Front. Agr. Sci. Eng. 2023, 10(1): 16–30 https://doi.org/10.15302/J-FASE-2023492

REVIEW

BUILDING CLIMATE-RESILIENT FOOD SYSTEMS IN EAST AND SOUTHEAST ASIA: VULNERABILITIES, RESPONSES AND FINANCING

Yunyi ZHOU[1], Ziqi CHEN[1], Kevin Z. CHEN (✉)[1,2]

1 China Academy for Rural Development and School of Public Affairs, Zhejiang University, Hangzhou 310058, China.
2 International Food Policy Research Institute, Washington DC 20005, USA.

KEYWORDS

food systems, climate change, East, policy, resilience and Southeast Asia

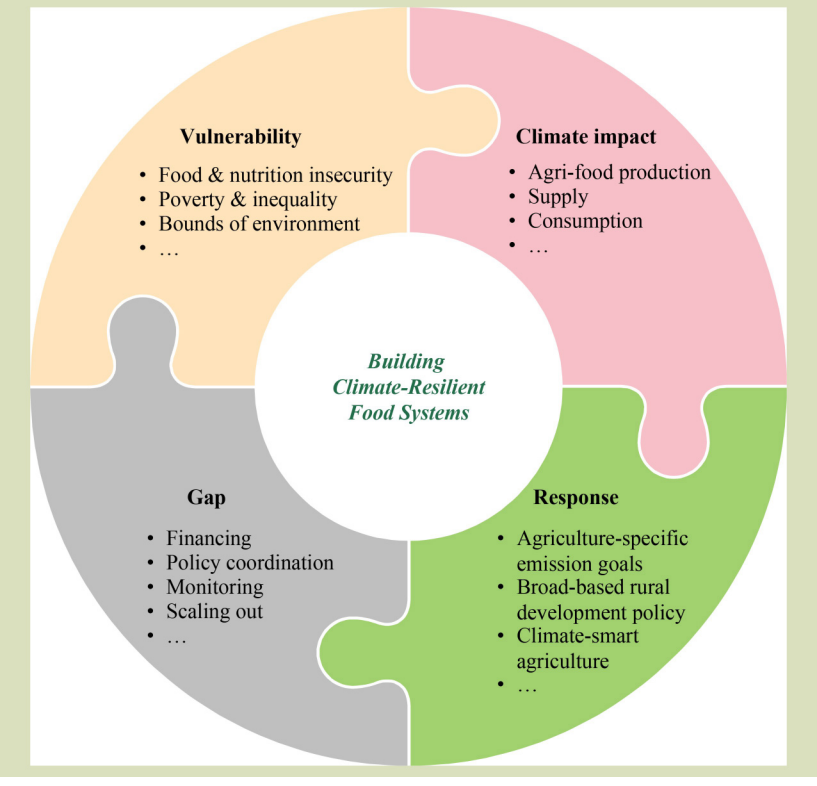
HIGHLIGHTS

- Food systems in East and Southeast Asia are vulnerable to global warming.
- Regional governments strive for adaption, mitigation and financing for climate resilience.
- Vulnerabilities of food system actors and activities exacerbate the challenges faced.
- Agriculture-specific goals, climate-smart agriculture and market integration are key to building climate resilience.

Received November 28, 2022;
Accepted February 22, 2023.

Correspondence: kzchen@zju.edu.cn

GRAPHICAL ABSTRACT



ABSTRACT

Food system resilience to climate change is uniquely imperative for bringing Sustainable Development Goals within reach and leaving no one behind. Food systems in East and Southeast Asia are interacting with planetary boundaries and are adversely affected by extreme weather-related events. A practical question for East and Southeast Asian stakeholders is how to foster climate-resilient food systems in the face of lingering food system vulnerabilities and policy gaps. This paper reviews food system vulnerabilities and policy responses to climate change. In the policy-based review, this paper compares the economy-wide and agriculture-specific targets of low-carbon development

across East and Southeast Asia. With China and member states of the Association of Southeast Asia Nations as case studies, multilevel policies in building and financing climate-resilient food systems are further synthesized. The findings confirm significant differences in agriculture-specific emission goals and public financing supports across East and Southeast Asian nations. With an objective to break practical barriers and finance climate-resilient food systems for the future, this paper recommends defining agriculture-specific greenhouse gas emission goals, reorienting the public finance scheme and enhancing mechanisms for the synergy of public and private resources.

1 INTRODUCTION

Climate change is one of the foremost challenges in reaching the Sustainable Development Goals (SDGs)[1]. Growing frequency and magnitude of extreme weather-related events sweep the globe, yet affect countries, sectors and population groups disproportionately[2]. East and Southeast Asian economies feed about 30% of the global population and deliver over 25% of the global GDP[3]. Most of the population and the economic activities of the region are based in coastal areas and river basins, but many governments lack the capability to respond to hazards. East and Southeast Asia has been on the frontline interacting with planetary boundaries and afflicted with extreme events, especially droughts, floods, heatwaves, typhoons, and sea level rise[4].

Food systems encompass actors and activities in the production, storage, aggregation, postharvest handling, transport, processing, distribution, marketing, disposal and consumption of agrifood commodities, which are intrinsically susceptible to climate factors[5]. For developing countries in East and Southeast Asia, although the economic share of agriculture has relatively decreased, the contribution this sector to the value-added remains at 10% or above[3]. Food systems in East and Southeast Asia not only underpin the rapid structural transformation in this region but also contribute to global food security[6]. For example, the food systems deliver half of the global rice yields and provide a significant portion of maize, wheat, rubber and oil palm[5,7]. However, the indigenous agricultural activities largely rest with weather conditions and intensive inputs, exposing food systems to climate and weather extremes[8]. As growing population and rapid urbanization drive up food and nutrition demand across East and Southeast Asia, the changing climate further keeps regional food security and sustainability limits of resources in an unpredictable state. Concurrent food-system shocks, including global economic recession, the ongoing COVID-19 pandemic, the Russia–Ukraine conflict and many other climate and non-climate stressors, have added concerns about the capacity and the picture of East and Southeast Asian food system transformation.

In addition, food systems have been shaping the process of climate change by generating about a third of global greenhouse gas (GHG)[9]. In particular, agriculture, forestry, and land-use change (AFOLU) account for nearly one-fifth of GHG emissions worldwide[10], wherein the synthetic nitrogen fertilizer supply chain is responsible for over 10% of agricultural emissions[11]. As for East and Southeast Asia, with an intensive pattern of synthetic N fertilizer use, food system emissions (CO_2 and CH_4) of the region represent up about 27% of global emissions[12]. Population growth, fast urbanization and increasing household income have been driving up the demand for food and better nutrition, especially in China and member states of the Association of Southeast Asia Nations (ASEAN). However, land-use change and overuse of agrochemicals and water in East and Southeast Asia have increasingly eroded the fundamental ecosystem services and compromised food system resilience under climate shocks[4].

Food system resilience is defined as the capacity over time of a food system to provide sufficient, appropriate, and accessible food to all in the face of disturbances[13]. A climate-resilient food system features the capacity against climate-induced shocks. Insofar as the pace to meet SDGs has been globally off track, actions to build food system resilience have been urged to go beyond the business as usual and be more realistic[9,14].

Suffering increasing frequency an intensity of extreme events, East and Southeast Asian governments have generally made political efforts to adapt to and mitigate adverse climate impacts on food security, agricultural livelihoods and other food-system-related contributors to wellbeing. Many have

submitted pledges under the United Nations Framework Convention on Climate Change and announced the low carbon development strategy, guidelines, and action plans that entail agriculture. Nevertheless, the wide-ranged policy scope for low carbon development across East and Southeast Asian countries is juxtaposed with gaps in financing, coordination and monitoring, such gaps further raise questions about the specific way forward in the policy system to build climate-resilient food systems. In other words, a practical question for the regional policymakers is how to create climate-resilient food systems in the face of lingering food system vulnerabilities and policy gaps.

