ASIA'S TRANSITION TO NET ZERO

OPPORTUNITIES AND CHALLENGES IN AGRICULTURE

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ABSTRACT

Asia is home to 60% of the world's population, 52% of global agricultural production, and 43% of agriculture-related greenhouse gas (GHG) emissions. While a large portion of the Asian population depends on agriculture for their livelihood and food security, the agriculture sector is one of the main sources of GHG emissions in the region. In some Asian economies, it accounts for more than 40% of total emissions. This report identifies the major sources of GHG emissions from the agriculture sector and reviews a variety of tools and technologies to change emission pathways. It also discusses the institutional, political, and economic challenges for achieving progress toward a cost-effective, inclusive, and resilient transition to net-zero agriculture.

***Keywords*:** climate change, net-zero agriculture, Asia and the Pacific, non-carbon dioxide equivalent, non-CO_2e

JEL codes: Q01, Q1, Q54

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I. INTRODUCTION

The agriculture, forestry, and other land use (AFOLU) sector contributes about 22% (13 gigatons of carbon dioxide equivalent [$GtCO_2e$]) of net global greenhouse gas (GHG) emissions in 2019 and can play an important role in achieving climate change mitigation targets due to substantial mitigation potential options in the sector (IPCC 2023). The AFOLU sector can provide 20%–30% of the global mitigation needed to achieve the 1.5°C or 2°C pathway by 2050 (IPCC 2022a). AFOLU activities contributed about 13% of carbon dioxide (CO_2) globally between 2007 and 2016, while methane (CH_4) and nitrous oxide (N_2O) emissions from human activities accounted for 44% and 81%, respectively (IPCC 2019). Recent evidence suggests that agricultural CH_4 emissions continue to increase, with enteric fermentation and rice cultivation remaining the main sources of emissions between 1990 and 2019 (IPCC 2022b). In 2018, global emissions from agriculture (within the farm gate and including associated land use and/or land-use change) totaled 9.3 billion tons of CO_2 equivalent (CO_2e). Of the total emissions in 2018, CH_4 and N_2O emissions from crop and livestock activities accounted for 5.3 billion tons of CO_2e, livestock production processes generated 3 billion tons of CO_2e, and emissions from land use and land-use change accounted for 4 billion tons of CO_2e (FAO 2020a). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C highlights the importance of achieving net-zero global emissions of CO_2 by mid-century or sooner to avoid the worst effects of climate change (IPCC 2018). Achieving net-zero GHG emissions primarily requires deep cuts in CO_2, CH_4, and other GHG emissions, and implies net-negative CO_2 emissions. To prevent global warming from exceeding 1.5°C, emissions need to be reduced by 45% by 2030 and reach net zero by 2050 (UN 2022). Aggregating CH_4 and N_2O to CO_2 equivalents (using IPCC AR6 GWP100 values) implies that AFOLU emissions escalated by 15% globally between 1990 and 2019 (IPCC 2022b).

As far as agriculture is concerned, Asian economies[1] occupy an important place in the global scenario. The sector provided livelihoods for more than 563 million people in 2021 and often characterized by low incomes, low skills composition, difficult working conditions, and high risks associated with agricultural activities, particularly for smallholder farmers (ILO 2022). Despite significant economic progress over the past decade, the coronavirus disease (COVID-

[1] Asia in this paper refers to Asian Development Bank (ADB) members in the Asia and Pacific region, unless otherwise stated.

19) pandemic has pushed about 78 million people in Asia back into extreme poverty and created another 162 million poor, particularly in South Asia (ADB 2021a).

Climate change vulnerability and disasters are a growing concern in the region. At the same time, Asia is also a major contributor of GHG emissions from agriculture. Achieving net-zero agriculture in Asia will be a major challenge, requiring significant reductions in emissions from agriculture and transformative changes in food, livestock, and dietary patterns. Climate action in Asia can have a huge positive impact on reducing global GHG emissions if appropriate and necessary steps are taken.

II. BACKGROUND

The term "net-zero emissions" means a balance between the current anthropogenic release of GHGs into the atmosphere and the active removal of greenhouse gases over a given period. In general terms, this means a situation in which human-induced carbon flows into and out of the atmosphere are balanced and temperature stabilizes temporarily or sustainably (Allen et al. 2022). To achieve net-zero emissions, negative net CO_2 emissions are required to offset the remaining CH_4, N_2O, and F-gas emissions. Agriculture, land use, and forestry play a significant role in achieving net-zero emissions by reducing carbon, CH_4, and N_2O emissions while protecting our food supply and other land resources. Emissions from agriculture will become more important as emissions from energy and industrial processes decline in the transition to net-zero emissions (IPCC 2018).

Agriculture contributes to GHG emissions in four ways: land-use change, agricultural activities, livestock, and food production. Agricultural activities emit several non-CO_2 GHGs. Methane and nitrous oxide are the most common farm-related emissions, contributing to about 65% of agricultural emissions globally (Searchinger et al. 2019). The largest sources of CH_4 emissions come from cattle belching, while N_2O comes from nitrogen deposition in land-based agriculture, primarily due to use of synthetic fertilizers or manure waste in soils. Compared to other countries, AFOLU emissions are generally higher in developing countries. In 2019, several regions in Asia—East Asia, South Asia, and Southeast Asia—accounted for 9%, 10%, and 22% of total absolute AFOLU GHG emissions, respectively. Southeast Asia had the highest AFOLU GHG per capita emissions in Asia (IPCC 2022b). The Asia has a collective commitment to reduce an estimated 13.5 $GtCO_2e$ of GHG emissions, or 32% of the estimated regional GHG emissions totaling 42.7 $GtCO_2e$, by 2030 under current climate policies to meet the 1.5°C target (UNESCAP et al. 2021). The IPCC has recommended required GHG emissions by 2030 for Asia, estimating them to be about 9.8 $GtCO_2e$ (IPCC 2021).

Due to high population density, high poverty levels, and heavy reliance on agriculture and natural resources, millions of people in Asia still suffer from food insecurity, making them more vulnerable to the impacts of climate change. Through Nationally Determined Contributions (NDCs), countries commit to reducing their GHG emissions to achieve the net-zero target. Currently, 49 members[2] in Asia have submitted their intended NDCs, of which 46 have become NDCs. Evidence suggests that the NDCs need to be significantly improved to achieve carbon neutrality in 2050–2060. If these unconditional and conditional commitments are put into effect by 2030, GHG emissions would decrease by only 8%, which is too low to achieve net-zero CO_2e by 2050 (UNESCAP et al. 2021). While NDCs and overall emission reduction targets are continuously being updated in Asia, each economy is different, and emission reductions in these economies may occur through different channels, so different measures may be required to bring emissions in the agriculture sector to net zero.

A. Status of Agricultural Emissions in Asia

In 2018, total emissions from agriculture and related land use worldwide reached 9.3 billion $GtCO_2e$. In Asia, emissions from agricultural activities amounted to 3.3 $GtCO_2e$ over the same period, representing nearly one-third of the global share of emissions from agriculture (FAO 2020a). Asia has the highest share of global AFOLU emissions, mainly due to deforestation and agricultural emissions. Under the business-as-usual scenario, global CO_2e emissions from agricultural production are projected to increase from 6.8 $GtCO_2e$ per year in 2010 to 9.0 $GtCO_2e$ per year in 2050 and from about 12 $GtCO_2e$ per year in 2010 to 15 $GtCO_2e$ per year by 2050 for agriculture and land-use change, respectively (Searchinger et al. 2019).

B. Drivers of Agricultural and Land-Use Emissions in Asia

Asia comprises many small and large economies with different characteristics of agriculture and land-use change. On the one hand, there are the world's largest agricultural emitters such as India and the People's Republic of China (PRC), each with about 650 million tons of CO_2e annual emissions in 2018, but on the other hand, there are carbon-negative

[2] Defined as UNESCAP members and associate members in the Asia and Pacific region.

countries such as Bhutan. Most of the GHG emissions from the global food system come from food production and land clearing for food production. About 80% of the opportunities to mitigate climate change in the land sector over the next decade come from transforming food systems and avoiding the associated deforestation by 2030 (Conservation International 2022). In terms of total absolute emissions, the PRC, India, Pakistan, and Indonesia are among the largest emitters (Figure 1).

Data from various studies on agricultural emissions from Asia reveal the following trends and patterns:

(i) The major sources of agricultural emissions in Asia are rice cultivation, synthetic fertilizer use, crop residue burning, and manure management. In most cases, the majority of emissions come from a few countries such as India, Indonesia, Pakistan, the Philippines, the PRC, and Viet Nam (see Figure 2). Evidence shows that Asia has the largest share (37%) of emissions from enteric fermentation and manure management since 2000 (IPCC 2022b).

(ii) Asia dominates global rice production, with Southeast Asia and the Pacific region mainly responsible for 89% of emissions from rice cultivation, which have been increasing since 2010 (IPCC 2019). For example, rice production accounts for 39% of total food system emissions in Thailand and 40% in Bangladesh. In addition, emissions from energy consumption in Asia have increased compared to the 1990s due to mechanization of the agriculture sector. Total GHG emissions from food systems in Asia have increased from 9.8 $GtCO_2e$ in 1990 to 24 $GtCO_2e$ in 2015 (Crippa et al. 2021). Irrigated flooded rice, which occupies about half of the total rice-growing area and accounts for 75% of global rice production, is a major source of CH_4 emissions. Emission reduction strategies in the rice sector include practices such as increased use of CH_4-reducing rice varieties (ADB 2019; Jiang et al. 2017; and Kraus et al. 2022), rice straw removal, alternative wetting and drying, and dry seeding.

