Chapter 3

ASEAN Food Security under the 2°C-4°C Global Warming Climate Change Scenarios

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CHAPTER 3

ASEAN Food Security under the 2°C–4°C Global Warming Climate Change Scenarios

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3.1 Introduction

Southeast Asia, comprising the 10 member states of the Association of Southeast Asian Nations (ASEAN), is a highly climate-vulnerable region but under-studied when it comes to climate science. Unlike the scientific and technical expertise in countries such as the United States (US), the United Kingdom (UK), Australia, and New Zealand, climate research studies in Southeast Asia remain challenging. In addition to lack of sufficient scientific contributions, Southeast Asia has limitations in available climate data, dense and robust observational networks, and technology to support such an intricate science as that of climate. As a result, most data sets and models are derived from European or American models, and in more recent years, from China, Japan, and Australia. Much more work is required for Southeast Asia, given the economic and humanitarian impacts. The Asian Development Bank (ADB, 2009) has reiterated the need for more adaptive measures and strategies to mitigate climate change impacts. The reports of the Intergovernmental Panel on Climate Change (IPCC, 2014) and ADB have indicated that much more detailed research is needed for Southeast Asian countries. This includes not just refinements in data collection, analysis, and modelling, but also a new look at the archipelagic and insular land and seascapes unique to Southeast Asia.

The Met Office (2014) reported that the climate future for Southeast Asia may not be bright. The region is likely to face an increase in warm day temperatures of 4.3°C; a 5% increase in the number of days in drought; 77% of the region is projected to have an increase in flood frequency; and staple crops are expected to experience increases and decreases, but in different areas. With projected population increases and rising sea levels, this exposure is projected to increase considerably. The frequency of inland flooding events is also projected to increase. Warmer sea surface temperatures and ocean acidification could likely threaten fish stocks in this major fishing region. The region is important for rice exports and is also a major producer of corn. There could also be increased water demand for irrigation, decreased water run-off, increased drought days, and intensified effects of storms.

The general international view is that food prices are likely to increase in the coming years as global food production is unlikely to keep up with the demand, given adverse climatic conditions that affect harvests, degrade soils, and cause water scarcity for irrigation with increasing population and rapid urbanisation. If climate change projections are included, most of today's key agriculture regions are likely to experience more extreme rainfall distributions which can highly impact food production through more frequent and extreme events such as droughts and floods.

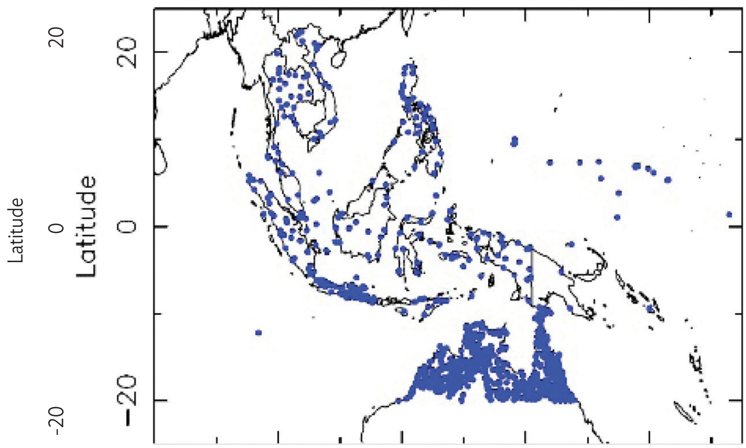
The reports of the IPCC suggest that the mean surface air temperature in this region has increased 0.1°C–0.3°C per decade from 1950 to 2000 (IPCC, 2007; 2014). The number of extreme weather events, or the number of heavy storm events and tropical cyclones, has also increased, as have the frequency of hot days and warm nights. These climate changes have impacts on other physical systems – increasing temperatures and extreme weather events also lead to a decline in crop yields in many Southeast Asian countries (Thailand, Viet Nam, and Indonesia); massive flooding in Hanoi and Hue (Viet Nam), Jakarta (Indonesia), and Vientiane (Lao People's Democratic Republic (Lao PDR)); landslides in the Philippines; and droughts in many other parts of the region (IPCC, 2007; 2014). Water shortages, agriculture constraints, risks to food security, infectious diseases, forest fires, and degradation of coastal and marine resources have also been increasing.