This review aims to contribute to three facets in providing reliable implications to this question. First, as the globe is recovering from the COVID-19 pandemic peak, recent studies recognize the universal opportunity to foster resilience while recovering[15–17]. By discerning the looming vulnerabilities of regional food systems to climate change, this paper also aims to be a timely contribution to rebuilding the post-COVID-19 pandemic policy systems. Second but more importantly, we provide a synthetic policy review across East and Southeast Asia for future studies and policy decisions. Food systems in the region share a spectrum of interests and vulnerabilities, especially for countries with a large population leaning upon agriculture for food and livelihood[4,18]. Implications for one country in the region are likely replicable for another. However, empirical clues for fostering food system resilience remain scattered, largely because the food-system-related projects tend to pivot intersectional fields such as poverty reduction and energy transition[19]. A lack of focused policy review and lack of reference country case studies restrains future food system endeavors from synergies at the regional level. Instead of confining to a country or a specific policy, this paper aims to elucidate the regional landscape of policy responses for developing food system resilience to climate change across East and Southeast Asia. Third, since recent studies reveal that financing is the key among all levers for low carbon development initiatives[20,21], the discussion section proposes ways forward with a particular focus on financing food system resilience to climate change.

After clarifying the methodology, the paper then introduces the looming vulnerabilities of East and Southeast Asian food systems in the face of climate shocks. The main body of this paper, entailing a synthetic review of low-carbon development goals and extant policy systems in response to climate impacts across East and Southeast Asian countries. To further climate-resilient of food systems, gaps within such a policy landscape are identified. The concerns flowing from recent policy analyses and financing the policy priorities are the focus of the final discussion.

2 METHODOLOGY

2.1 A brief analytical framework

Figure 1 gives the analytical framework of this paper. Concurrent development uncertainties (including global economic recession, the ongoing COVID-19 pandemic, the Russia–Ukraine conflict, and many other climate and non-climate factors) continue to create food system vulnerabilities in such a way as to generate a perfect storm. Among all the long-term stressors, climate change has rather stubborn impacts throughout value chains in the food systems. To mitigate and adapt to those adverse effects, East and Southeast Asian governments have been developing food system resilience with policy responses, ranging from low-carbon development goals and strategies to agriculture-specific measures. However, gaps last on the way forward, where financing is primary[20,21].

2.2 Review method

This paper provides a literature review, focusing on East and Southeast Asia. The review covers both vulnerabilities and responses. The former gathers empirical evidence and evidence-based projections regarding food system vulnerabilities in the face of extreme weather-related extreme events, while the latter synthesizes pledges and policies for food systems to adapt to and mitigate climate impacts.

Climate change, economic transformation, many anthropogenic uncertainties and their mixed repercussions have been reshaping vulnerabilities and outlooks of food systems[22]. For climate- and weather-induced vulnerabilities, the complexity of food systems and the lack of data lead to the fragmentation and deficit of empirical evidence. Thus, the review of food system vulnerabilities aims to capture the trends of climate impact, rather than the verified causal mechanisms. The High Level Panel of Experts on Food Security and Nutrition (HLPE)[23] identifies components of food systems toward SDGs, which is widely accepted in the ongoing discourse of food system transformation. Following HLPE and an economic perspective[14], this paper summarizes the trends of climate impact on agrifood production, supply and consumption.

In the policy-based review, low-carbon development goals and

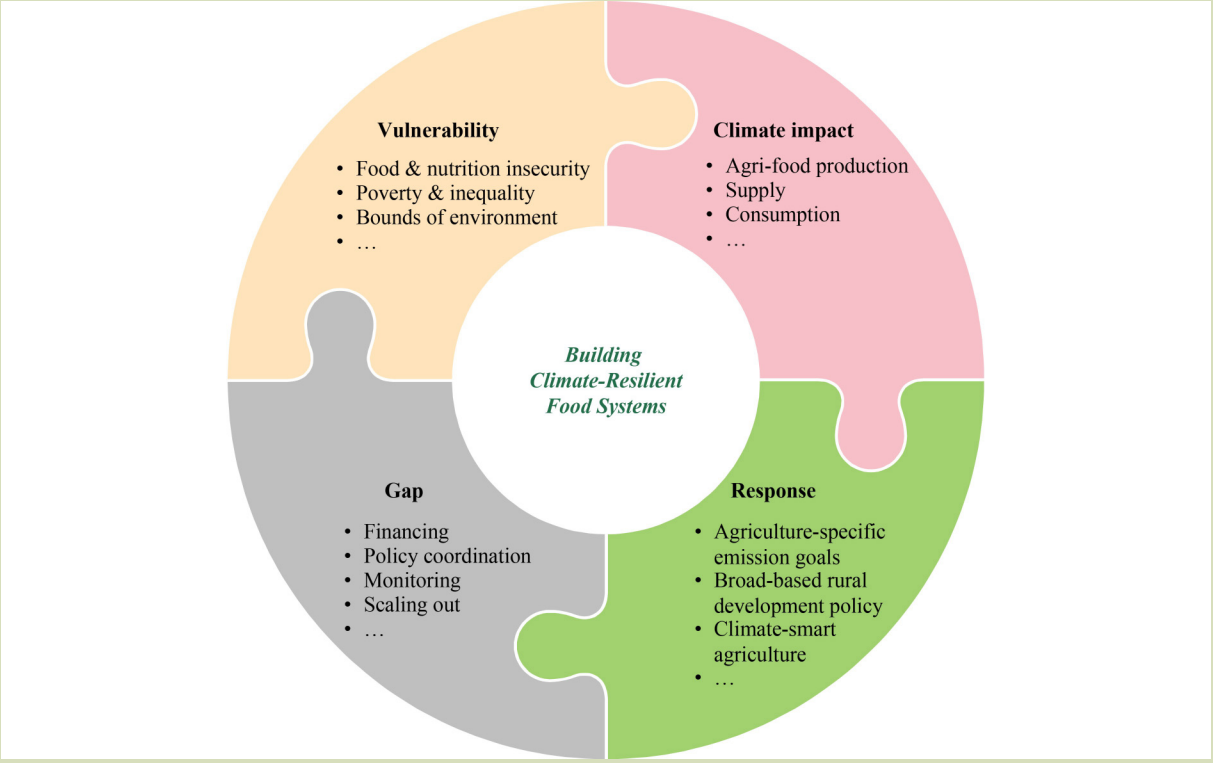


Fig. 1 Conceptual framework for building climate-resilient food systems.

agriculture-specific targets of East and Southeast Asian countries are compared. Then, this paper selects economic powerhouses in the East Asian subregion and representative member states of ASEAN, and reviews policies focusing on food system resilience to climate. Sources of the policy documents include web pages of the United Nations and governmental departments, and related news platforms. Whether to incorporate the policy documents from search results into this study follow two criteria. The one is the issued year no earlier than 2015, with exceptions for long-term strategies and legislation. The other is the mandate and thematic relevance of the policy documents, which diversifies per review steps.

Specifically, as outlined in Fig. 2, the selection and review of policy documents comprise four steps. The first step is to consider the nationally determined contributions[24] of East and Southeast Asian countries, in such a way as to draw their economy-wide and agriculture-specific GHG mitigation targets.

The second step looks for the predominant climate strategies in China, Myanmar, Laos, Cambodia, Thailand, Vietnam, Indonesia and the Philippines. Keywords at this phase include "adaptation", "carbon/low carbon/carbon peak/carbon neutral", "climate/climate change", "mitigation", and "resilience/resilient" with "plan", "strategy" or "vision" as affixes. The aims and food system priorities of those climate strategies are highlighted in Table S1.