(iii) Asia accounted for 15% of the global forest area in 2020. Agriculture is one of the main drivers of land-use change leading to deforestation. Global agricultural land area increased by 1% in Asia and the Pacific between 2000 and 2019 (IPCC

2022a). Between 2010 and 2014, there was a net emission of 2.6 $GtCO_2$ year-1 due to deforestation associated with the expansion of cropland, pasture, and forest plantations in the tropics (Pendrill et al. 2019) (Figure 3). In Indonesia, almost half of the emissions (0.3 $GtCO_2$ year−1) come from oilseeds (mainly oil palm) and peatland drainage (0.3–0.4 $GtCO_2$ year−1).

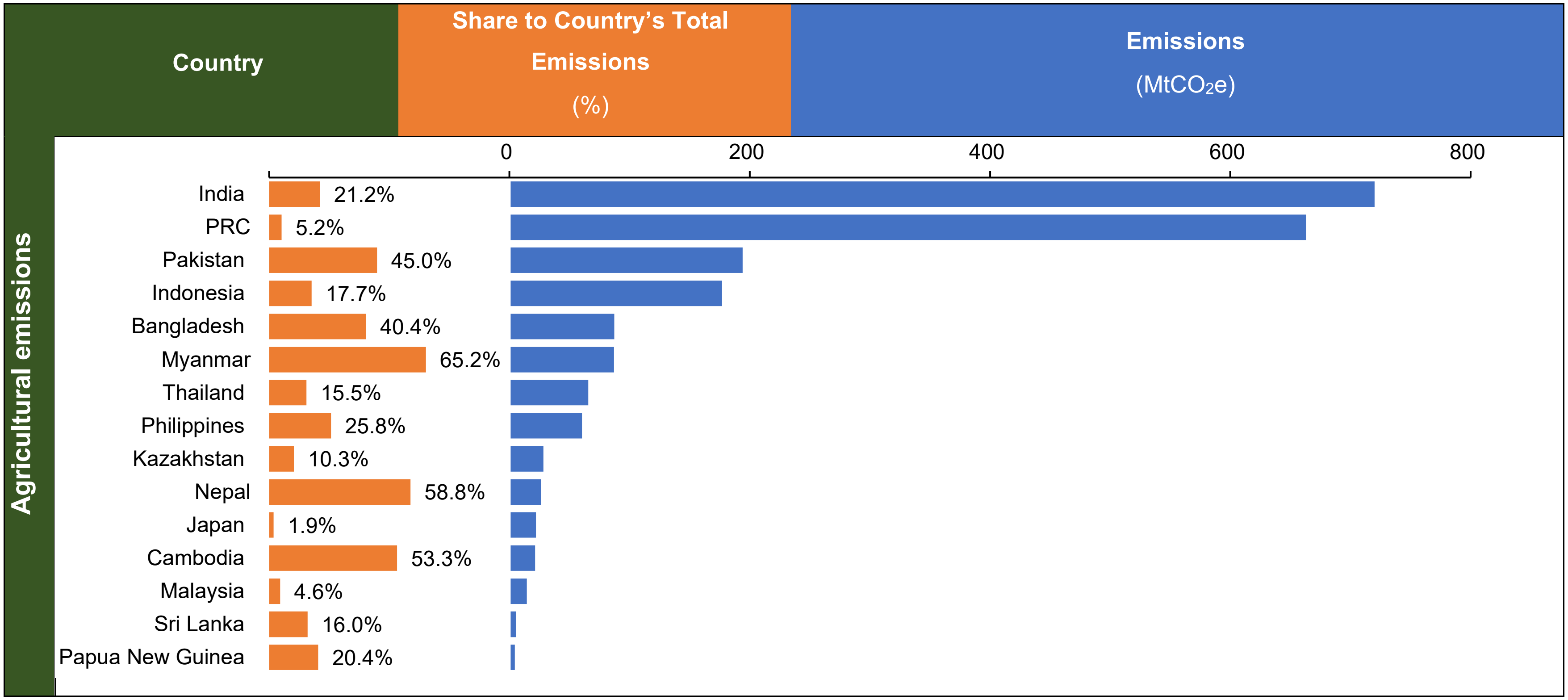
(iv) The use of synthetic fertilizers has been identified as a major source of global N_2O emissions. South Asia recorded the highest growth N_2O emissions from the AFOLU sector between 1990 and 2019 (Lin et al. 2021). Grazing lands were the notable sources of N_2O emissions in East Asia and South Asia (IPCC 2019). Between 2000 and 2010, Asia was the largest source and highest growth rate of N_2O emissions from synthetic fertilizers, according to the IPCC AR5 (IPCC 2014).

(v) Reductions in emissions from the food system, which consists of emissions from consumption, production, and food waste, vary across Asia. Recent analysis shows that a few countries, such as India, the PRC, Indonesia, Myanmar,[3] the Philippines, and Pakistan, are responsible for a large share of food system emissions (Figure 4) because they require materials and energy for processing, packaging, transportation, and storage. From an emissions mitigation perspective, this trend suggests that the food sector requires specific sectoral energy efficiency and decarbonization policies, as well as emissions mitigation policies for both consumers and producers (Crippa et al. 2021; Poore and Nemecek 2018).

(vi) GHG emissions from enteric fermentation dominate agricultural CH_4 emissions in Asia. According to recent estimates, total emissions from livestock production in Asia in 2015 were 2.64 billion tons of CO_2e, from major sources such as enteric fermentation, feed, and manure (FAO 2020b).

[3] ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Figure 1: Agricultural Emissions by Country in 2019, Excluding Land-Use Change and Forestry



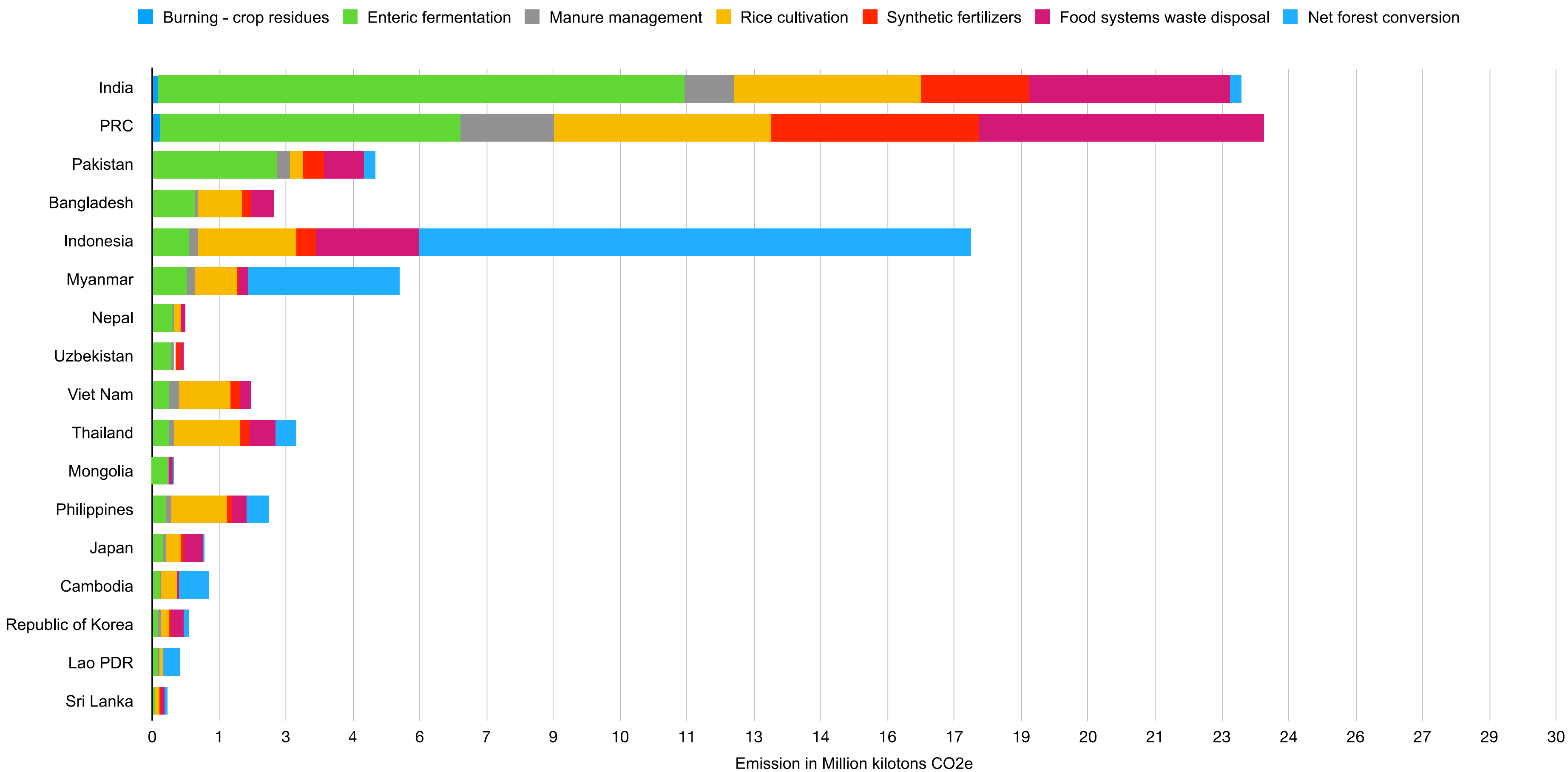
$MtCO_2e$ = million tons of carbon dioxide equivalent, PRC = People's Republic of China.