Future increases in precipitation extremes related to the monsoon are very likely in Southeast Asia. The region's temperatures may increase by 3°C–4°C and rainfall could rise by 40% by the end of the century. The strongest and most consistent increases are in northern Indonesia, Singapore, and Malaysia in June, July, and August; and southern Indonesia and Papua New Guinea in December, January, and February. Under scenarios of high levels of global warming, the IPCC report states that models based on current agricultural systems suggest large negative impacts, mainly related to water availability and a reduction in crop yields. The report also mentioned substantial risks to global food production and security, and high confidence regarding the adverse link between climate change on crop and food production in several regions of the world, including Southeast Asia (IPCC, 2014).

3.2 Climate Data, Models, and Scenarios

Information on the current climate and its change over the past decades is only available through observational data. Several gridded observational data sets, mainly on precipitation and temperature, have been developed by different research institutes. However, a close examination of these data sets (Raghavan et al., 2017) – especially rainfall – reveals substantial differences amongst them at sub-regional and local scales with respect to the rainfall amounts, and shows that extreme rainfall magnitudes are not being captured. These different data sets do not show large deviations on monthly time scales, but many uncertainties exist on daily scales. This suggests that, in general, data quality needs to be improved in the ASEAN region; and a dense, robust network of observing gauges needs to be installed and monitored, including in some of the developing countries in ASEAN which have a sparse network of observations. A co-ordinated effort in this data archival is important to ensure that climate data from now on are not lost forever. These data would help the climate community and policymakers to understand changes in the climate to better quantify climate projections provided by the climate models. A recent study (van den Besselaar et al., 2017), which developed a gridded data product, showed the distribution of stations in the region – highlighting the sparse network. In addition, although individual countries might hold the records of such station data, they are not made available to the community because of data sharing policies.

Figure 3.1: Rainfall Data Stations in Southeast Asia



Source: van den Besselaar et al., 2017.

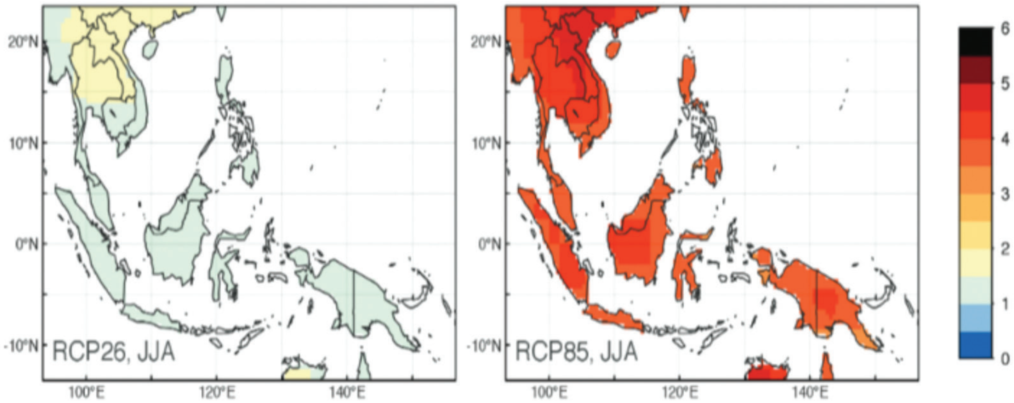
General circulation models (GCMs), also called global climate models, are the primary tools for the prediction of global climate. These models provide reasonable simulation accuracy of the current climate on a global, hemispheric, or continental scale, but their simulation accuracies are poor on a regional scale representation (Giorgi, 1990) because of coarse spatial resolutions (100–300 kilometres (km)). The representation of global climate models has advanced scientifically since 2001 to improve climate predictions. This is largely attributable to technological developments which facilitate simulations of the earth's climate at higher spatial resolutions. Regional climate is often affected by atmospheric phenomena, which occur at a sub-grid scale of the GCM. Some of the regional and local scale climate forcings – caused by land-use characteristics, complex topography, land–ocean contrasts, aerosols, radiatively active gases, snow, sea, ice, and ocean currents – are not resolved well by GCMs. They are computationally expensive because of their complexity; and the length of the simulations required for the present and future climates ranges from a few years to decades. Therefore, GCMs cannot capture the fine scale structure that characterises climate variables in many regions of the world, which is required to run impact models. This becomes particularly problematic for important climate variables like precipitation, which have high variability in space and time. As a result of their coarse spatial resolution and their inability to include mesoscale atmospheric features in their large-scale circulation, GCMs do not simulate the precipitation fields with adequate fine scale detail to be applied to impact models such as hydrological models. Hence, before the GCM output information of key variables can be used to drive the impact models at a regional or local scale, an intermediate step requires the downscaling of this large-scale GCM information to the regional scale. This is done by applying some downscaling techniques that are widely employed in the climate community – dynamical and statistical. The dynamical approach involves the climate simulation of a desired region at high spatial resolution (10–30 km) using a mathematical three-dimensional model, called a regional climate model. This approach, though climate-realistic, is expensive in terms of computational time and resources such as supercomputing, which few can afford. The statistical method is more empirically based on certain assumptions of climate statistics. A general review of downscaling methods by Trzaska and Schnaar (2014) suggests that there is no single best downscaling approach, and that these approaches depend on the desired spatial and temporal resolution of outputs and the climate characteristics of the region of interest.