The third step reviews agriculture-specific policies closely related to resilience to climate change. The online search puts in additional keywords, including "agricultural products/fisheries/livestock", "fertilizer", "green agriculture", "good agricultural practices (GAP)", "quality improvement/high quality", "sustainable", and "technology". Strategic documents stand out from vast policies in the specific agrifood fields by appending "agenda", "guideline/guide", "law", "policy", "standard" or "strategy".

The fourth step explores the financial policy landscape to identify the way forward. In doing so, the review further confirms the efforts and gaps in financing food system transformation toward climate resilience. The keywords contain "finance/climate finance/green finance", "budget", "fund", "credit", and "investment" with "program", "guideline" or "international cooperation" as affixes.

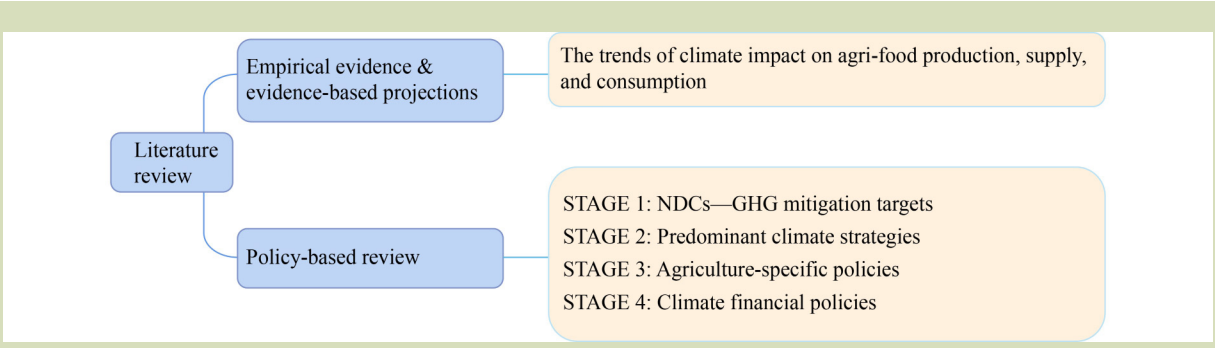


Fig. 2 Abstract of the review method.

3 FOOD SYSTEM VULNERABILITIES TO CLIMATE CHANGE IN EAST AND SOUTHEAST ASIA

3.1 Susceptible population groups

In recent years, global economic downturns and conflicts have increasingly driven food insecurity and malnutrition, eroding the capacity of susceptible groups to develop. Meanwhile, the ongoing COVID-19 pandemic has compromised global progresses toward sustainability, leaving poor households and many other vulnerable groups with deepened uncertainties[9]. In terms of food systems, climate change is another foremost factor to impede efforts for SDG1 No Poverty and SDG2 Zero Hunger. This further increases vulnerabilities to the poor and marginalized population groups under future weather extremes and natural hazards.

Over a quarter of workers in the developing countries of East and Southeast Asia relied on agriculture for livelihoods before the COVID-19 pandemic[3]. However, there is an astounding empirical gap in tracking farmer health status weathering extreme events such as heatwaves, droughts and floods[25]. Recovering from the COVID-19 pandemic peak, the proportion of agricultural employment has increased with uneven economic recovery and the dilation of informal employment[26]. The Southeast Asian population trapped in extreme poverty (living below 1.90 USD per day) was estimated to increase by 5.4 million and 4.7 million in 2020 and 2021, respectively[27]. While East Asia continued to reduce its prevalence of undernourishment (PoU) to below 2.5%, the PoU of Southeast Asia has retrogressed since 2020. A similar picture manifested in the malnutrition of children[28]. Overall, the population in East and Southeast Asia suffering from chronic hunger expanded to 62.3 million in 2021[29]. Till 2022, Myanmar, Cambodia and the Philippines faced the highest prevalence of insufficient food consumption among the member states of ASEAN, with over 32.6 million people affected[30].

Women, children, poor people and vulnerable households fare worse with increasing prices for energy and food (especially healthy diet), which are fermented by climate change, the COVID-19 pandemic, and the Russia–Ukraine conflict[31]. Since informal employment, migrant workers, and most rural population have limited and uncertain access to social security, inequality in income and human capital investment can be further enlarged and therefore burden socioeconomic development in the long run[32,33]. With weakened human capital accumulation in the region, measures for food systems to adapt to and mitigate climate impact become increasingly challenging.

3.2 Vulnerable food system activities

At a country level, Myanmar, the Philippines and Thailand have been ranked among the most affected countries for long-term climate risks over the last two decades. For other economies in the region, Vietnam and Cambodia ranked high after the top ten. While China, Mongolia, Laos and Japan were about the fiftieth, climate-induced losses in economic powerhouses of this region, both China and Japan, averaged at the top[34]. As global warming compounds beyond 1.5 °C, the direct negative impacts of extreme weather-related events on agrifood systems are expected to far outweigh the possible increase in crop yields. Since marine heatwaves became a new threat, Vietnam, Thailand, China and the Philippines have been warned of high vulnerabilities in aquaculture and marine production and related livelihoods[28].

Strengthened shocks of the extreme events can damage the contribution of the region as a major producer of grains and

industrial crops (e.g., rubber, palm oil and sugarcane). For rice, the chief staple in this region, climate change is estimated to cause a substantive reduction in its yields, with the highest loss rate beyond 35%[35]. Countries in the south-east subregion are likely to encounter considerable rice yield gaps (Cambodia, Myanmar, the Philippines and Thailand) and further dependence on regional trade (Indonesia and the Philippines) by 2040[36]. In a long-term projection under climate change without CO_2 fertilization, those south-eastern nations are likely to experience desperate yield losses in a wider range of crops by 2050 as compared to the 2000 benchmark[37]. With intensified inputs (especially fertilizers) to secure yields, climate change leads food systems further exceed the planetary boundaries. Those climate-induced changes have salient ramifications for development, especially for several of which agriculture comprises a significant proportion of growth and livelihoods[38].

Value chain embeddedness continues to deepen in the region, contributing to fostering resilience through trade linkages. However, cascading impacts of climate change on domestic food supply can disturb intraregional trade flows, further increasing economic and welfare losses throughout global value chains. For examples, China experienced a mix of record-breaking heatwaves, severe drought and heavy rainfall in 2022, potentially causing a slip in its annual rice production. Although the contracted production in China is expected to be buffered by domestic reserves, it is likely to have repercussions on global cereal markets[39]. Vietnam is the major rice producer in the region and a net exporter. However, rice and maize production in the Vietnam Mekong Delta have high exposure to flooding, sea level rise, salinity intrusion, and drought, which persist in confronting regional food security[40]. Rural infrastructure, energy networks and telecommunications in ASEAN and developing countries elsewhere in the region are bearing the growing brunt of extreme events and sea level rise. The rising temperature, in particular, challenges the supply of perishable food, such as livestock products[41].

Directly or indirectly, climate change challenges food availability and access[42]. For example, the number of people suffering from hunger is estimated to be around 105 million in 2050, of which over 13 million people would have escaped from hunger without climate change[43]. Empirical studies have documented key mechanisms of climate impacts, including increasing food losses and lessening farm income[42]. A recent study models that, under changing temperature and precipitation patterns in Malaysia, urban and rural household consumption are about to decline by 1.3%–6.3% and 1.3%–6.6%, respectively[44]. In another case of the Philippines, when rainfall shocks upset income through lower payoffs, the decrease by one percentage point in wages can drive up the rate of food poverty by 22%[45].