Notes:

ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Source: FAO (2020b).

Figure 2: Total Agricultural Emissions by Country, 1990–2020

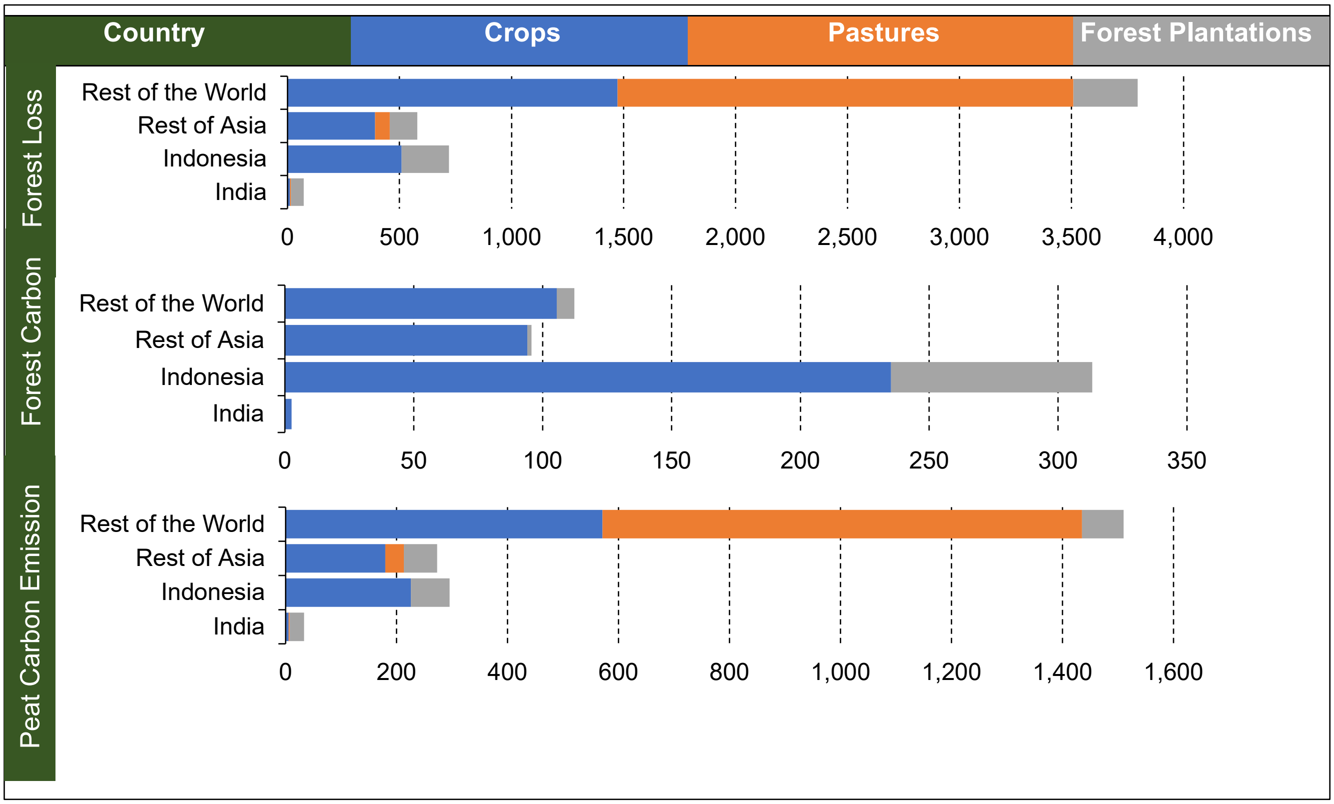


CO_2e = carbon dioxide equivalent, Lao PDR = Lao People's Democratic Republic, PRC = People's Republic of China.

Note: ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Source: FAO (2022b).

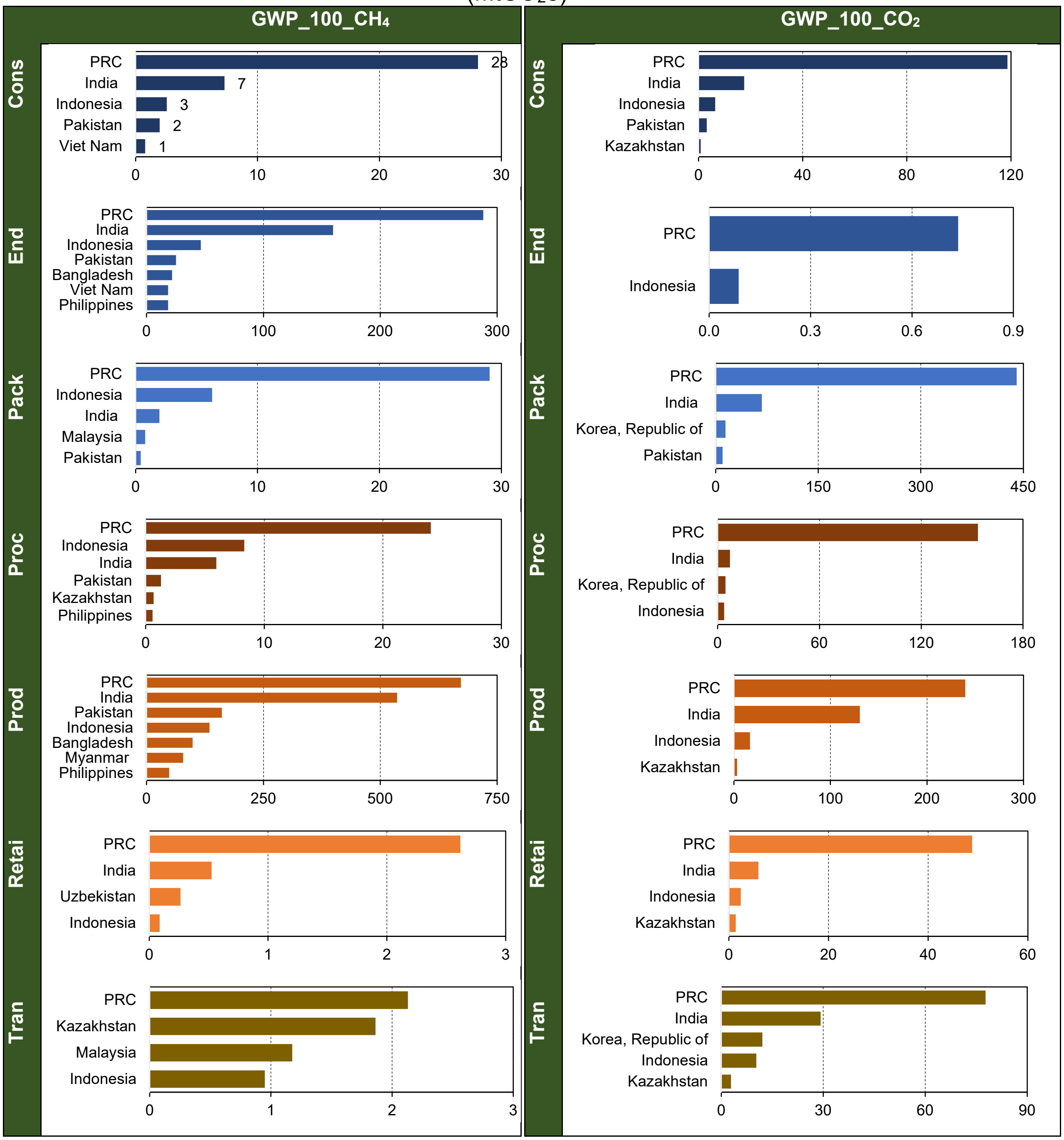
Figure 3: Average Forest Loss Attributed to the Expansion of Cropland, Pasture, or Plantations in Asia, 2010–2014 (hectare) **and Emissions** ($MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.

Source: Based on data from Pendrill et al. (2019).

Figure 4: Emissions from Food Systems in Asia, 2015
($MtCO_2e$)



CH_4 = methane, CO_2 = carbon dioxide, cons=consumption, GHG=greenhouse gas, IPCC = Intergovernmental Panel on Climate Change, $MtCO_2e$ = million tons of carbon dioxide equivalent, N_2O = nitrous oxide, Cons= Consumption, Pack = packaging, Pro = production, Proc = processing, End = end of life, PRC = People's Republic of China, Reta = Retail, Tran = Transportation.