GCMs use certain climate scenarios to assess future climate change based on the plausible trajectories of greenhouse gas emissions. The IPCC has made use of such climate scenarios since 1995 and, with the subsequent development of such scenarios, global models have been simulated under such prescribed scenarios to better quantify future climate changes. The IPCC (2014) report made use of the Representative Concentration Pathways (RCPs), which provide assessments of future changes by the end of the century related to a particular net radiative forcing. These are termed scenarios 2.6, 4.5, 6.0, and 8.5. Scenarios 4.5 and 8.5 have been widely used by the climate research community to study future climate changes, and provide a range of the low to high end of greenhouse gas trajectories, based on mitigation and no mitigation options, respectively. The 2.6 scenario is deemed almost unlikely, given the rate of global warming. This paper discusses some of the findings from studies that have used the 4.5 and 8.5 scenarios.

3.3 Studies of Southeast Asia for 2°C–4°C Warming

The Potsdam Institute for Climate Impact Research conducted a study for the World Bank on climate change impacts with respect to different warming scenarios (World Bank, 2013). The study projects the average summer warming around the 2040s in Southeast Asia to be about 1.5°C (1.0°C–2.0°C) for a 2°C rise; and the average summer temperatures over land are projected to increase by about 4.5°C (3.5°C–6.0°C) by 2100, for a 4°C rise. The region is also expected to experience a strong rise in monthly heat extremes, with the number of warm days projected to increase from 45 to 90 days (2°C) and 300 days (4°C). The strongest warming is expected in the regions of northern Viet Nam and the Lao PDR, with the multi-model mean projecting up to 5°C under 4°C global warming by 2071–2099 and up to 2°C under 2°C global warming. The changes in temperature and rainfall over Southeast Asia by the end of the century under two different climate scenarios (RCP 4.5 and 8.5) are shown in Figures 3.2 and 3.3, respectively.