4 RESPONSES FOR BUILDING CLIMATE-RESILIENT FOOD SYSTEMS

4.1 Mitigation targets and major policies

Responses to climate change have edged up to the fore of the development policy landscape, especially since the Paris Climate Agreement. As summarized in Table 1, many countries in East and Southeast Asia have submitted nationally determined contributions and made pledges for economy-wide GHG emission reduction by 2030. Nevertheless, many developing countries leave the agriculture-specific emission reduction targets in a unaddressed or on condition to international support, which neatly mirrors the limited capacity of domestic public financing to transform food systems. This is especially the case for countries fared worse in economic development and financial position. Although the overall commitment reflects on sectoral contributions, the lack of explicit targets in agriculture and rural areas somehow sets back the initiatives of policy responses to build climate-resilient food systems.

In the case of Vietnam, around 2020, the agricultural proportion in GHG emissions and water abstraction was about 32% and 95%, respectively. Being a contributor to Vietnamese exports, rice production is simultaneously a driver of methane emissions and water use. As such, the government has actively committed to cutting agricultural emissions by 20% every 10 years and also signed the global methane pledge[46]. In response to its National Climate Change Adaptation Plan for 2021–2030, the country approved the plan for agriculture and the scheme for restructuring the rice sector. Since the potential of agricultural land expansion and higher fertilizer use have already been fully exploited, the scheme sets specific objectives to: maintain paddy production, ensure annual rice production, reduce the use of mineral fertilizers and agrochemicals, reduce GHG emissions in rice production and ensure farm profits with concrete goals by 2025 and 2030. Notwithstanding practical challenges in building climate-resilient food systems, the specific emission reduction goals in agriculture have guided the measurement, reporting and verification of related policy initiatives to surmount those challenges.

Fostering resilience with a food system perspective becomes

Table 1 Economy-wide and agriculture-specific GHG mitigation targets of the countries in East and Southeast Asia

Country	Economy-wide emissions reduction targets		Long-term strategy submitted to UNFCCC	Agriculture-specific target	Global methane pledge (reduce global CH_4 −30% from 2020 levels by 2030)
	2030 target	2050 target			
Myanmar	−244.52 Mt CO_2 eq; −414.75 Mt CO_2 eq conditional on int. support	None	No	Conditional cumulative target of sequestrating 10.4 Mt CO_2 eq over the period of 2021–2030	No
Cambodia	−42% (BAU)	Net zero	Yes	19 Mt CO_2 eq by 2050	Yes
Timor-Leste	None	None	No	None	Yes
Laos	−60% (BAU)	Net zero (conditional)	No	−120 kt CO_2 eq per year conditional on int. support	No
The Philippines	−2.7% (2020); up to −75% conditional on int. support	None	No	−29.4% by 2030 (BAU) conditional on int. support	Yes
Vietnam	−9% (BAU); up to −27% conditional on int. support	Net zero	No	−20% every 10 years	Yes
Indonesia	−29% from BAU; up to −41% conditional on int. support	Net zero by 2060	Yes	None	Yes
Mongolia	−22.7% (2010)	None	No	−5283.3 Gg CO_2 eq	Yes
Thailand	−30% (BAU); up to −40% conditional on int. support	Carbon neutrality; net zero by 2065	Yes	None	No
Malaysia	−45% (2005)	None	No	None	Yes
China	Peak CO_2; −65% GDP emission intensity (2005)	Net zero by 2060	Yes	None	No
Republic of Korea	−40% (2018)	Net zero	Yes	−27.1% by 2030; −37.7% by 2050 (2018)	Yes
Japan	−46% (2013)	Net zero	Yes	49.5 Mt CO_2 eq by 2030	Yes
Brunei	−20% (BAU)	None	No	None	No
Singapore	Reduce emissions to around 60 Mt CO_2 eq in 2030	Net zero	Yes	None	Yes
Democratic People's Republic of Korea	−16.4% (BAU); up to 52% conditional on int. support	None	No	None	No

Note: BAU represents the business-as-usual scenario. Conditional on int. support means conditional on international support. Source: Data on the Philippines, Vietnam, Indonesia, China, Republic of Korea, and Japan are adapted from OECD[46]. Data for Myanmar, Cambodia, Timor-Leste, Laos, Mongolia, Thailand, Malaysia, Brunei, Singapore, and Democratic People's Republic of Korea was based on documents issued by their governments.

progressively accepted by climate-related policies and schemes. To unveil initiatives in the developing countries of the region, Table 2 lists major climate strategies, the agriculture-specific policies, and targeted public financial supports (e.g., policies, programs and funds). A further clarification on the aims and food-system-related priorities of those climate strategies are given in Table S1. Although China is yet to set an agriculture-specific target to reduce emissions, the country initiated a campaign for zero growth of mineral fertilizer use in 2015 and reported accomplishing the goals in 2021[47]. China has now developed an overarching climate strategy and relatively systematic agricultural polices as listed in Table 2. In the southeast subregion, ASEAN member states that are deeply suffering from climate change have generally developed strategic frameworks for mitigating climate change. For example, among the most exposed to climate change over the long-term, Thailand has already set short-, medium-, and long-term goals for measures in the Climate Change Master Plan 2015–2050[48].

Table 2 Climate strategy, agricultural policies, and the related financing support

Country	Climate strategy	Agricultural policies (for example)	Financing support (for example)
Myanmar	The Myanmar Climate Change Strategy 2018–2030 (2019)	• The Myanmar Climate-Smart Agriculture Strategy (2015) • Myanmar Good Agricultural Practice Standards for Crops • Fertilizer Law	Myanmar Agriculture Development Strategy and Investment Plan (2018)
Cambodia	The Cambodia Climate Change Strategic Plan 2014–2023 (2013)	• Agricultural Sector Master Plan toward 2030 (2020); Five-Year Strategic Plan 2019–2023 for Agriculture Sector (2019) • Master Plan for Crop Production in Cambodia to 2030 (2016) • Strategic Planning Framework for Fisheries 2015–2024 (2015)	Climate Change Financing Framework (2015)
Laos	National Strategy on Climate Change of Lao PDR (2012)	• Agriculture Development Strategy to 2025 and Vision to 2030 (2015)	Climate Investment Plan Agriculture and Forestry (2018)
The Philippines	National Climate Change Action Plan 2011–2028 (2011)	• The Adaptation and Mitigation Initiative in Agriculture • Food Resiliency Protocol	The Philippine Sustainable Finance Roadmap (2022)
Vietnam	National Climate Change Strategy to 2050 (2022)	• Scheme on Development of Organic Agriculture in the Period of 2020–2030 (2018) • Law on Fisheries (2017)	Vietnam Climate Finance Framework (2022)
Indonesia	Long-Term Strategy for Low-Carbon and Climate Resilience 2050 (2021)	• The Strategic Plan of the Indonesian Ministry of Agriculture 2020–2024 • National Action Plan on Indonesian Sustainable Palm Oil 2019–2024 • Law on Protection of Sustainable Food Agricultural Land (2009)	Presidential Regulation on Management of Environmental Funds (2018)
Thailand	Climate Change Master Plan 2015–2050 (2015)	• The Agriculture Strategic Plan on Climate Change (2017)	Sustainable Financing Framework (2020)
Malaysia	National Policy on Climate Change (2009) Long-term Low Emission Development Strategy (upcoming)	• National Agro-Food Policy 2021–2030 (2021) • The Malaysian Good Agricultural Practices (2013)	Green Technology Financing Scheme 2.0 (2019)
China	Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (2021)	• The 14th Five-Year Plan of National Agricultural Green Development (2021) • Reformation Plan for Establishing a Green and Ecology Oriented Agricultural Subsidy System (2016) • Implementation Plan for Agricultural and Rural Carbon Reduction and Fixation (2022)	Notice on Financial Support for Carbon Neutralisation (2022) Climate Investment and Financing Pilot Work Plan (2021)
ASEAN	The Establishment of the Climate Resilient Network (2018)	• ASEAN Multi-Sectoral Framework on Climate Change and Food Security • The Development of Agricultural Standards and Guidelines (Good Agriculture Practices and Good Animal Husbandry Practices) • ASEAN Good Animal Husbandry Practices for Animal Welfare and Environmental Sustainability Module (2016)	ASEAN Guidelines on Promoting Responsible Investment in Food, Agriculture and Forestry (2018)

Note: ASEAN is the abbreviation of the Association of Southeast Asia Nations.

