BENEFITS

In Thailand, adaptation and mitigation practices have been adopted. This is in line with climate smart agriculture practices, which pursue the triple objectives of sustainably increasing productivity and incomes, adapting to climate change and reducing greenhouse gas emissions where possible. Some practices can be used for many crops such as application of site-specific nutrient management, reducing field burning of crop residues, organic farming, drip irrigation system, crop insurance, breeding plants to withstand drought, while some of them can be adopted for a specific crop such as alternate wetting and drying for off-season rice, and dry direct rice seeding machine. For livestock, the adaptation and mitigation practices include, for example, improving feed quality using fresh grass for livestock, anaerobic digester replacing uncovered anaerobic lagoon, breeding animals to withstand heat and drought, and livestock ventilation systems and indoor environments. For the aquaculture, adaptation and mitigation practices include, for example, water storage for pond culture, strengthen cages for river cage culture, and harvest fish early in response to imminent threat of extreme weather event to reduce.

Like the impact of climate change, previous studies investigating the potential of adaptation and mitigation options and their corresponding co-benefits were limited in Thailand. They mostly focused on the major cash crops especially rice. A few studies explored options related to the livestock and aquaculture. Pengthamkeerati and Attavanich (2018) was the first study that attempted to analyze the adaptation and mitigation potentials in the Thai agriculture sector at the national level using the instrumental variable approach with generalized method of moments (GMMs). The population projections were drawn from NESDB (2010) under the moderate fertility rate. This study used future climate projections from the IPCC AR5 report under representative concentration pathway 6.0 (RCP6.0) to account for uncertainty in climate projections (Stocker, 2014). By using scoring criteria from a group of experts and literature reviews, five out of 26 mitigation options were selected to investigate the mitigation potential.

Their study revealed that, for Improve feed quality option by using fresh grass instead of rice straw, the GHG emissions estimated to drop 0.83%, 1.05%, and 1.28% from the BAU in 2030 under low, moderate, and high adoption scenarios, respectively. For the option 2 (Anaerobic digester replacing uncovered anaerobic lagoon), the GHG emissions will be reduced up to 5.78%, 7.83%, and 9.88% from the BAU in 2030 under low, medium, and high adoption scenarios, respectively. For the option 3 (AWD Rice cultivation), the GHG emissions of off-season rice can be reduced up to 2.32%, 4.54% and 6.33% from the BAU in 2030 under low, medium, and high adoption scenarios, respectively. For the option 4 (Application of site-specific nutrient management), the GHG emissions of major rice (irrigated) and off-season rice can be reduced 8.54%, 14.57%, and 20.56% from the BAU in 2030 under low, medium, and high adoption scenarios, respectively. Finally, for the option 5 (Reducing field burning of crop residues), the GHG emissions of all crops are projected to decrease 22.22, 44.28, and 66.47 percent from the BAU in 2030 under low, medium, and high adoption scenarios, respectively (Table 1).

In addition to the interview with a group of experts in Pengthamkeerati and Attavanich (2018), Thailand's Office of Agricultural Economics (OAE) (2018) conducted the field survey to estimate the benefits of alternate wetting and drying (AWD) rice cultivation by collecting the data from a questionnaire for 106 farmers growing off-season rice in six central provinces: Chainat, Suphan Buri, Ang Thong, Sing Buri, Phra Nakhon Si Ayutthaya and Pathum Thani. The study revealed that off-season rice cultivation by AWD method yielded a net farm income per hectare at US$392.61 /ha, an increase of US$71.42 /ha compared to conventional off-season cultivation in 2018. OAE (2018) also revealed that growing off-season rice cultivation by AWD method can reduce greenhouse gas emissions by 267.31 $KgCO_2e$/ha or 20.52% of greenhouse gas emissions from farming.

Table 1. Projected percent change of national GHG emissions from the business-as-usual scenario under the mitigation options with different adoption rates by 2030

Mitigation option	**BAU (Without option) (GgCO2-eq)**	**% Change under different adoption rates**		
		Low	**Medium**	**High**
1) Improving feed quality for livestock	4,779.35	-0.83	-1.05	-1.28
2) Anaerobic digester replacing uncovered anaerobic lagoon	613.22	-5.78	-7.83	-9.88
3) Alternate wetting and drying for off-season rice	24,147.43	-2.32	-4.54	-6.33
4) Application of site-specific nutrient management for rice cultivation	863.02	-8.54	-14.57	-20.56
5) Reducing field burning of crop residues	1,558.36	-22.22	-44.28	-66.47