Figure 3.2: Multi-Model Mean Temperature Anomaly under RCP 2.6 and RCP 8.5 for June–August (2071–2099 vs 1951–1980) (°C)

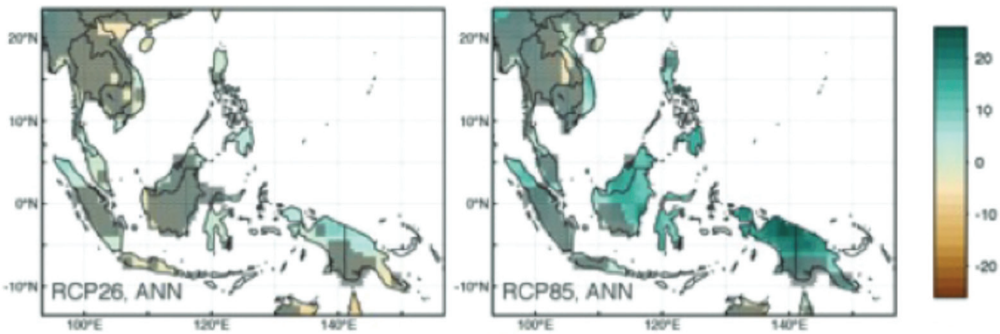


JJA = June, July, August; RCP = Representative Concentration Pathway.

Source: Adapted from World Bank (2013).

The report also predicts that population growth will largely exert pressure on water resources, which could be augmented because of climate change. Water reduction of up to 20% is projected for many regions under 2°C warming and up to 50% under 4°C warming. Vulnerabilities could increase because of greater variability in precipitation and disturbances in the monsoon systems (World Bank, 2013).

Figure 3.3: Multi-Model Mean Annual Rainfall Anomaly under RCP 2.6 and RCP 8.5 (2071–2099 vs 1951–1980) (%)



ANN = annual, RCP = Representative Concentration Pathway.

Source: Adapted from World Bank (2013).

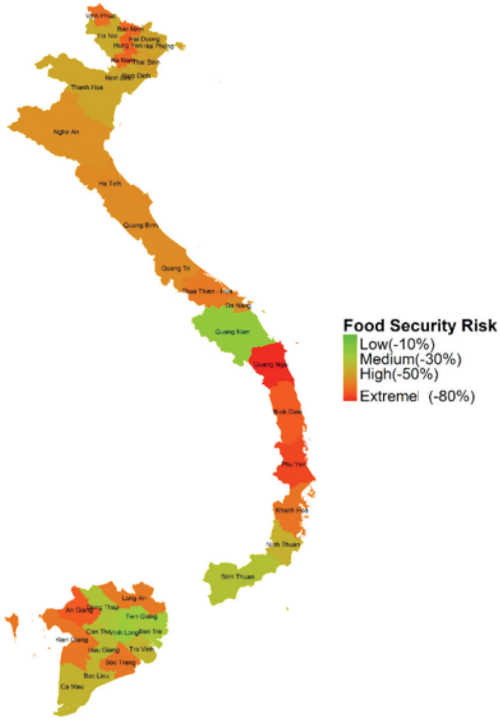
The World Bank also reported that crop yields will be under pressure to meet global demand for food supplies; and at 2°C warming, Southeast Asia will have reduced crop yields and production losses. Such impacts would strongly affect food security and could trigger reduced economic growth in the region. In addition to temperature increases, other factors such as saltwater intrusion, sea level rise, and tropical cyclones add to the uncertainties in agricultural production and losses, in addition to losses caused by pests and crop diseases. Deltaic regions such as the fertile Mekong River Delta (MRD), native to rice farming, could be particularly affected by saltwater intrusion; and temperature increases during critical growing periods could hamper productivity (Wassmann et al., 2009). Some cultivars could also be affected by prolonged flooding (Jackson and Ram, 2003). Although rice is resilient to salinity and water changes, sudden and total inundation could render the crops vulnerable to losses. The World Bank reported that a sea level rise could raise the MRD by 30 centimetres by 2040, resulting in an agricultural loss of about 12% because of a 193,000 hectare (ha) loss of crops (4.7% of the MRD); and saltwater intrusion could cause about 295,000 ha (8% of the MRD) to experience losses. A loss in export revenue of $1.22 billion in 2011 prices (World Bank, 2010) could incur when no adaptation measures are in place, and rice production could decline by about 2.6 million tons per year, assuming 2010 rice productivity.