However, a scrutiny of policy contents indicates that, the strategic guidance remains biased toward agricultural production and food security. More systematic and food-system-based action portfolios feature a large scope to reconcile carbon neutrality, food security, dietary diversity and many other actions. Projections for China suggest that the combination of improving agricultural technologies, reducing food loss and waste, and shifting dietary patterns could reduce GHG emissions from the food system by 47% as of 2060[49]. Also, policymakers should be vigilant that, notwithstanding AFOLU's bulky contribution to GHG emissions, the use of relevant mitigation measures is sensitive to food and nutrition security. Afforestation was estimated to have a larger benefit for global food security than non-CO_2 emissions policies (e.g., emission tax) in agriculture could have[50]. Supply-side management (e.g., soil conservation and conservation agriculture) and demand-side improvements (e.g., dietary transformation toward sustainability and reducing food waste)

are expected to relieve the side effect of mitigation in AFOLU[51,52].

In recent years, policies are increasingly embracing green development, thereby extending food-system-related actions beyond agricultural production and food security, such as developing ecosystem services, reducing food loss and waste and broad-based rural development through strengthened urban-rural linkages. Resource conservation (e.g., soil, water and biodiversity) and ecosystem restoration (e.g., forest management and land restoration to forestry) can foster long-term food system resilience and the potential of rural added values. Rapid urbanization, income increase and population growth have been generating a large market for premium ecosystem services in rural areas[33]. However, governmental capacities in evaluating, managing, and monitoring ecosystems and eco-environmental resources vary substantially. Constrained financing, either from public finance or private sectors, to support the conservation and restoration has been identified as a gap, which increasingly constrains the wider application of nature-based solutions in building climate-resilient food systems[53].

The dietary transformation toward humanity and planetary health is a possible contributor to reduce GHG emissions and sustain food and nutrition security from the consumption sectors. In the case of China, dietary change toward the Chinese Dietary Guidelines, the EAT-Lancet diet, the Mediterranean diet, or a low-meat diet was projected to reduce agricultural GHG emissions up to 25% by 2030, compared to the 2020 benchmark scenario without any improvements[49]. As the ongoing dietary transformation is unprecedented in especially ASEAN countries and China, governments in those nations will need substantial efforts from both authorities and market shaping to nudge the emission abatement driven by consumption[54].

As such, collaboration between governmental departments and social agencies is essential for building climate-resilient food systems, which echoes the substance of the ASEAN Multi-Sectoral Framework on Climate Change and Food Security. To strengthen their implementation, countries made further strides in the configuration of institutional organizations and agricultural policy revision. For example, Indonesia established a new national food agency in 2021, with responsibilities to ensure food and nutrition security. The agency was supposed to coordinate cross-ministry policy trade-offs and therefore replace some decision-making authorities[55]. However, the COVID-19 pandemic and global economic downturns have rendered food system actions of all nations more complex. Challenges such as incentive trade-offs and lack of financial capacity further block the pathway to meeting the ambitious goals.

4.2 Specific practices for building climate-resilient food systems

Building on the emission targets and climate change adaptation policies concerning food system transformation, governments have a spectrum of instruments at their disposal, including agricultural and rural development support (e.g., infrastructure, grants and preferential credits), environmental regulations, emissions pricing instruments, as well as research and development and capacity building. Evidence suggests that these specific approaches perform differently in availability (e.g., producers, consumers and government budgets), public access and effectiveness (e.g., synchronizing emission reduction, food and nutrition security and cost efficiency)[46]. Among technologies and practices for climate-smart agriculture (CSA), good agricultural practices (GAP) and carbon pricing schemes show promise and efficiency in building climate-resilient food systems in East and Southeast Asian countries[56–58]. Recent practices also indicate opportunities and looming challenges for expanding proactive approaches.

To balance agriculture productivity within sustainability limits, many countries in the region have been supporting technologies and practices of CSA, including climate-resilient crops and planting calendar adjustment systems (e.g., direct-seeded rice, and alternate wetting and drying), efficient machinery and capacity building[59–61]. Internet and communication technologies (ICTs) and digital instruments are a productive and fast-growing field for developing CSA and mitigating climate change. In decision support, techniques such as light detection and ranging, and geographic information systems have been evaluated by farmers to match crop cultivars and field plots with forecasts[62]. In the case of China Weather Index Insurance Project, digital insurance has shown promise to stabilize income of small-scale farmers under climate-induced natural disasters[58]. While ICTs and digitalization have large possibilities in traceability and monitoring along the post-harvest procedures, gaps in financing and relevant institutional surroundings are considerable. A cross-country evaluation of experiences expanding location-specific climate-smart agriculture models (e.g., climate-smart villages) in ASEAN recommends that, starting with knowledge sharing, then mainstreaming the

tested interventions into government policies, and ending up sustaining efficiency with proper market strategies[57].

GAP is a set of standards applied throughout agrifood production in line with green development and sustainability, which shows scope to facilitate food system resilience under climate change. Most countries in East and Southeast Asia have already developed GAP to increase the competitiveness of domestic agrifood products in the global market and reduce spillovers from non-tariff barriers[63,64]. As market integration deepens, those domestic standards have incrementally converged at higher levels. The ASEAN Good Agricultural Practice standard (ASEAN GAP) was introduced in 2006, focusing on food safety, environmental management, work health, safety and welfare, and produce quality[65]. Specific guidelines and regulations on key agrifood products (fresh fruit and vegetables, food fish, poultry products including broilers and layers, and organic produces) have been released progressively[66]. Recent evidence in Indonesia affirms that following GAP standard can significantly reduce GHG emissions from the dairy and horticultural sectors[57]. However, standards vary between countries and regions. Market integration in the form of deepened value chain embeddedness and concordant food standards is expected to drive multilevel food systems transformation toward resilience through bilateral and multilateral trade linkages.

In addition to CSA and food standards, broad rural development policies help foster development of food systems. For China and ASEAN member states, rapid urbanization and income growth have caused unprecedented domestic demand for healthy and green rural products, including ecological services and agrifood products. Physical infrastructure, such as roads and ICT facilities, remains the key to livelihoods of food system actors residing in rural areas and marginal communities[67]. Strengthened urban-rural linkages have been stressed as fundamental for farmers to develop added values and for rural vulnerable groups to accumulate human capital[33]. E-commerce has developed in major regional economies before the COVID-19 pandemic and has demonstrated proactive in facilitating urban-rural income growth and leaving no one behind. Building on that, fintech has leveraged the recovery of small and medium-sized enterprises (SMEs) from the COVID-19 pandemic in ASEAN member states, where SMEs account for a large economic share[68]. Overall, broad-based rural development policies including poverty reduction and rural revitalization, as well as common prosperity, reduce food system vulnerabilities and thus move food system transformation toward resilience.

5 FINANCING FOOD SYSTEMS FOR CLIMATE RESILIENCE

Food system transformation is now at a critical process where it is still possible to mitigate roaring climate change, but only if the climate-resilient pursuit is fulfilled with firm action. Considering the closing windows of opportunity, persistent gaps to underpin CSA and other proactive responses imply that countries in East and Southeast Asia have urgent work to do. Among structural barriers that burden climate-resilient food systems, finance has been repeatedly recognized as a crux to overcome[69,70].