Source: Pengthamkeerati and Attavanich. (2018)

Note: **Option 1** considered meat cattle and buffalo. Low, medium, and high adoption rates equal to 36%, 45% and 54% of total heads of cattle and buffalo, respectively. **Option 2** considered only swine. Low, medium, and high adoption rates equal to 80%, 85% and 90% of total swine heads in commercial farms, respectively. **Option 3** considered only off-season rice. Low, medium, and high adoption rates equal to 10%, 20% and 30% of total harvested area, respectively. **Option 4** considered both in-season and off-season rice in the irrigated areas. Low, medium, and high adoption rates equal to 16.65%, 33.33% and 50.00% of total harvested area, respectively. **Option 5** considered rice, maize, and sugarcane. Low, medium, and high adoption rates for rice are equal to 25%, 50% and 75%, respectively. Low, medium, and high adoption rates for sugarcane are equal to 20%, 35% and 50%, respectively. Lastly, Low, medium, and high adoption rates for maize are equal to 15%, 30% and 45%, respectively.

While Pengthamkeerati and Attavanich (2018) explored the potential of climate change mitigation and adaptation options, the study focused only on the economic aspect of these options and did not include their social and environmental benefits. To promote sustainable agriculture, Pengthamkeerati and Attavanich (2022) assessed the overall impact of growing rice with the alternate wet and dry (AWD) practice covering economic, social and environment aspects. The economic value is measured by increased net returns, while the social benefit is calculated by the added value obtained from water transfers from the agricultural sector to the non-agricultural sector. The environmental benefit is estimated by the benefit from reducing greenhouse gas emissions. These benefits, then, are subtracted to the cost of investment in rice cultivation with AWD practice (e.g., costs of rice production, opportunity cost, laser grading, etc.). The results showed that the net benefit from AWD rice cultivation was US$71.42 /ha. The added value of the saved water transfer for off-season rice to non-agricultural sectors is equal to US$2,090.02 /ha. Finally, the benefit value from the reduction of greenhouse gas emissions is equal to US$13.56 /ha. Overall, every 1 hectare from AWD rice cultivation can generate net benefit of US$2,175.01 /ha.

Besides the above five mitigation options, crop insurance can play a crucial role to reduce the impact of climate change. However, the current crop insurance program in Thailand has been less effective and far from sustainability (Attavanich *et al*. 2022). The program lacks of effective farm loss assessment. There are also other challenges including: 1) Disincentive effects from the co-existence with government disaster assistance program; 2) The currently high subsidization rates; 3) The current insurance design with ineffective loss assessment and low insurance coverage, which reduces its value to farmers; and 4) Other behavioral biases that could obstruct farmers' willingness to pay.

Sinnarong *et al*. (2022) showed that the crop insurance scheme (if implemented) can increase the risk reduction performance (RRP) of key economic crops. Their study designed weather index insurance schemes in four regions of Thailand for 2030, 2060 and 2090 (Table 2). According to the weather index insurance design, the simulation results show that, under the A2 temperature change scenario, the risk reduction performance (RRP) of rice farmers will increase 8.76%, 11.31%, and 12.68% for 2030, 2060, and 2090, respectively, in the Northeastern region. In addition, under the A2 rainfall change scenario, RRP of rice farmers will increase 8.14%, 11.40%, and 13.37% for 2030, 2060, and 2090, respectively, in the same region. For oil palm production in the Southern region, under the A2 temperature change scenario would increase farmers' RRP by about 2.43%, 4.07%, and 6.48% for 2030, 2060, and 2090, respectively. For the rubber production in the Southern region, under the A2 temperature change scenario would increase farmers' RRP by about 8.89%, 13.15%, and 13.44% for 2030, 2060, and 2090, respectively.

Table 2. The risk reduction performance (RRP) of key economic crops from weather index insurance schemes under climate scenarios (%)

Climate scenario	2030	2060	2090
A2 temperature change			
Rice in the Northeast	8.76	11.31	12.68
Oil Palm in the South	2.43	4.07	6.48
Rubber in the South	8.89	13.15	13.44
A2 precipitation change			
Rice in the Northeast	8.14	11.4	13.37

Source: Sinnarong et al. (2022)

Organic farming is another potential option to address the impact of climate change in Thailand. This finding is from Lee (2021) who reviewed policies related to the development of organic agriculture in Thailand. The study found that the organic farming has been mainly influenced by the agricultural cooperatives and non-governmental organizations (NGOs), which have provided various support ranging from technology transfer, production, financing, distribution, to marketing of organic products. Nevertheless, organic farming is not widespread in Thailand. Inconsistent policies and limited support from the government are key constraints. To improve organic farming, Lee (2021) suggested that government agencies should work together with all relevant stakeholders in the organic sector including agricultural cooperatives, NGOs, and consumers.