A regional dynamical downscaling climate study for Southeast Asia was performed at the Tropical Marine Science Institute, National University of Singapore, using the Weather Research and Forecasting model, documented in detail by Skamarock et al. (2008). As mentioned earlier, this is a regional climate model that can be used to simulate climates for desired regions. Developed from a numerical weather prediction model, it is equipped with a large number of physical parameterisations which can be used to optimise the model for a specific region. The model is flexible, to be simulated at different resolutions, and is commonly used to downscale the GCMs dynamically over a specific region. Using this model, the study (Raghavan et al., 2017) involved simulating the climate in Southeast Asia at a 20 km spatial resolution over the baseline period (1986–2005), which was used as a reference period to compare against future climate periods (2020–2040 and 2070–2090). The study downscaled a few of the global models of the Coupled Model Intercomparison Project Phase 5 (CMIP5) under the RCP scenarios 4.5 and 8.5. The main findings from the assessments of climate change simulated by this model suggest that temperatures in the region could likely increase by 1.0°C–2.0°C by the 2020s and more than 3.5°C–4.5°C by the end of the century. Rainfall projections indicate both decreases and increases throughout the region, with significant decreases over Java Island in Indonesia and parts of northern/northeastern Thailand, parts of northern Viet Nam, and the Lao PDR.

Earlier studies on droughts in central Viet Nam (Vu et al., 2015) and some assessments of extreme rainfall in Viet Nam (Raghavan et al., 2017) suggest future climate impacts that have implications for crop production systems. A risk map (Figure 3.4) for rice production was developed as part of the same study, which applied the climate model outputs for crop (rice) growth simulation using the Decision Support System for Agrotechnology Transfer crop assessment tool. This risk map, developed for major regions of Viet Nam, shows areas of low to high risks in terms of rice production under future climate change and a temperature increase of about 4°C.

The findings of this study also indicated that rain-fed crops, in general, produce less yield than irrigated crops. Although irrigation could significantly improve crop yields, the main challenge is to find water sources given decreases in rainfall. The MRD falls in the category of high vulnerability to climate change, given other risks such as sea level rise and saltwater intrusion, droughts, and floods. Hence, prudent planning is necessary to counter negative impacts of climate change. This study provides some preliminary assessments of possible changes in the future though it is by no means exhaustive in its findings, as the science is growing and more research remains to be done both on the climate and crop modelling aspects.

Figure 3.4: Risk Map of Food Security over Viet Nam



Source: Liong et al. (2016).

3.4 Discussions on Policy Perspectives

In Southeast Asia, where agriculture is a major source of livelihood, about 115 million ha of land are devoted to the production of rice, maize, palm oil, natural rubber, and coconut (ADB, 2009). Rice has been feeding the region's population for well over 4,000 years and is the staple food of about 557 million people (Manzanilla et al., 2011). Climate change is likely to impact the agricultural sector in the ASEAN region. The World Bank (2013) stated that irrigation systems are likely to be affected by changes in rainfall and run-off, leading to problems in the availability of water and water quality. As the Southeast Asian region already faces water stress, future climate changes are likely to cause varied rainfall patterns that would further impact agriculture. Temperature increases, as mentioned earlier, are also likely to threaten agricultural productivity because of crop stress and yield reduction. These harsh impacts would affect low-income rural populations that depend on traditional agricultural systems, as in Khon Kaen Province, Thailand, which has seen reduced rice cultivation and production because of drought. Despite the government's efforts in training farmers to cultivate alternative crops, traditional rice farmers are unwilling to farm other crops. It is also notable that rice exports by Thailand have fallen since 2013 (Keck, 2013).

The reduction in crop yields in the MRD caused by climate change is important, as regional climate change is also likely to impact neighbouring regions in Thailand or even India. If the MRD has lower yields, parts of Thailand, Indonesia, and/or India are also likely to have lower yields. This should be borne in mind when it comes to the regional influence of climatic conditions. A reduced number of rainy days during the dry season, along with an increased number of rainy days during the wet season, are likely to cause considerable negative effects during growth seasons.