To realize all SDGs and keep global warming within 2 °C by 2050, the worldwide annual investment gap in nature-based solutions (e.g., restoring and improving forestry, peatland, mangroves and regenerative agriculture) was estimated at 400 billion USD, using 133 billion USD circa 2020 as the baseline. Regarding the base-year annual flow, public finance provided the majority share, while only 14% was from the private sector[52]. In a typology based on country clusters, G20 (including China, Indonesia, Japan and the Republic of Korea from this region) takes up about 92% of the nature-based global spending[70]. For Indonesia, only 13.2 billion USD was from private businesses and invested in building climate resilience between 2015 and 2018. The country has a shortfall of 247 billion USD needed to meet the national emission reduction target by 2030[71]. In particular, financing loopholes elsewhere are even more considerable. In the case of Vietnam, with an agriculture-specific emission reduction target, keeping the agricultural sector on the net zero pathway would require an extra 15.6 billion USD over the period of 2022 to 2040[72].

As East and Southeast Asian economies are recovering from COVID-19 pandemic shock, building climate-resilient food systems is at a critical point. For one perspective, many recommend that the post-COVID-19 pandemic rebound is a key opportunity to build resilience, inclusiveness and sustainability, wherein more robust and expanded financing[73]. The other perspective is that financing agrifood system transformation is increasingly lucrative opportunity for domestic or foreign businesses. For example, many climate-vulnerable countries amid ASEAN (e.g., Cambodia, Indonesia, Myanmar, the Philippines and Thailand) face emerging market demand for green agrifood products. The global market will be over 10 trillion USD as of 2030 and features productive and regenerative agriculture as well as healthy and productive oceans[15].

However, the fiscal position of countries in both regions has

already tightened during the COVID-19 pandemic and also by the war in Ukraine and the lackluster economic growth worldwide. Further price surges and inflation regarding agrifood commodities are likely to increase budgetary costs of government subsidies and price controls, limiting the scope for further policy support in agriculture. Considering differing governmental capacities (fiscal positions) to sustain fiscal buffers, the progress to finance climate-resilient food systems in the Philippines, Thailand and Malaysia may be lagged by tightening support[74]. Closing the financing gap in food system transformation would require a reorientation of the public finance scheme and the reform in financing mechanisms to mobilize multifaceted financial resources and increase efficiency.

Currently, public financial incentives dependent on agrifood production (e.g., subsidies for sustaining inputs such as fertilizers, water and pesticides) often lead to trade-offs with the climate-resilient actions. For example, to cushion the socioeconomic impact of the COVID-19 pandemic, most nations provided rescue packages (e.g., in-kind food distribution, cash transfer programs and widened social protection) and targeted measures to support domestic food production and consumption. For sustaining food supply and protecting producers, governments provided input subsidies, and distribution and price support through procurement and regulation, and other broad-based rural development policies. However, those short-term measures (mostly public policy support through price fixation and trade barriers) distorted the market and contradict the trend of green production and dietary diversification. In China and Vietnam in particular, over 60% of budgetary agricultural support went to production subsidies and hydrological infrastructure between 2010 and 2020 on average[17]. Relocation of distorting support can liberate considerable funds and efficiency that can enhance food system transformation to sustainable and resilient.

The concordance between planetary health, cost efficiency and inclusiveness is a key criterion for relocating public finances in building climate-resilient food systems. East and Southeast Asian economies have strived to protect ecosystems, reduce emissions from agricultural production and decarbonize the food supply chain. Nonetheless, value creation or spillovers from food system conservation and restoration is yet to be priced and transformed into income incentives for farmers or other forces to participate. China's eco-compensation schemes, which amalgamate the pilot of policy instruments, the incorporation into mainstream frameworks, and the funding source diversification through market efficiency, provides a model of an integrated pathway to escalate capital accumulation in food system transformation. For escalating finances to build food system resilience under climate change, governments may need to embody environmental regulation and taxation for enhancing ecosystem services and insulating market failures during development; valuation, healthy markets and income regarding environmental services to compensate farmers and especially the vulnerable groups under climate change and natural disasters; as well as traceability and eco-labeling that can foster markets with high premiums on rural and food products[20].

Private spending has contributed only a small proportion of the finance for climate-resilient food systems but has clear potential to close the financing gap. A paucity of appropriate assessment models and large-scale long-term bankable projects takes a toll on mobilizing financial resources from domestic and foreign businesses[75]. An enabling and stabilized market with institutional support and supervision is necessary for mitigating risks and sustaining returns for both investors and recipients. Carbon pricing and trading frameworks, as accentuated in relocating public efforts, are opportunity for private investments to define costs and returns. With these conditions and incentives, private climate finance is expected to develop and apply innovative financial instruments for better building climate-resilient food systems.

A recent synthesis recommends potential market instruments through public-private partnerships involving multilateral, regional and national development banks. Those include commercial bank lending with climate considerations; green bonds and loans; sustainability-linked bonds and loans; green asset-backed securities; environmental, social and governance funds, vertical capital, and other forms of private sources[76]. In practice, as captured by a cross-country evaluation of green bond policies from 2010 to 2020, green bond grants, tax incentives and cooperation are effective in facilitating private green bond issuance in Asia. However, private green bond issuance within ASEAN is less motivated by regional cooperation and standardization than in the European Union. Global integration of markets and standards have positive impacts on the issuance of private green bonds in general[77].

6 CONCLUSIONS

The development outlook of East and Southeast Asia parallels food system resilience. By 2040, the demand for rice is projected to increase by about 18% in the south-east subregion, simply due to population growth[36]. Population growth and rising income continue to increase the demand for food,

especially animal products and cereals serving as animal feed. Dietary and lifestyle changes are also reshaping food systems in the region at different levels[78]. Linear economic growth models based on high agrochemical inputs have already been recognized as unsustainable and inefficient. However, given intensive farming and prevalent small-scale household farms, a high rate of mineral N fertilizer use seems inevitable to ensure yields, especially under climate shocks and resource limitations. Since 2022, contracted availability and the surging price of fertilizers (nitrogen and phosphates) and other agricultural inputs have raised concerns about systemic crises[79]. Food system resilience becomes singularly critical.

Given the interconnections between food systems and climate dynamics, enhancing food system resilience in the face of climate change is the forefront of SDGs. As such, this paper has aimed to offer reliable and timely knowledge for building climate-resilient food systems in the face of lingering food system vulnerabilities and policy gaps. The literature review affirms that, food systems in East and Southeast Asia are on the frontline interacting with planetary boundaries and are adversely affected by extreme weather-related events. Production, supply, international trade, consumption and food services are all susceptible. Food system resilience to climate change is imperative for leaving no one behind, especially farmers, poor households, women, children, and other vulnerable groups suffering most from extreme events in the developing economies of this region. Policy scope for the regional economies to support climate-resilient food systems spans from overarching emission goals to agriculture-specific measures. Broad rural development policies are common approaches in building climate-resilient food systems in East and Southeast Asian countries. Recent development practices further verify climate-smart agriculture and sustainable food standards as proactive priorities. However, this review found significant differences in agriculture-specific emission goals and public financing supports across East and Southeast Asian nations. Overall, clear-defined agriculture-specific goals, sustainable practices and technologies for climate-smart agriculture and market integration of food standards are recommended for building food system resilience in East and Southeast Asia. To break practical barriers and finance climate-resilient food systems, both a reorientation of the public finance scheme and the reform in financing mechanisms are required to mobilize multifaceted financial resources and increase efficiency.

This paper provides a supplement to scattered policy analyses and empirical clues for fostering food system resilience, and explores the financing at the window to rebuild the post-COVID-19 pandemic policy systems across East and Southeast Asia. However, this study applied a literature review, which entails validity weaknesses. Future work in theory and practice are expected to test, monitor, report and verify the recommended priorities and mechanisms, which can bring climate-resilient food systems further within reach in the region and elsewhere.

Supplementary materials

The online version of this article at https://doi.org/10.15302/J-FASE-2023492 contains supplementary material (Table S1).