Notes:

Non-CO_2 GHG emissions (CH_4, N_2O) are stated as CO_2e computed using the 100-year global warming potential values (GWP100) adopted in the IPCC Fifth Assessment Report (AR5).

ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Source: Data from Crippa et al. (2021).

C. Emissions Reduction from Land-Use Change in Asia and the Pacific

The patterns and drivers of GHG emissions from land management and land-use change (land-use emissions) in Asia have not been analyzed as thoroughly as those of GHG emissions from fossil fuels. The following is a summary of some of the most important findings from the studies now available on emissions from land-use change and the possibility of emission reduction interventions:

(i) After fossil fuel use, carbon emissions from deforestation and forest degradation in the tropics are the second-largest source of emissions worldwide (Sharma, Thapa, and Matin 2020).

(ii) Commercial agriculture is responsible for about 35% of deforestation in Asia and Africa. According to Griscom et al. (2017), nearly 80% of global deforestation is caused by agriculture. As a result of the conversion of forests and peatlands to agricultural and grazing lands, countries in Asia such as Indonesia and India play a significant role in the buildup of greenhouse gases (Figure 3).

(iii) From 1961 to 2017, Southeast Asia has had some of the highest emissions from land-use change. Land-use emissions are due to the expansion of croplands and spikes caused by more intensive land-use conversion as a result of rapid and extensive growth in agricultural production (Hong et al. 2021; Smith et al. 2019).

(iv) Since 2001, annual forest carbon loss in tropical Asia has increased substantially and steadily, amounting to 43% of the surge in pantropical carbon loss. Parts of Southeast Asia are hotspots of forest carbon loss (Curran et al. 2004; Feng et al. 2022).

(v) While Southeast Asia was the largest contributor to emissions from forest degradation between 2005 and 2010, the harvesting of timber and wood fuels is the largest contributor to emissions associated with forest degradation (Pearson et al. 2017).

(vi) Southeast Asia is one of the regions with the largest number of natural forests. However, a recent study predicts a decline in natural forests from 213.46 million hectares (ha) in 2000 to 180.70 million ha in 2030, suggesting a decline in carbon stocks (Sasaki et al. 2021). It is important for Southeast Asia to commit to sustainable forest management to avoid the consequences of forest resource loss. Implementation of REDD+, which stands for reducing emissions from deforestation and forest degradation in developing countries, mechanisms could result in net carbon revenues of $8 billion–$180 billion between 2020 and 2030, depending on the carbon price.

(vii) According to recent studies, pre- and post-production activities accounted for the remaining emissions from agri-food activities in 2018, making up only about 4% of global gross domestic product (GDP). Thus, agricultural production and new land used for agricultural production generated nearly two-thirds of all emissions. Over the past 60 years, 309 million ha have been used for agriculture, despite an increase in agricultural land of only 7% (205 million ha for grain production and 104 million ha for cattle pastures). Conversion of forests for agricultural use has therefore historically been a significant source of GHG emissions, bringing about 11% of global emissions between 2007 and 2016 (Gautam et al. 2022).

(viii) Agriculture is one of the biggest drivers of biodiversity loss and imposes huge economic costs through the loss of ecosystem services (Johnson et al. 2021; Almond, Grooten, and Petersen 2020; Prudhomme 2020).

There are many opportunities to reduce sector emissions and improve removals associated with land use, land-use change, and forestry, including minimizing deforestation, increasing afforestation, improving sustainable forest management, and raising forest carbon stocks. Asia is made up of emerging economies where emissions from land-use change are minimal but emissions from agriculture are increasing rapidly (East Asia, South Asia, and the Middle East) and countries where emissions from land-use change are both substantial and increasing (Southeast Asia). For the first group of countries, the most effective means of mitigating climate change is to restrict land-use change, particularly the conversion of carbon-dense tropical forests to soy, rice, maize, and oil palm. Reduced input efficiency, improved soil and livestock waste management, decreased food waste or behavior, and policy changes in agricultural demand are all ways to reduce the emissions intensity of agricultural production for countries in the second category (Hong et al. 2021).

In addition to increased annual carbon removals in the land-use sector, emissions reduction is essential to achieving the net-zero goal. This includes the possibility of extensive use of bioenergy and land use in combination with negative emissions technologies (Box 1),[4] such as carbon capture and storage, and the use of various natural climate solutions (NCSs)[5] like conservation, restoration, and/or improved land management techniques that promote carbon storage and/or sequestration of GHG emissions in global forests, wetlands, grasslands, and agricultural lands (Griscom et al. 2017).

Reforestation, avoided forest conversion, and grasslands have the greatest potential reddto cut emissions among the various NCS pathways examined to achieve a drastic reduction in emissions, and they merit additional consideration to find opportunities for cost-effective emissions reductions. At a cost of no more than $100 per ton of CO_2 (tCO_2), these solutions could contribute 37% of the GHG reductions needed in 2030 to have a > 66% chance of avoiding a 2°C increase in global mean temperature (Griscom et al. 2017). The highest carbon stocks per hectare are found in tropical forests, peatlands, and mangroves. However, the potential for avoiding forest conversion is 4–5 times greater than the potential for avoiding impacts on peatlands and 10–12 times greater than the potential for avoiding impacts on coastal wetlands such as mangroves, salt marshes, and seagrass beds (UNEP and IUCN 2021).

To help achieve the goals of the Paris Agreement, the land-use sector in Asia and the Pacific offers tremendous opportunities for emissions reductions (see Boxes 2 and 3). Designing high-priority land-use-based mitigation policies should aim to reduce GHG emissions from land use in countries with high emissions from land-use change.

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[4] Negative emissions are not about the natural processes of CO_2 removal. Rather, they are defined as the deliberate efforts of humans to remove CO_2 emissions from the atmosphere (Minx et al. 2018).

[5] “Natural climate solutions” (Griscom et al. 2017) are described as a subset of nature-based solutions (NBS) that focus on mitigating climate change. NBS are “actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (IUCN 2016). There are variations in the use and interpretation of the definition (UNEP and IUCN 2021).

Box 1: Agriculture and the Bioenergy Market in Southeast Asia

Bioenergy has the potential to become the most important energy source in Southeast Asia's entire energy mix, accounting for more than 40% of total primary energy supply by 2050, in accordance with the Paris objective of 2 degrees Celsius (IRENA 2022). Evidence suggests that Southeast Asia's bioenergy supply is still untapped. This holds the potential for a net present socioeconomic value of $144 billion in 2050, as well as the creation of more than 452,000 new resilient jobs and the reduction of about 442 million tonnes of carbon dioxide equivalent greenhouse gas (GHG) emissions per year. The agricultural residues (palm oil, rice, sugarcane), cassava pulp, rubber, teak, sugarcane molasses, and acacia generated by Southeast Asia's high productivity generate substantial amounts of underutilized residues. Malaysia, Indonesia, and Thailand have already completed several bioenergy projects that generate energy from agricultural products such as palm oil, sugarcane, corn, cassava, and rice. However, most of the attempts are currently small in scale and there are considerable difficulties, such as legal and institutional barriers, high costs, lack of research and development, lack of commercial feasibility of the technologies, and lack of regulatory frameworks.

Governments in the region need to adopt effective measures to address climate change-influenced changes. For example, recent evidence predicts that the area suitable for rubber farming in the Greater Mekong Subregion could expand by more than 50% by 2030 due to climate change. Similarly, in Indonesia, most biomass burning is caused by forest clearing for oil palm agriculture, which is a substantial source of GHG emissions. Any decision to achieve net-zero emissions in Asia must consider the region's growing concerns and challenges related to land-use change.

Source: IRENA (2022); Vardrevu and Ohara (2020).

Box 2: Emissions Reduction through REDD+ in Asia and the Pacific

Reducing emissions from deforestation and forest degradation and other related measures (REDD+) in developing countries is critical to achieving the net-zero emissions target in Asia and the Pacific. Many countries in Asia have participated in the process of national REDD+ strategy (Ochieng et al. 2018). Through the Forest Carbon Partnership Facility (FCPF), some countries have also received funding from the FCPF Reediness Fund and the FCPF Carbon Fund. These include countries such as Fiji, Indonesia, the Lao People's Democratic Republic, Nepal, and Viet Nam (World Bank 2022). Other countries such as Thailand and Cambodia have recently submitted their forest reference emission levels and are preparing to receive funding from certified emission reductions. Fifty-six countries have included it in their Intended Nationally Determined Contributions as a climate change mitigation instrument (Hein et al. 2018). However, more than 10 years after the launch of REDD+, there are still many challenges that need to be addressed before it becomes an effective means of reducing emissions from deforestation. For example, REDD+ has not been effective against the immediate causes of deforestation, such as the expansion of agriculture for high-value crops (Andoh et al. 2022). There is an urgent need to address the issues related to the drivers of deforestation in Asia to achieve tangible results from the process of REDD+.

Sources: World Bank (2022); Andoh et al. (2022); Hein et al. (2018).