Evidence that climate change has affected food production implies challenges to food security (Porter et al., 2014), though quantifying this needs to incorporate many non-climate factors that interact with climate. The Fifth Assessment Report of the IPCC states that one important aspect of food security is the price of internationally traded food commodities (IPCC, 2014; Chapter 7, Section 7.1.3). These prices reflect the overall balance of supply and demand, and the accessibility of food for consumers linked to regional and global markets. The Food and Agriculture Organization of the United Nations (FAO) reported that food prices declined gradually for most of the 20th century (FAO, 2009), yet there have been several periods of rapid increases in international food prices. These spikes are attributable to increased crop demand, which may be further attributed to increased biofuel production and oil price fluctuations (Wright, 2011).

Climate-smart agriculture has become an active area of research and implementation towards adaptation to climate change. This new area of science and technology has led to addressing shortcomings in the agricultural practices and tools available for farmers – using modern agricultural practices, new devices, forecast warnings, and climate outlooks – which suggest that non-climatic factors that impact food security can be well managed. Using seasonal forecasts, in addition to climate-smart technological services, helps farmers in the short term to be better prepared to counter adverse impacts. However, climate change still poses uncertainties because of strong temperature increases (that hamper cultivar seeds) and uncertain rainfall (as in the case of irrigation). Although new cultivars have been developed and continue to be developed in light of climate change, they may be unable to withstand sudden fluctuations in temperature and rainfall.

Building on a multi-stakeholder partnership, with the support of the ASEAN governments and in collaboration with the ASEAN Secretariat, the World Economic Forum has launched a regional initiative called Grow Asia which is country-led and locally driven. This attempts to serve as a platform to help actions that contribute to food security; and paves the way for sustainable, inclusive agricultural development in support of national and regional priorities in the ASEAN region (Prakash-Mani and Tanvir, 2014).

The Global Agriculture and Food Security Program, a fund that supports country-led efforts to fight hunger and poverty, reported that seven countries – Burkina Faso, Ethiopia, Haiti, Myanmar, Nepal, Rwanda, and Tanzania – would receive grants of about $160 million to help each country increase food security, raise rural incomes, and reduce poverty. The program seeks to address multiple problems faced by farmers through a holistic approach that applies integrated, consolidated, and area-specific interventions responding to local constraints and opportunities. These include strengthening farmers' groups and building their technical and business capacities, increasing the productivity of food and high-value crops through efficient water usage, and improved agricultural inputs and technologies. This is expected to expand farmers' access to markets through post-harvest and market infrastructure support, and linkages to domestic and export markets. A similar scheme should be considered for the ASEAN countries to help developing countries in ASEAN. It is also important to develop a database based on the feedback and experience of farmers who have experienced diverse changes in weather and climate. Their experience and strategies will be useful to both the scientific community and the stakeholders. This would be a good source of 'ground data' to be recorded.

Climate change adaptation needs to be incorporated in strategies to achieve agricultural development goals by building resilience in the entire food system, not just production systems (FAO, 2012). This would lead to opportunities for additional funding for research and implementation by institutes of higher learning and policymakers. Since extreme weather and climate events are setbacks to farmers, price volatility is especially damaging to small-scale food producers when prices are too low because of good harvests or too high owing to crop damage. Any decreases in production in such circumstances affect both levels of income and food consumption (Haryadi, 2016).

A study by the Organisation for Economic Co-operation and Development (OECD, 2017) summarised some climate projections for Southeast Asia, which are in line with those mentioned earlier in this paper. Mixed rainfall patterns in the future are likely to reduce crop yields in some Southeast Asian countries, especially rice regions such as Thailand, Myanmar, the Lao PDR, and Cambodia, which mainly use rain-fed agriculture. Despite some challenges, the medium-term (next few years) outlook is likely to be in balance, giving a positive picture. By the 2050s, however, climate change could play a greater role in determining the outcomes for the agricultural sector. OECD (2017) also reports that following the production and price effects of climate change, agricultural trade between ASEAN and the rest of the world could reduce and climate change is expected to increase real prices for agricultural commodities. Price increases are predominately driven by changes in crop yields. Substantially lower yield growth, particularly for staples, combined with inelastic demand, leads to higher prices.
In Southeast Asia, prices for staple crops such as rice, maize, and cassava are expected to increase.