Acknowledgements

We acknowledge the partial funding support of the Zhejiang University and IFPRI Center for International Development Studies (126000-541902), the Ecological Civilization Project (115000 + 194432201/001/013) supported by the Academy of Ecological Civilization of Zhejiang University, and CGIAR MITIGATE + (research for low-emission food systems).

REFERENCES

1. United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development. New York: *United Nations*, 2015
2. Eckstein D, Künzel V, Schäfer L, Winges M. Global Climate Risk Index 2020. Bonn: *Germanwatch*, 2019
3. World Bank. World Bank Open Data. *World Bank*, 2022. Available at World Bank website on February 26, 2023
4. Chen K, Zhan Y. East and Southeast Asia Regional Chapter in 2022 Global Food Policy Report. Washington DC: *International Food and Policy Research Institute (IFPRI)*, 2022
5. Food and Agriculture Organization of the United Nations (FAO). The State of Food and Agriculture (SOFA) 2021: Making Agri-Food Systems More Resilient to Shocks and Stresses. Rome: *FAO*, 2021
6. Birthal P S, Joshi P K, Roy D, Pandey G. Transformation and

Sources of Growth in Southeast Asian agriculture. Washington DC: *International Food Policy Research Institute (IFPRI)*, 2019
7. Food and Agriculture Organization of the United Nations (FAO). Crop Prospects and Food Situation—Quarterly Global Report No. 2. Rome: *FAO*, 2022
8. Redfern S K, Azzu N, Binamira J S. Rice in Southeast Asia: facing risks and vulnerabilities to respond to climate change. In: Meybeck A, Lankoski J, Redfern S, Azzu N, Gitz V, eds. Building Resilience for Adaptation to Climate Change in the Agriculture Sector: Proceedings of a Joint FAO/OECD Workshop. Rome: *FAO, OECD*, 2012
9. Mosnier A, Springmann M, Fan S. Transforming Food Systems. Nairobi: *United Nations Environment Programme (UNEP)*, 2022
10. Food and Agriculture Organization of the United Nations (FAO). The Future of Food and Agriculture—Alternative Pathways to 2050. Rome: *FAO*, 2018
11. Menegat S, Ledo A, Tirado R. Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Scientific Reports*, 2022, **12**(1): 14490
12. Food and Agriculture Organization of the United Nations (FAO). Emissions Totals. *FAOSTAT*, 2023. Available at FAO website on February 26, 2023
13. Tendall D M, Joerin J, Kopainsky B, Edwards P, Shreck A, Le Q B, Kruetli P, Grant M, Six J. Food system resilience: defining the concept. *Global Food Security*, 2015, **6**: 17–23
14. Fan S, Headey D, Rue C, Thomas T. Food systems for human and planetary health: economic perspectives and challenges. *Annual Review of Resource Economics*, 2021, **13**(1): 131–156
15. Asian Development Bank (ADB). Implementing a Green Recovery in Southeast Asia. Manila: *ADB*, 2022
16. Organisation for Economic Cooperation and Development (OECD). Economic Outlook for Southeast Asia, China and India 2022: Financing Sustainable Recovery from COVID-19. Paris: *OECD*, 2022
17. World Bank. Reforms for Recovery: World Bank East Asia and Pacific Economic Update October 2022. Washington DC: *World Bank*, 2022
18. Fan S, Teng P, Chew P, Smith G, Copeland L. Food system resilience and COVID-19—Lessons from the Asian experience. *Global Food Security*, 2021, **28**: 100501
19. Azhgaliyeva D, Kapoor A, Liu Y. Green bonds for financing renewable energy and energy efficiency in Southeast Asia: a review of policies. *Journal of Sustainable Finance & Investment*, 2020, **10**(2): 113–140
20. Asian Development Bank (ADB). Financing Sustainable and Resilient Food Systems in Asia and the Pacific. Manila: *ADB*, 2021
21. Kimura S, Chen K, Gong B. Circular Agriculture for Sustainable and Low-Carbon Development in the People's Republic of China. Manila: *Asian Development Bank (ADB)*, 2022
22. Pingali P, Abraham M. Food systems transformation in Asia—A brief economic history. *Agricultural Economics*, 2022, **53**(6): 895–910
23. High Level Panel of Experts on Food Security and Nutrition (HLPE). Food Security and Nutrition: Building a Global Narrative towards 2030. *HLPE,* 2020. Available at FAO website on February 26, 2023
24. United Nations Framework Convention on Climate Change (UNFCCC). Nationally Determined Contributions Registry. Bonn: *UNFCCC*, 2022. Available at UNFCCC website on February 26, 2023
25. Pörtner H O, Roberts D C, Tignor M, Poloczanska E S, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B. Climate Change 2022: Impacts, Adaptation and Vulnerability. Geneva: *Intergovernmental Panel on Climate Change (IPCC)*, 2022
26. Asian Development Bank (ADB). Key Indicators for Asia and the Pacific 2022. Manila: *ADB*, 2022
27. Asian Development Bank (ADB). Southeast Asia Rising from the Pandemic. Manila: *ADB*, 2022
28. von Grebmer K, Bernstein J, Wiemers M, Schiffer T, Hanano A, Towey O, Chéilleachair R N, Foley C, Gitter S, Ekstrom K, Fritschel H. 2021 Global Hunger Index: Hunger and Food Systems in Conflict Settings. Dublin: *Concern Worldwide*; Bonn: *Welthungerhilfe*, 2021
29. Food and Agriculture Organization of the United Nations (FAO). Suite of Food Security Indicators. *FAO*, 2020. Available at FAO website on February 26, 2023
30. World Food Programme (WFP). HungerMap: Asia and the Pacific Insights and Key Trends. Rome: *WEP*, 2022
31. United Nations Development Programme (UNDP). Reducing Inequality in the Decade of Action to Achieve the SDGs and Accelerate Post-Pandemic Recovery. Bangkok: *UNDP Bangkok Regional Hub*, 2022
32. Deaton A. Health, inequality, and economic development. *Journal of Economic Literature*, 2003, **41**(1): 113–158
33. Chen K Z, Mao R, Zhou Y. Rurbanomics for common prosperity: new approach to integrated urban-rural development. *China Agricultural Economic Review*, 2023, **15**(1): 1–16
34. Eckstein D, Künzel V, Schäfer L. Global Climate Risk Index 2021. Who Suffers Most from Extreme Weather Events? Weather-related Loss Events in 2019 and 2000 to 2019. Bonn: *Germanwatch*, 2021
35. Kim H Y, Ko J, Kang S, Tenhunen J. Impacts of climate change on paddy rice yield in a temperate climate. *Global Change Biology*, 2013, **19**(2): 548–562
36. Yuan S, Stuart A M, Laborte A G, Rattalino Edreira J I, Dobermann A, Kien L V N, Thúy L T, Paothong K, Traesang P, Tint K M, San S S, Villafuerte M Q II, Quicho E D, Pame A R P, Then R, Flor R J, Thon N, Agus F, Agustiani N, Deng N, Li T, Grassini P. Southeast Asia must narrow down the yield gap to continue to be a major rice bowl. *Nature Food*, 2022, **3**(3): 217–226
37. Nelson G C, Rosegrant M W, Koo J, Robertson R D, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo A, Batka M, Magalhaes M,

Valmonte-Santos R, Ewing M, Lee D R. Climate Change: Impact on Agriculture and Costs of Adaptation. Washington DC: *International Food Policy Research Institute (IFPRI)*, 2009