Besides crops and livestock, aquaculture also provides a significant contribution to Thai agriculture. Unfortunately, there is a limited study investigating the potential of climate change mitigation and adaptation options. For example, Lebel *et al*., (2018) assessed climate change adaptation strategies for addressing the impacts of climate change on the water resources available to aquaculture in Chiang Mai and Phayao provinces located in Northern Thailand. Their study used a series of participatory local assessment meetings and related activities with groups of pond and cage farmers with four future climate change scenarios (Wetter, Drier, More Seasonal, Less Seasonal).

The study found that: 1) A few individual strategies were profitable only in the one or two systems for which that practice was relevant (water storage for pond culture; strengthen cages for river cage culture); 2) No-regret (e.g., Provide supplementary aeration as appropriate during periods of water- and climate-related stress; Harvest fish early in response to imminent threat of extreme weather event to reduce losses) and low-regret responses (e.g., Adjust stocking date or density to avoid floods and droughts; Pump groundwater when facing shortages) yielded positive profit differences in all culture systems for which they were relevant; 3) Future-benefits strategies (e.g., Protect and restore ecosystems for flood protection, water storage, and water quality services; Mass selection and breeding for higher thermal tolerance) varied substantially from each other and across culture systems, implying that overall, averages for this group should be treated carefully.

CURRENT POLICIES ADDRESSING THE IMPACTS OF CLIMATE CHANGE

From the past to the present, the Thai government has addressed the impact of climate change in agriculture and food system by launching plans and strategies such as National Strategy 2018-2037, The 13th National Economic and Social Development Plan 2023-2027, Policy and Plan on Promotion and Conservation of National Environmental Quality 2017-2037, National Adaptation Plan 2018 – 2037, Climate Change Master Plan 2015 – 2050, Long-Term Low Greenhouse Gas Emission Development Strategy, and Climate Change Action Plan for the Agricultural Sector 2023-27.

The recent Climate Change Action Plan for the Agricultural Sector 2023-27 plays a crucial role of changing the policies into actions. The plan's vision is "Thai agriculture has the capacity and resilience to climate change based on information and favourable environment." There are 5 Missions of this action plan including: 1) Enhance the adaptive capacity of farmers and related businesses throughout the agricultural supply chain; 2) Contribute to reducing greenhouse gas (GHG) emissions throughout the agricultural supply chain to mitigate the long-term impact of climate change; 3) Develop database and knowledge, and support raising awareness of climate change impacts, and the importance of climate change adaptation and mitigation; 4) Develop manpower capacity in agriculture and promote cooperation of network partners to deal with climate change in all sectors and levels; and 5) Enhance contributions and efforts of different agencies in implementing climate actions.

There are 8 main indicators of the action plan including: 1) The value of damage and assistance in agricultural disasters is reduced by 20% during 2023-2027 period compared to 2017-2022 period; 2) The production of major agricultural products is damaged from climate change 20% less than during the 2017-2022 period[1]; 3) The market value of low-

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[1] Major agricultural products are rice, rubber, cassava, maize, oil palm, durian, beef cattle, dairy cattle, swine, chicken, tilapia, Vannamei shrimp.

carbon agricultural products grows at 5% per year[2]; 4) The agricultural sector reduces annual greenhouse gas emissions by 1 million tons of carbon dioxide equivalent; 5) Prerequisites are in place for the international trading of GHG offsets in offset markets; 6) At least 100 current researchers involved in climate change in scarce fields are developed annually[3]; 7) The agriculture sector has at least 100 new researchers per year in the scarcity fields related to climate change; and 8) Have the database related to climate change.

CONCLUSION

Thailand's food security is threatened by climate change especially the pillars of food availability and its stability. Previous studies investigated the impact of climate change only on major cash crops such as rice, maize, sugarcane, cassava, rubber and oil palm. All selected crops are expected to be negatively affected by climate change. Northeastern Thailand suffers the most from food insecurity compared to other regions. Studies exploring the potential mitigation and adaptation options to reduce the impact of climate change are limited in Thai agriculture. Large part of studies focused on major cash crops especially rice, while a few studies explored options related to the livestock and aquaculture.