D. Emissions Reduction Potential in Asia: An Assessment

Asia is one of the regions with the fastest-growing emissions from agriculture and land-use change (Fujimori et al. 2022; OECD 2019). The agricultural industry offers a variety of solutions to mitigate GHG emissions (Roe et al. 2021). To reach the net-zero target more quickly, both conventional agricultural emissions reduction techniques, such as fertilizer and water management, and negative emissions technologies must be used (Fuss et al. 2018; Minx et al. 2018). In addition, it is important to remember that agriculture contributes to deforestation and that policies that affect land-use change also influence agricultural mitigation strategies. The 'potential abatement, benefits, cost-effectiveness, and side effects of the transition must be considered (Eory et al. 2018).

In terms of policy, there are also concerns about how to incentivize and implement practices that would boost agricultural productivity growth and sustainable resource use, and whether there would be trade-offs with GHG mitigation and adaptation goals (Lankoski, Ignaciuk, and Jésus 2018). The availability of data on global emissions from the agriculture sector lags behind that of data on fossil fuel emissions, despite growing interest in the ability of the agriculture sector to reduce GHG emissions (Tubiello et al. 2013). The fact that agriculture is quite heterogeneous both spatially and temporally presents additional difficulties (Beach et al. 2015). This makes it necessary to consider biophysical and management conditions that affect the efficiency and cost of alternative mitigation options at a disaggregated scale.

To achieve AFOLU emission reductions and removals without jeopardizing global food security, poverty, economic growth, and resilience, technological advances that enhance mitigation must be developed and used. Technological solutions will enable climate change mitigation while minimizing negative effects on food production. Asia will suffer significant economic losses as a result of climate change. For example, the economies of the Association of Southeast Asian Nations would lose nearly 37% of their GDP by 2048. According to the Swiss Re Institute (2021), the economies of Indonesia, Malaysia, the Philippines, Singapore, and Thailand would lose more than seven times their 2019 GDP by 2050.

Land-based and agriculture-based mitigation measures can potentially[6] help achieve climate change goals. For example, nature-based climate solutions, including conservation, restoration, and/or improved land management measures that avoid GHG emissions in global forests, wetlands, grasslands, and agricultural lands, can provide more than one-third of the cost-effective mitigation needed to keep warming below 2°C by 2030 (Griscom et al. 2017). However, between 2009 and 2019, mitigation policies and programs have resulted in only about 8 $GtCO_2$ of mitigation from AFOLU, or about 0.5% of total emissions.

Asia has the highest mitigation potential in the agriculture sector, with large opportunities for mitigation options with low or negative costs in the major agriculture sectors in all years (Beach et al. 2015). In terms of the livestock industry potential, (i) the most promising practices to reduce enteric CH_4 emissions and sequester soil carbon on grazing lands could reduce emissions by up to 11% of annual global ruminant GHG emissions; and (ii) some of the most affordable practices

[6] The GHG mitigation potential in the agriculture sector can generally be divided into technical, economic, and social and political (OECD 2019). Technical potential is the total amount of GHG mitigation that could be achieved if all feasible mitigation methods were fully adopted, ignoring any adoption constraints. Economic potential represents the costs and advantages of various mitigation strategies and illustrates the potential for mitigation at a specific carbon price. Political and social barriers limit the use of mitigation measures and are related to potential negative distributional effects of policy options (Wreford, Ignaciuk, and Gruère 2017; OECD 2019).

to reduce ruminant emissions include improved grazing management and cultivation or planting of legumes (Henderson et al. 2017).

Recent studies have also demonstrated that the economic potential for lowering agriculture's non-CO_2 emissions is up to four times greater than initially estimated.

Accordingly,

(i) Considering supply-side alternatives for structural and technical solutions, as well as consumer responses to price changes, non-CO_2 emissions from agriculture could be reduced by up to 2.6 $GtCO_2e$ by 2050.

(ii) Approximately 70% of the mitigation potential is attributable to CH_4 emission reductions and 30% to the reduction of N_2O emissions.

(iii) There is particularly high potential for reducing emissions in Asia and Latin America. At a carbon price of \$100/tCO_2e, technical solutions can reduce direct emissions by about 0.85 $GtCO_2$ per year, or about 33% of all global mitigation efforts in agriculture. Adoption of these technical solutions will cost the world \$13 billion annually in investment and operating expenses by 2050 (\$12 billion in 2030), about half of which would be spent in Asia and other emerging and developing regions.

(iv) In Asia, better rice management presents the opportunity to significantly reduce CH_4 emissions of up to 0.3 $GtCO_2e$ per year at \$100/ton of carbon dioxide equivalent (tCO_2e) (more than 50% emissions reduction) from flooded rice paddies. This can be achieved by adopting dryland rice (with residue incorporation) instead of paddy rice and reducing chemical fertilizer application.

(v) At \$100 per tCO_2e, structural adjustments,[7] such as production system changes or relocations due to international trade, make up about 39% (1.0 $GtCO_2e$/year) of the entire mitigation potential. Changes to the livestock production system can significantly reduce non-CO_2 emissions, especially in East Asia (Frank et al. 2018). Through emissions-reducing technologies or structural adjustments, the livestock sector will be crucial to achieving emissions reductions consistent with the 1.5°C

[7] Shifts in production systems or relocation through international trade account.

objective. At just $20 per tCO_2e, agriculture can help reduce emissions by 0.8 Gt to 1.4 $GtCO_2e$ year−1 in 2050.

(vi) At carbon prices commensurate with the 1.5°C objective, emissions reductions can be enhanced to 1.7–1.8 $GtCO_2e$ year−1 when combined with dietary improvements (Frank et al. 2019).

To illustrate the economic and technical potential of land-based mitigation actions in Asia, we examined data from one of the most recent studies that updated the mitigation potential[8] for 20 land-based measures in more than 200 countries and 5 regions (Roe et al. 2021). The results for Asia are presented in Table 1 and Figure 5. The results show that enteric fermentation (32%), rice cultivation (21.5%), and the use of synthetic fertilizers (18%) are the main drivers of agricultural emissions in Asia, while agricultural commodities (57%) and forestry (27%) are the main drivers of tree cover loss (a proxy for land-use change). However, the highest cost-effective mitigation potential comes from reducing deforestation, followed by biochar application and dietary change (Roe et al. 2021). In Asia, there is great potential to reduce emissions from agriculture through various structural, technical, and demand-side measures. We examine further the details of some of the major sectors in Asia where there is high potential for emissions reduction.

Table 1: Selected Mitigation Measures and Their Technical and Economic Potential in Asia, 2015–2050

($MtCO_2$ per year)

Mitigation Measure	Technical Potential ($MtCO_2$/year)	Economic Potential ($MtCO_2$/year)	Countries with Highest Potential
A. Forest and Other Ecosystems (Protect, Manage, and Restore)			
Reduce deforestation	1,489.88	918.78	Indonesia, Papua New Guinea, India, Malaysia, Myanmar, PRC, Viet Nam
Afforestation/reforestation	1,633.02	233.27	Indonesia, India, PRC, Myanmar, Thailand
Forest management	529.20	247.04	PRC, Indonesia, India, Viet Nam
Grassland and savanna fire management	0.11	0.03	Indonesia, India, Papua New Guinea
Reduce peatland gradation	68.83	38.54	Indonesia, PRC, Malaysia, Thailand, Viet Nam

[8] "Technical" potential (possible with available technology, regardless of cost) and "cost-effective" economic potential (possible up to $100/$tCO_2e$) in 2020–2050 for 20 land-based measures in the 250 countries in the IPCC AR6 Working Group III (WGIII) list of countries and regions.

Mitigation Measure	Technical Potential ($MtCO_2$/year)	Economic Potential ($MtCO_2$/year)	Countries with Highest Potential
Peatland restoration	726.18	390.62	Indonesia, PRC, Malaysia, Thailand, Viet Nam
Reduce conversion of mangroves	36.71	33.04	Indonesia, Myanmar, Malaysia, Papua New Guinea, Thailand
Mangrove restoration	7.92	2.37	Indonesia, Myanmar, Thailand, Viet Nam, Bangladesh
Total ecosystem	**4,491.89**	**1,863.74**	**Indonesia, PRC, India, Myanmar, Papua New Guinea, Thailand, Malaysia, Viet Nam, Cambodia**
B. Agriculture			
Enteric fermentation	57.40	32.754	PRC, India, Bangladesh, Pakistan, Nepal
Manure management	31.98	26.07	PRC, Myanmar, Thailand, Bangladesh
Improved rice production	202.63	141.78	India, PRC, Bangladesh, Indonesia, Myanmar, Thailand
Alternative wetting and drying	Annual decrease in CH_4 emissions by −23%		Philippines (Kraus et al. 2022)
Nutrient management	178.70	160.21	PRC, India, Pakistan, Bangladesh, Thailand, Viet Nam
Agroforestry	1,829.65	365.93	PRC, India, Mongolia, Myanmar, , Thailand
Biochar applications	1,004.84	767.30	PRC, India, Indonesia, Thailand, Viet Nam
Total agriculture	**3,955.05**	**1,996.17**	**PRC, India, Mongolia, Indonesia, Bangladesh, Myanmar, Thailand, Viet Nam**
C. Bioenergy			
Bioenergy	676.35	97.47	PRC, India, Myanmar, Indonesia, Pakistan
Global carbon removal potential by 2050 ($GtCO_2$)	1. Afforestation and reforestation 2. BECCS 3. Biochar 4. Soil carbon sequestration	0.5–3.6 0.5–5.0 0.5–2.0	(Fuss et al. 2018)
Market for sustainable bioenergy production in Southeast Asia	Saving about 442 million tons of CO_2e greenhouse gas emissions per year. Economically meet 2.8 exajoules of the energy demand by 2050.		Indonesia, Thailand, Viet Nam, Malaysia, Myanmar (IRENA 2022)
D. Demand-Side Measures			
Food waste	353.52	185.76	PRC, Pakistan, India, Viet Nam, Republic of Korea
Healthy diets	929.41	588.53	PRC, Pakistan, India, Viet Nam, Indonesia
Reduce wood fuel	192.56	57.76	PRC, India, Indonesia, Pakistan, Viet Nam
Total demand side	1,282.94	774.30	PRC, India, Pakistan, Viet Nam, Myanmar