38. Ghadge A, Wurtmann H, Seuring S. Managing climate change risks in global supply chains: a review and research agenda. *International Journal of Production Research*, 2020, **58**(1): 44–64
39. Ratings F. China's Drought Unlikely to Unsettle Global Rice Markets. Hong Kong: *Fitch Ratings*, 2022
40. Parker L, Bourgoin C, Martinez-Valle A, Läderach P. Vulnerability of the agricultural sector to climate change: the development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making. *PLoS One*, 2019, **14**(3): e0213641
41. Godde C M, Mason-D'Croz D, Mayberry D E, Thornton P K, Herrero M. Impacts of climate change on the livestock food supply chain: a review of the evidence. *Global Food Security*, 2021, **28**: 100488
42. Wheeler T, von Braun J. Climate change impacts on global food security. *Science*, 2013, **341**(6145): 508–513
43. Swinnen J, Arndt C, Vos R. Climate change and food systems: transforming food systems for adaptation, mitigation, and resilience. In: Swinnen J, Arndt C, Vos R, eds. 2022 Global Food Policy Report: Climate Change and Food Systems. Washington DC: *International Food Policy Research Institute (IFPRI)*, 2022
44. Solaymani S. Impacts of climate change on food security and agriculture sector in Malaysia. *Environment, Development and Sustainability*, 2018, **20**(4): 1575–1596
45. Bayudan-Dacuycuy C, Baje L K. When it rains, it pours? Analyzing the rainfall shocks-poverty nexus in the Philippines *Social Indicators Research*, 2019, **145**(1): 67–93
46. Organization for Economic Co-operation and Development (OECD). Agricultural Policy Monitoring and Evaluation 2022. Paris: *OECD Publishing*, 2022
47. Jin S, Zhou F. Zero growth of chemical fertilizer and pesticide use: China's objectives, progress and challenges. *Journal of Resources and Ecology*, 2018, **9**(1): 50–58
48. Ministry of Natural Resources and Environment. Climate Change Master Plan 2015–2050. Bangkok: *Ministry of Natural Resources and Environment*, 2015. Available at Ministry of Natural Resources and Environment website on February 26, 2023
49. Academy of Global Food Economics and Policy (AGFEP). 2021 China and Global Food Policy Report: Rethinking Agrifood Systems for the Post-COVID World. Beijing: *AGFEP*, 2021
50. Fujimori S, Wu W, Doelman J, Frank S, Hristov J, Kyle P, Sands R, van Zeist W J, Havlik P, Domínguez I P, Sahoo A, Stehfest E, Tabeau A, Valin H, van Meijl H, Hasegawa T, Takahashi K. Land-based climate change mitigation measures can affect agricultural markets and food security. *Nature Food*, 2022, **3**(2): 110–121
51. Hasegawa T, Havlík P, Frank S, Palazzo A, Valin H. Tackling food consumption inequality to fight hunger without pressuring the environment. *Nature Sustainability*, 2019, **2**(9): 826–833
52. Pozza L, Field D J. The science of soil security and food security. *Soil Security*, 2020, **1**: 100002
53. United Nations Environment Programme (UNEP). State of Finance for Nature. Nairobi: *UNEP*, 2021
54. Baker P, Friel S. Food systems transformations, ultra-processed food markets and the nutrition transition in Asia. *Globalization and Health*, 2016, **12**(1): 80
55. Amanta F A. Can the National Food Agency Strengthen Indonesia's Food System Governance? Jakarta: *The Jakarta Post*, 2021. Available at The Jakarta Post website on February 26, 2023
56. de Vries M, Pronk A, Adiyoga W. Potential of Reducing GHG Emissions through Improved Nutrient Circularity in Agriculture in West Java. Wageningen, the Netherlands: *CGIAR Research Program on Climate Change*; *Agriculture & Food Security*, 2021
57. Barbon W J, Punzalan B, Wassmann R, Vinh B L, Vidallo R, Villanueva J, Talsma T, Bayot R, Gonsalves J. Scaling of Climate-Smart Agriculture via Climate-Smart Villages in Southeast Asia: Insights and Lessons from Vietnam, Laos, the Philippines, Cambodia and Myanmar. Wageningen: *CGIAR Research Program on Climate Change*; *Agriculture & Food Security*, 2021
58. International Finance Corporation (IFC). China Weather Index-Based Insurance Project (China WII). Beijing: *International Finance Corporation, the World Bank Group*, 2021
59. Bastakoti R C, Gupta J, Babel M S, van Dijk M P. Climate risks and adaptation strategies in the Lower Mekong River basin. *Regional Environmental Change*, 2014, **14**(1): 207–219
60. Weller S, Kraus D, Ayag K R P, Wassmann R, Alberto M C R, Butterbach-Bahl K, Kiese R. Methane and nitrous oxide emissions from rice and maize production in diversified rice cropping systems. *Nutrient Cycling in Agroecosystems*, 2015, **101**(1): 37–53
61. International Rice Research Institure (IRRI). Going Beyond Rice: Transitioning toward Equitable, Profitable, and Environmentally Sound Rice Agri-food Systems. Laguna: *IRRI*, 2020
62. Bantayan R B, Cadiz M C H, Sajise P E. Learning and Coping with Change: Case Stories of Climate Change Adaptation in Southeast Asia. Laguna: *Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA)*, 2016
63. Terano R, Mohamed Z, Shamsudin M N, Latif I. Factors influencing intention to adopt sustainable agriculture practices among paddy farmers in Kada, Malaysia. *Asian Journal of Agricultural Research*, 2015, **9**(5): 268–275
64. Laosutsan P, Shivakoti G P, Soni P. Factors influencing the adoption of good agricultural practices and export decision of Thailand's vegetable farmers. *International Journal of the Commons*, 2019, **13**(2): 867–880

65. The ASEAN Secretariat. Environmental Management Module—Good Agricultural Practices for Production of Fresh Fruits and Vegetables in ASEAN Countries. Jakarta: *The ASEAN Secretariat*, 2015
66. The ASEAN Secretariat. Food Safety in Agri-Products-Enhancing Food Safety through Harmonized Quality Standards. Jakarta: *The ASEAN Secretariat*, 2015
67. Qin Y, Zhang X. The road to specialization in agricultural production: evidence from rural China. *World Development*, 2016, **77**: 1–16
68. Asian Development Bank (ADB). Fintech and COVID-19: Impacts, Challenges, and Policy Priorities for Asia. Manila: *ADB*, 2022
69. Saner P, Haeni M. Review of the Financial Support to the Implementation of the Convention. Bonn: *United Nations Convention to Combat Desertification (UNCCD)*, 2015
70. United Nations Environment Programme (UNEP). The State of Finance for Nature in the G20. Nairobi: *UNEP*, 2022
71. Anantharajah K, Setyowati A B. Beyond promises: realities of climate finance justice and energy transitions in Asia and the Pacific. *Energy Research & Social Science*, 2022, **89**: 102550
72. World Bank Group. Vietnam Country Climate and Development Report. CCDR Series. Washington DC: *World Bank*, 2022
73. O'callaghan B J, Murdock E. Are we building back better? Geneva: *United Nations Environment Programme (UNEP)*, 2021
74. Economics O. The Economic Impact of the Agri-food Sector in Southeast Asia. Oxford: *Oxford Economics*, 2022
75. Quatrini S. Challenges and opportunities to scale up sustainable finance after the COVID-19 crisis: lessons and promising innovations from science and practice. *Ecosystem Services*, 2021, **48**: 101240
76. Prasad A, Loukoianova E, Feng A X, Oman W. Mobilizing private climate financing in emerging market and developing economies. Washington DC: *International Monetary Fund*, 2022
77. Azhgaliyeva D, Kapsalyamova Z. Policy Support in Promoting Green Bonds in Asia. ADBI Working Paper 1275. Tokyo: *Asian Development Bank Institute*, 2021
78. Pingali P, Abraham M. Food systems transformation in Asia—A brief economic history. *Agricultural Economics*, 2022, **53**(6): 895–910
79. Global Market Analysis, Modeling Team. Impacts and Repercussions of Price Increases on the Global Fertilizer Market. *United States Department of Agriculture (USDA)*, 2022