The IPCC stresses that food security studies are urgently required to estimate the actual range of adaptation open to farmers and other actors in the food system and their implementation paths, especially when possible changes in climate variability are included (IPCC, 2014). The negative effects of climate change on food security can be counteracted by broad-based economic growth – particularly improved agricultural productivity – and robust international trade in agricultural products to offset regional shortages (Nelson et al., 2010).
Adaptation does not necessarily imply acting only on the negative consequences of climate change but also harnesses positive changes where appropriate, as in the case of the warming climate zones/seasons where higher crop productivity could be obtained. Therefore, a

holistic approach and concerted effort to address these challenges in a broader perspective are needed. A joint effort on a regional scale and sharing of the science and adaptive measures with the regional community could benefit both the research community and policymakers, leading to effective planning that paves the way for mitigating harsh climate impacts.

However, while improvements in technology and advances in science are in progress, it is very important to have reliable seasonal forecasting and a real-time climate outlook to help farmers obtain early warning on the evolving weather/climate patterns. This gives them adequate time to develop adaptive strategies for their cropping patterns and harvests. It is also time to consider new breeds of different crops which require less water consumption and have high tolerance to soil salinity, soil moisture deficiency, droughts, and floods.

3.5 Summary and Conclusions

This paper is an overview of the possible changes to food security based on 2°C–4°C changes in future temperatures. It provides analyses based on the synthesis of available literature and climate modelling studies. Recent climate studies indicate that the average summer warming around the 2040s in this region is projected to be about 1.5°C (1.0°C–2.0°C) for a 2°C rise; and the average summer temperatures over land are projected to increase by around 4.5°C (3.5°C–6.0°C) by 2100, for a 4°C rise. Water reduction of up to 20% is projected for many regions under 2°C warming and up to 50% under 4°C warming. Climate vulnerabilities could increase because of greater variability in the precipitation and disturbances in the monsoon systems, which are the primary climate drivers of rainfall in the Southeast Asian region. Combined with responses to high temperature and variations in precipitation, it appears that yield reduction from severe climatic changes cannot be compensated, without adaptation measures, even accounting for the fertilising effects of carbon dioxide. The large reduction in crop yields, especially rice, is also likely to affect exports and the entire regional supply chain because of higher demand. This could influence the insurance markets and inflate prices – disrupting economic stability.

As the science of climate change is evolving and newer climate scenarios are being developed, the changes highlighted in this study serve as an early warning signal to the local agricultural sector to prepare for drastic changes and to be able to counter risks effectively.

Apart from increasing funding for both science and technology, coupled with policies, there is an imminent need for detailed food security studies. This could encompass several areas of study, including both climatic and non-climatic factors, to make in-depth assessments of the actual range of adaptations open to farmers and other actors in the food system. Yet, it is possible to counteract the negative effects of climate change on food security through broad-based economic growth, improved agricultural productivity, and robust international trade in agricultural products to offset regional shortages while concomitant measures to monitor climate change damages are in place.

References

ADB (2009), *The Economics of Climate Change in Southeast Asia: A Regional Review*. Manila: ADB.

van den Besselaar, E.J.M., G. van der Schrier, R.C. Cornes, A.S. Iqbal, and A.M.G. Klein Tank (2017), 'SA-OBS: A Daily Gridded Surface Temperature and Precipitation Dataset for Southeast Asia', *Journal of Climate* 30(14), pp.5151–65.

FAO (2008), *The State of Food Insecurity in the World, 2008: High food prices and food security – threats and opportunities*. Rome: FAO.

FAO (2009), *The State of Agricultural Commodity Markets 2009: High food prices and the food crisis – experiences and lessons learned*. Rome: FAO.

FAO (2012), 'UN Climate Change Conference COP18', presentation at the Hotel Crown Plaza, Doha, Qatar, 1 December.

Giorgi, F. (1990), 'Simulation of Regional Climate Using a Limited Area Model Nested in a General Circulation Model', *Journal of Climate*, 3(9), pp.941–63.