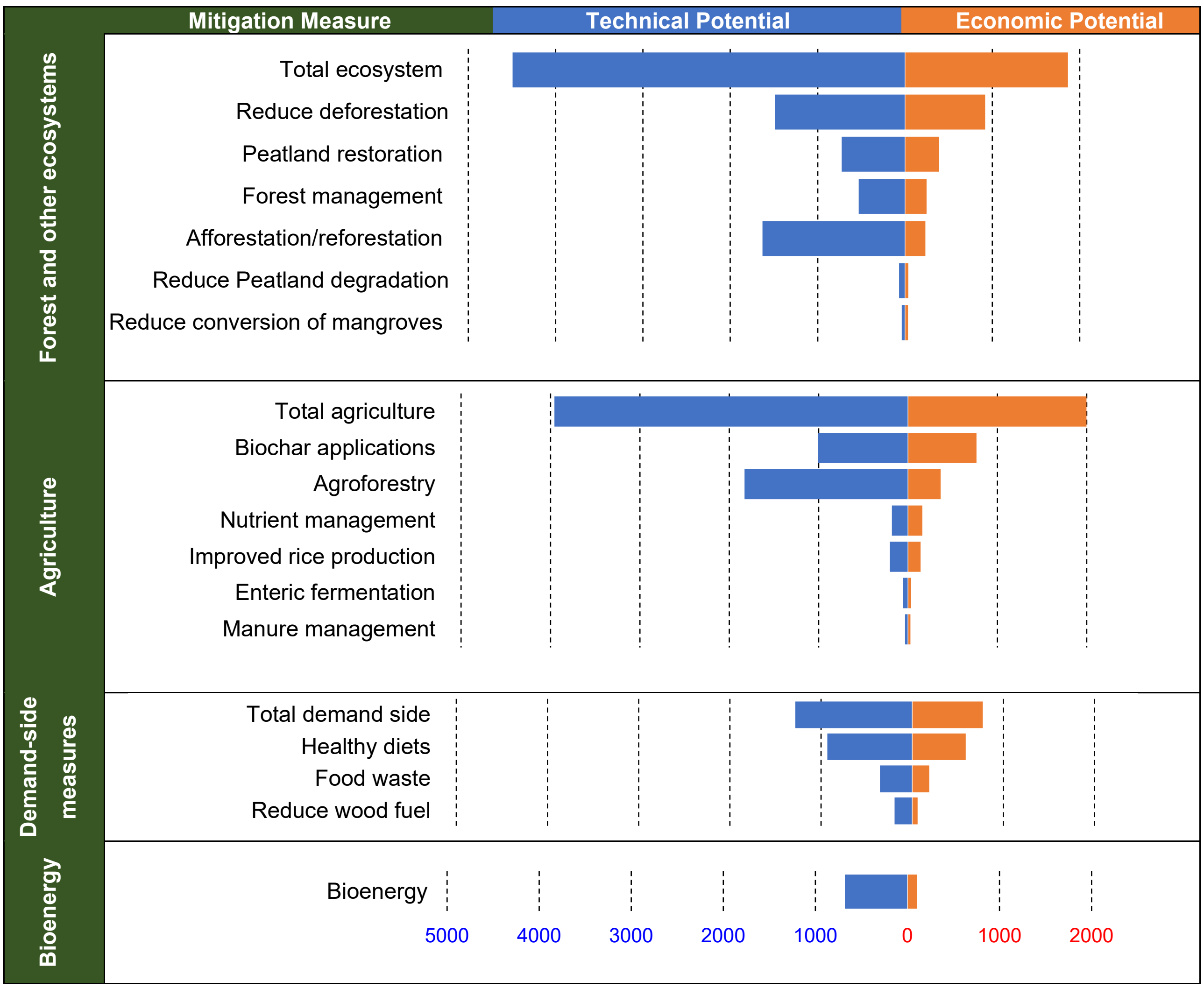
Mitigation Measure	Technical Potential ($MtCO_2$/year)	Economic Potential ($MtCO_2$/year)	Countries with Highest Potential
Total mitigation	**9,729.88**	**4,634.21**	**PRC, India, Indonesia, Myanmar, Thailand, Viet Nam, Malaysia, Pakistan**

BECCS = bioenergy with carbon capture and storage, CH_4 = methane, CO_2e = carbon dioxide equivalent, $GtCO_2e$ = gigaton of CO_2 equivalent, $MtCO_2e$ = million tons of CO_2 equivalent emission, PRC = People's Republic of China.

Note: ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Sources: Based on data from Roe et al. (2021) and other studies; Fuss et al. (2018); IRENA (2022); and Kraus et al. (2022).

Figure 5: Various Mitigation Measures and Their Technical and Economic Potential in Asia ($MtCO_2$/year), **2015–2050**



Source: Based on data from Roe et al. (2021). "Technical" potential (possible with available technology, regardless of the cost, GtCO2eq yr^{-1}) and "cost-effective" economic potential (possible up to \$100/tCO_2eq) in 2015–2050.

The review of various studies on mitigation potential clearly shows that there is high potential to reduce emissions from agriculture in Asia through various structural, technical, and demand-side measures. We examine the details of some of the major sectors in Asia where there is high potential for emissions reduction.

E. Food Consumption: Reduce Food Loss and Waste and Shift to a Healthier Diet (Example 1)

The population of Asia and the Pacific is estimated to reach 4.3 billion by 2030, with GDP per capita at purchasing power parity reaching $14,000, more than double the 2015 number (ADB 2019). The number of people living in cities in emerging Asia increased from 375 million in 1970 to 1.84 billion in 2017. By 2030, about 55% of the region's population will live in urban areas (ADB 2019). These demographic shifts are expected to increase demand for food and shift dietary preferences away from staple foods and toward more diverse diets rich in meat, seafood, eggs, and dairy products of animal origin, as well as more fruits and vegetables.

Food waste, diets, and emissions from the food supply chain process, including transportation, storage, and production, are some of the elements that influence food system emissions (Figure 4). The Food and Agriculture Organization of the United Nations (FAO) estimates that in 2009, about one-third of all food produced globally was lost or wasted. Losses, particularly during harvest and storage in some areas such as South Asia, reduce farmers' incomes and occasionally even their ability to feed their families. In Asia, each person loses 750 kcal per day, according to Searchinger et al. (2019).

Searchinger et al. (2019) calculated that a 30% shift from ruminant meat to plant-based proteins could close half of the GHG mitigation gap and nearly all the combined land-use gap by 2050. Therefore, it is critical to shift to a sustainable and healthy diet that is also socially acceptable and economically accessible to everyone. Encouraging a largely plant-based diet, limiting red meat consumption, promoting seafood from sustainable stocks, and reducing food loss and waste throughout the supply chain are some approaches to achieve this.[9]

[9] Food loss is the quantity or quality diminished by postharvest and wholesale food decisions and actions, as well as by food waste in food retailing, provisioning, and consumption.

F. Rice Cultivation (Example 2)

In most rice-growing countries in Southeast Asia, rice contributes about 50% of GHGemissions from agricultural production and 2.5%–20% or more of total national emissions. Based on FAO projections, Searchinger et al. (2019) forecast a 32% increase in rice demand between 2010 and 2050. Microbial processes in rice paddy soils produce both CH_4 and N_2O. These GHG emissions from rice fields are known to be influenced by several factors, including soil conditions, agronomic inputs, practices, and management (Yagi, Tsuruta, and Minami 1997; Conrad 2002).

There are several options for mitigation and policy measures: (i) faster increase of rice yields; (ii) breeding of rice with low CH_4 emissions; (iii) removal of rice straw; and (iv) shortening of flooding times, i.e., dry seeding, alternative wetting and drying (AWD), and anaerobic rice. Among them, AWD is known as one of the most promising measures. Any reduction in flooding can help reduce CO_2 emissions. There is conflicting evidence on the effects of different water management strategies on rice yields. However, recent studies in Bangladesh, the Philippines, and Viet Nam generally indicate yield benefits rather than yield losses. Without considering economic expenses, published data suggest a high potential for reducing GHG emissions from rice cultivation. A coordinated sequence of rice emissions reduction programs that focus on synergies with water savings and yield gains is needed (Searchinger et al. 2019).