There are several important policies that can be implemented to reduce impacts of climate change and simultaneously improve the national food security.

1) Replace the current unconditional farm assistance policies with conditional farm assistance policies to improve food availability, food access and the stability of

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[2] Low-carbon agricultural products are agricultural products that emit less greenhouse gases during production than other similar products, such as rice grown with alternate wetting and drying practice; livestock and aquatic animal production through feed improvement; livestock production with biogas production from manure by using anaerobic digester system instead of open fermentation system; crop production with appropriate fertilization according to the GAP principle, or according to the analysis of soil values and plant needs; and planting crops without burning agricultural waste, etc.

[3] Examples of fields facing shortage of experts such as breeders/physiologists in plants, livestock and aquatic animals, genetic improvement in economic aquatic animals, agronomists, rice production technologists, plant pathologists, epidemiologists and prevention of diseases in livestock and aquatic animals and an entomologist (Attavanich et al. (2021). Project "Manpower Development Plan in Thailand's Agricultural Sector, Fiscal Year 2021", Agricultural Research Development Agency (Public Organization)).

both food availability and food access. Studies revealed that unconditional farm assistance policies in Thailand could not increase net farm income (Attavanich, 2021), had insignificant effect on farm modernization investment (Attavanich, 2016), provide limited means to break the poverty circle of some Thai rice farms in the irrigated area (Faysse *et al*., 2020), and reduced motivation to adapt and increased production risks (Attavanich *et al*., 2019).

2) Increase accessibility and promote the management of demand for water resources especially in the provinces that have a small portion of access to irrigation system (e.g., Ubon Ratchathani, Tak, Surat Thani, Nakhon Ratchasima, and Chiang Mai). Studies found that water management policy increasing the access to water enhanced net farm income of farm households in irrigated areas or non-irrigated areas with access to other water sources approximately 12,395 USD/year (Attavanich, 2021) and investment in small farm ponds is an effective way to reduce flood and drought problems in the Mun River Basin located in the Northeast (Prabnakorn *et al*., 2021).
3) Promote sharing economy and the adoption of modern machines and farm digital technologies. Using Farmer's Registration database, Attavanich *et al*. (2019) found that Thailand's cropland is concentrated on each type of crop, giving the opportunity to benefit from economies of scale from investment in costly modern machines and farm digital technologies. The investment worthiness will increase through the promotion of the rental market for machinery services, strengthening of farmer institutions and promote the consolidation of farmland for small farmers.
4) Promote the development and adoption of effective crop insurance. This can be done through promoting the use of behavioral insights to incentivize active market participation; and reforming roles of government to rather support (not replace) market development including redesigning government's insurance subsidization and government disaster assistance to complement each other in promoting development of market (Chantarat *et al*., 2017; Attavanich *et al*., 2022).
5) Promote research and development to assess the impact of climate change on agricultural products along food supply chain and investigate the appropriate climate smart agriculture practices that are consistent to the context of the location. Examples of climate smart agriculture practices include: exploring appropriate planting dates; soil and water management, drought-tolerant crops, dairy and fishery development, and carbon finance to restore crop fields.
6) Promote the adoption of climate smart agriculture practices that are consistent to

the context of the location. For example, it is recommended to: promote the adoption of the AWD rice cultivation for off-season rice in irrigated areas; promote the farm diversification in a variety of ways in the affected areas to improve net income and reduce production and marketing risks instead of monoculture.

7) Promote the nature-based solutions by increasing water infiltration and retention to reduce the impact of climate change on crop production in the negatively affected regions and crops. Applying the organic matter (Manures and organic fertilizers) is an example to help fill large pores in sandy soil. The organic matter assists the soil retain water and can loosen particles in the clay to allow water to flow down to deeper levels. Growing cover crops can also increase organic matter through protecting the soil from erosion, adding organic content to the soil through roots and foliage, and creating habitat for microorganisms. Growing tree to hold the water in the farmland is another important action that should be promoted.
8) For aquaculture, in the short-term, it is recommended to promote rearing practices, providing aeration, withholding feed and moving fish, as well as sharing information about extreme flow or weather conditions and helping each other cope with extreme events. In the longer term, tactics related to timing, siting, stocking and harvesting decisions each year are important under both current and future climate variability (Lebel *et al*., 2018).

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W.A. designed, conducted and analyzed research including writing the paper.

COMPETING INTERESTS

W.A. declares that he has no conflict of interest.