Haryadi, S. (2016), 'How food production and climate change are intertwined', *Eco-Business*, 29 September. http://www.eco-business.com/news/how-food-production-and-climate-change-are-intertwined/ (accessed 18 February 2019).

IPCC (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY: Cambridge University Press.

IPCC (2014), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B, et al. (eds.)]. Cambridge, United Kingdom and New York, NY: Cambridge University Press.

Jackson, M.B. and P.C. Ram (2003), 'Physiological and molecular basis of susceptibility and tolerance of rice plants to complete submergence', *Annals of Botany*, 91, pp.227–41.

Keck, Z. (2013), 'Thailand's Rice Exports Hit 12-Year Low', *The Diplomat*, 25 January. https://thediplomat.com/2013/01/thailands-rice-exports-hit-12-year-low/ (accessed 18 February 2019).

Liong, S.Y., J. Ze, J. Hur, and S.V. Raghavan (2016), 'Impacts of Climate Change on Rice Crop Yields in Vietnam', presentation at the Lee Kuan Yew School of Public Policy Seminar, National University of Singapore, 5 September.

Manzanilla, D. et al. (2011), 'Submergence risks and farmers' preferences: Implications for breeding Sub1 rice in Southeast Asia', *Agricultural Systems*, 4, pp.335–47. doi/10.1016/j.agsy.2010.12.005

Met Office (2014), 'Human Dynamics of Climate Change', Met Office Hadley Centre Technical Report. https://www.metoffice.gov.uk/climate-guide/climate-change/impacts/human-dynamics (accessed 18 February 2019).

Nelson, G. et al. (2010), 'Food Security, Farming, and Climate Change to 2050: scenarios, results, policy options', IFPRI Research Monograph. Washington, DC: International Food Policy Research Institute.

OECD (2017), *Building Food Security and Managing Risk in Southeast Asia*, Paris: OECD. http://dx.doi.org/10.1787/9789264272392-en (accessed 18 February 2019).

Porter, J.R. et al. (2014), 'Food security and food production systems', in C.B. Field et al. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part A: Global and Sectoral Aspects. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY: Cambridge University Press, pp. 485–533.

Prakash-Mani, K. and T. Tanvir (2014), 'How can we strengthen food security in South-East Asia?', World Economic Forum, Agenda, 19 May. https://www.weforum.org/agenda/2014/05/future-agriculture-east-asia/ (accessed 18 February 2019).

Raghavan, V.S., M.T. Vu, and S.Y. Liong (2017), 'Ensemble climate projections of mean and extreme rainfall over Vietnam', *Global and Planetary Change*, 148, pp.96–104. doi:10.1016/j.gloplacha.2016.12.003

Skamarock, W.C. et al. (2008), 'A Description of the Advanced Research WRF Version 3', *NCAR Technical Note*, NCAR/TN-475+STR. Boulder, CO: National Center for Atmospheric Research. doi:10.5065/D68S4MVH.

Trzaska, S. and E. Schnarr (2014), *A Review of Downscaling Methods for Climate Change Projections*, prepared by Tetra Tech ARD for the US Agency for International Development. Washington, DC: USAID.

Vu, M.T., S.V. Raghavan, D.M. Pham, and S.-Y. Liong (2015), 'Investigating drought over the Central Highland, Vietnam, using regional climate models', *Journal of Hydrology*, 525, pp.265–73. doi:10.1016/j.jhydrol.2014.11.006

Wassmann, R. et al. (2009), 'Climate Change Affecting Rice Production: The Physiological and Agronomic Basis for Possible Adaptation Strategies', *Advances in Agronomy*, 101, 59–122.

World Bank (2010), *Economics of Adaptation to Climate Change: Vietnam*. Washington, DC: World Bank.

World Bank (2013), *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*. A report for the World Bank by the Potsdam Institute for Climate Impact Research. Washington, DC: World Bank.

Wright, B.D. (2011), 'The Economics of Grain Price Volatility', *Applied Economic Perspectives and Policy*, 33(1), pp.32–58.