There are also opportunities to reduce emissions by breeding low CH_4 rice varieties (ADB 2019). Experimental studies show that high-yielding rice cultivars reduce CH_4 emissions from typical paddy soils in a number of experiments. On average, a 10% increase in biomass resulted in a 10.3% decrease in CH_4 emissions in a high carbon soil for 33 rice cultivars (Jiang et al. 2017). However, there is still a need for further research and implementation in this area.

III. AGRICULTURE, INTERNATIONAL TRADE, SUPPLY CHAINS, AND EMISSIONS

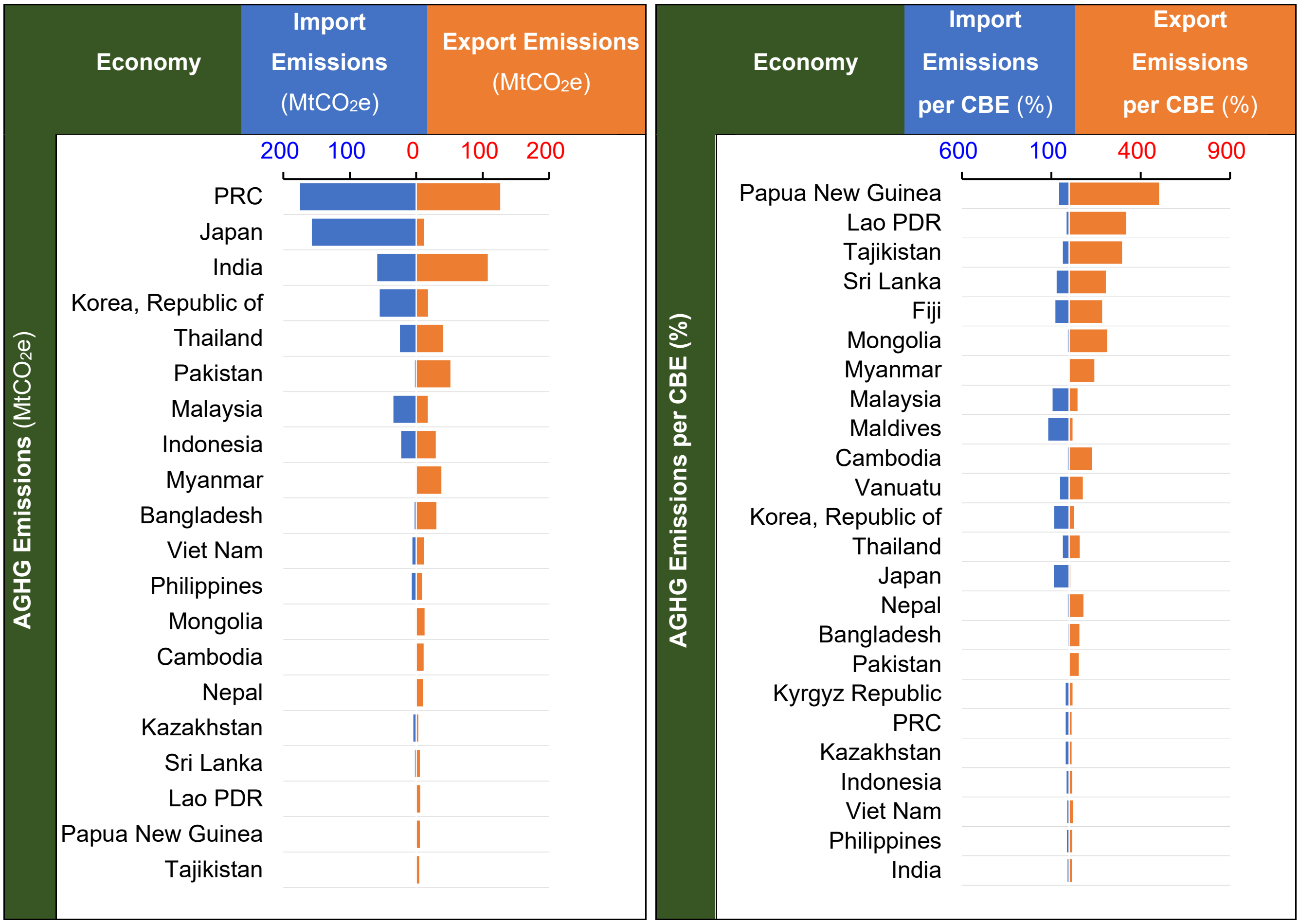
Emissions from the food supply chain are evolving into a significant source of emissions as global traffic in food and agricultural products increases. Some of the most significant emission drivers in this process are the demand and supply of agricultural products through bilateral and multilateral international trade, trade networks, and supply chains, as well as the associated direct GHG emissions (production) and indirect emissions through land-use change (conversion to cropland). According to Poore and Nemecek (2018), the global food supply chain currently generates 13.7 billion metric tons of carbon dioxide equivalent, or 26% of all anthropogenic GHG emissions. International trade patterns influence embodied emissions, and a net-zero shift in this industry can present both opportunities and difficulties. For example, the impact of trade on national emissions accounting cannot be overlooked, as food is sold internationally and consumed globally. According to the 2017 FAO report, global trade in agricultural goods increased from $433.2 billion in 2000 to $1,310.8 billion in 2016. This has led to an increase in studies looking at many facets of the global food sector and its impact on GHG emissions (Caro et al. 2014; Foong et al. 2022; Hong et al. 2022; Poore and Nemecek 2018; Zhao et al. 2020).

In their analysis of trade-adjusted agricultural emissions (TAEs),[10] Foong et al. 2022 observed that global TAEs increased in absolute terms from 3.86 GtCO_2e/year in 1987 to 5.02 GtCO_2e/year in 2015, with some of the highest absolute TAEs occurring in several countries in Asia where paddy rice was a larger contributor to TAEs. Figures 6 and 7 show the international trade-related emissions of various countries in Asia and the Pacific. The figures show that (i) a few countries that import agricultural products are responsible for large amounts of GHG emissions generated in exporting countries (Figure 6), and (ii) large amounts of GHG emissions are traded in livestock and paddy rice trade (Figure 7).

Rigorous analyses at the level of Asia and the Pacific still lack this aspect. Considering that the Asia and Pacific region is among the largest exporters of agricultural products, there is an urgent need to incorporate these aspects into national and regional policy making. For example, emissions-based accounting that considers the various impacts of trade is still largely absent from national food-related emissions accounting in Asia. In addition, the NDCs and intended NDCs of many countries in Asia have not yet considered the role of trade in displacing agricultural emissions, and climate change mitigation efforts have hardly been extended to emissions from land use.

[10] TAEs from agriculture are estimated using the sum of production-related emissions and import emissions, from which the value of export emissions is then subtracted.

Figure 6: Agricultural Greenhouse Gas Emissions Embodied in the Global Trade Network ($MtCO_2e$)

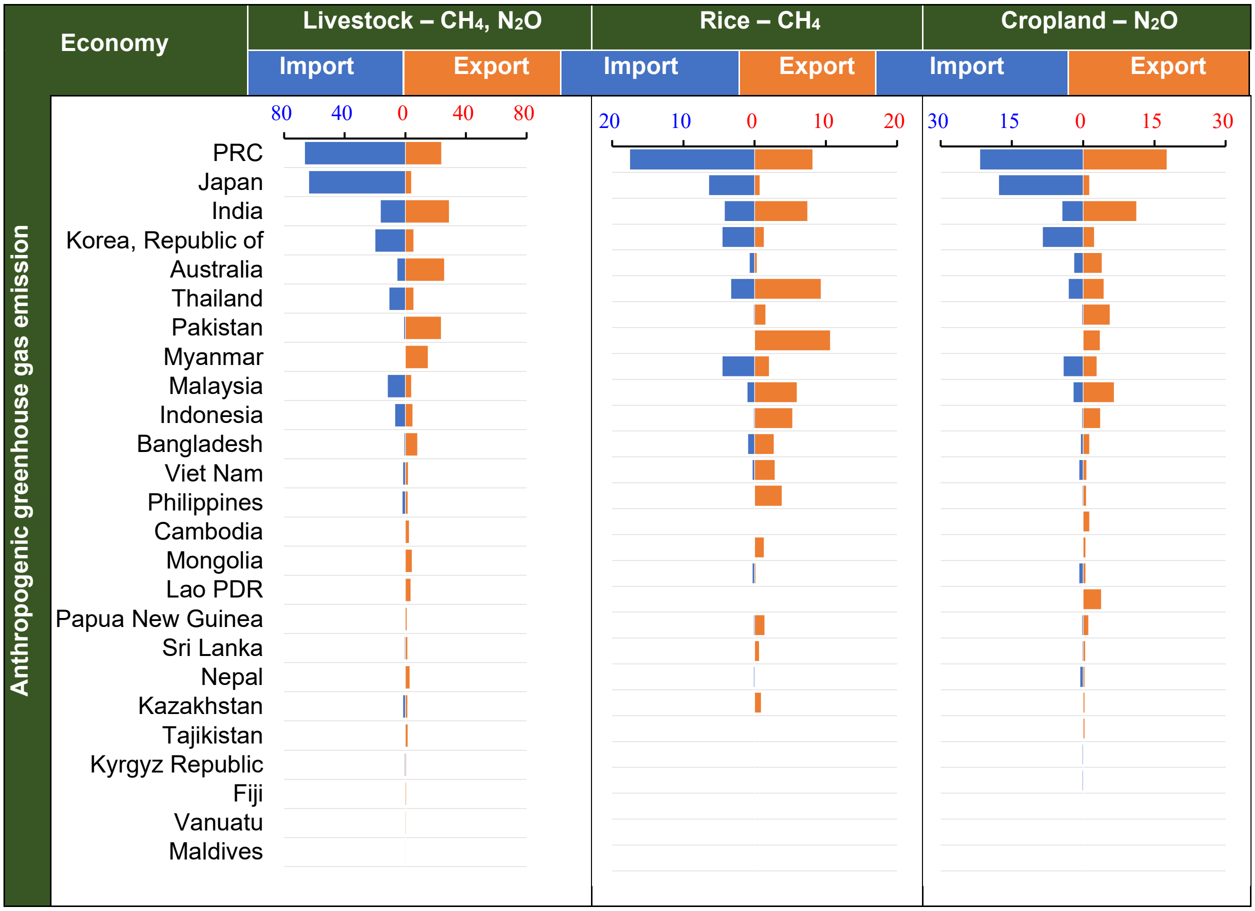


AGHG = agricultural greenhouse gas, CBE = consumption-based emissions, Lao PDR = Lao People's Democratic Republic, $MtCO_2e$ = million tons of CO_2 equivalent of GHG emissions, PRC = People's Republic of China.

Note: ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Source: Zhao et al. (2020).

Figure 7: Agricultural Greenhouse Gas Emissions Embodied in Final Trade by Source
($MtCO_2e$)



CH_4 = methane, Lao PDR = Lao People's Democratic Republic, $MtCO_2e$ = million tons of carbon dioxide equivalent, N_2O = nitrous oxide, PRC = People's Republic of China.

Note: ADB placed on hold its assistance in Myanmar effective 1 February 2021. ADB Statement on Myanmar | Asian Development Bank (published on 10 March 2021). Manila.

Source: Zhao et al. (2020).

A. Net-Zero Transition in Agriculture in Asia: Potential Opportunities and Policy Challenges

The challenges of a net-zero transition by 2050 are global, and decarbonization of all economies in Asia is required. However, the distribution of the effects and the exposure would be uneven. To enable economic development and growth, countries would need to strike a balance between several imperatives, including decarbonizing their agriculture, managing the exposure of significant portions of their agriculture to a net-zero transition, and improving access to affordable and low-emission food and livelihood options. Although many countries in the Asia and Pacific region have resources that could support low-emission innovations, it may be necessary to invest in adaptation measures, adopt the proper economic policies, and develop and employ low-emission technologies to complete the transition.

B. Economic Policies and Climate Change Mitigation

Significant policy reforms are needed in Asia to support both food security and climate change mitigation due to the growing impacts of climate change, population increase, urbanization, and the need to preserve food security. Due to population growth, rapid urbanization and rising affluence, the demand for food will increase, especially for fruits, vegetables, and livestock. According to a recent study, the effects of climate change are being felt more acutely in tropical regions such as Africa and Asia. Since 1961, total factor productivity in agriculture worldwide has declined by about 21%, equivalent to the loss of productivity growth in the previous 7 years (Ortiz-Bobea et al. 2021). It will be more difficult to sustain food security in the face of climate change without proper economic, social, and technological policy assistance, which will have many unexpected implications. As part of this shift to aggressive carbon reduction in agriculture, economic mechanisms will be crucial. However, the amount of emissions reduction needed could be achieved with current agronomic and policy methods while still allowing food production ranges from 21% to 40%. New technologies and policy choices are needed to minimize non-CO_2 emissions, as current technologies are not sufficient to meet the target (Wollenberg et al. 2016).

Price incentives (e.g., import tariffs and export subsidies) and fiscal subsidies (e.g., those linked to the production of certain commodities) in the agriculture sector that incentivize production practices that are harmful to nature and the environment can have significant negative impacts on food systems. For example, recent analysis shows that emissions-intensive commodities receive the most agricultural support worldwide (FAO, UNDP, and UNEP 2021). There are a variety of economic tools that can directly or indirectly target emissions reductions, including taxes, subsidies, payments for emissions abatement, domestic support, and market price support[11] for emissions reductions at the producer or consumer level. Recent analyses at the global level have found that global GHG taxes, with or without subsidies, appear to be the most effective mitigation measure and offer the greatest mitigation potential, equivalent to 28% of global non-CO_2 emissions from agriculture in 2050. GHG taxes can lead to significant emissions reductions with relatively small impacts on paddy rice production in East Asia and Southeast Asia (OECD 2019).

Recent research suggests that to reduce the enormous current GHG emissions from agriculture, a change in current incentive systems is needed as well as a move in favor of policies that more directly aim to reduce emissions, including GHG taxes on consumer demand or output, or increased investment for the development of technologies that boost productivity and reduce emissions while covering the costs of their adoption (Laborde et al. 2021).

GHG emissions are highly concentrated by product. For example, ruminant meat, milk, and rice production generate more than 80% of agricultural emissions, with ruminant meat alone accounting for half of these emissions in both Organisation for Economic Co-operation and Development (OECD) and developing countries. While the intensity of agricultural emissions (emissions per unit of output) has declined much faster in non-OECD countries than in OECD countries, the share of developing countries in global emissions from agricultural production remained at about 74% in 1991 (Mamun, Martin, and Tokgoz 2019). There are obvious trade-offs among the environmental, economic, nutritional, and social objectives associated with the possibility of withdrawing domestic support, even though existing agricultural support policies are not fully focused on promoting emissions reductions (Gautam et al. 2022). When policies are developed with the characteristics of the target population in mind, programs that are associated with short-term economic benefits have a higher acceptance rate than those that are simply aimed at providing an ecological service, regardless of the type of incentive (Piñeiro et al. 2020).

[11] Direct domestic support refers to a small financial assistance or transfers linked to the production of specific outputs or the use of certain inputs. This support is provided through market prices, usually resulting from public trade measures aimed at changing the price producers receive for their products.

There is an emerging discussion that efficient repurposing of agricultural subsidies can lead to a significant contribution to net-zero transition. However, most analyses to date have been limited to the global level (OECD 2022; Gautam et al. 2022; Springmann and Freund 2022), and there are no clear answers on how to achieve effective repurposing at the regional and national levels. Further research is needed to explore the potential opportunities and consequences of using different economic instruments to reduce emissions, considering the needs of many low- and middle-income countries.

C. Climate Finance and Net Zero in Asia and the Pacific

Current national and international funding is far from sufficient to make the investments needed for net-zero agriculture. Numerous bilateral, multilateral, and other funding methods are needed to implement the various agricultural climate change initiatives in Asia. The agriculture and land-use change sector will require $423 billion annually by 2030 to transition to a low-carbon economy, up from the current average of $16.3 billion in 2019/2020 (CPI 2022). There is a need for better analysis of the role of climate finance in achieving net-zero emissions in this sector, as current financial flows are driven by public funding sources that are concentrated in a few regions (CPI 2022).

Targeted emissions reduction interventions would not be possible without effective channeling of climate finance to small-scale farmers in the region. Globally, climate finance for small-scale agriculture reached $10 billion per year in 2017/2018. While adaptation finance is important and accounts for a large share of climate finance for small-scale farmers globally, targeted climate finance for small-scale farmers remains underfunded, with most of the private domestic investment coming from farmers themselves and four times exceeding public investments (FAO 2012). A potential entry point for identifying and increasing investment in measures that can have significant impact at scale has been tested in the field and evaluated. In addition, it is important to identify sectors and mechanisms that can use climate finance to achieve equitable GHG reductions across countries.

Box 3: Greening the Rice Sector in Southeast Asia

Rice is one of the main crops and is responsible for 25% to 33% of methane emissions in Southeast Asia. Flooded paddy fields provide ideal anaerobic conditions for bacteria to thrive in the decomposing organic matter and release methane (CH_4). The region's rice-growing areas cover 48 million hectares, or nearly 30% of the world's rice crop harvest. In 2018, 220 million tons of rice were produced there. Viet Nam and Thailand are among the top three rice-exporting countries in the world. To achieve a net-zero balance in Asian agriculture, CH_4 emissions in the rice sector must be reduced. There are many available technologies and approaches that can help reduce emissions from the rice sector in Southeast Asia, such as alternative wetting and drying (AWD), climate-smart agriculture practices, modified rice production practices, and proper management of rice residues. For example, AWD is expected to reduce greenhouse gas (GHG) emissions by 14% under the unconditional mitigation options and by nearly 18% under the conditional mitigation target (Government of Viet Nam 2015). Similarly, agriculture is the second-largest GHG-emitting sector in Thailand. The Thai rice sector is not only responsible for nearly 60% of Thailand's emissions from agricultural activities, but is also the fourth-largest emitter of rice-related GHGs—mainly CH_4—globally. In this area, there are many active initiatives to lower emissions from the rice industry. In its revised Nationally Determined Contributions, Viet Nam has increased its target for reducing GHG emissions in the agriculture sector, with most of the increase coming from the rice industry. With the help of the International Rice Research Institute and the Climate Change, Agriculture and Food Security Programme, Viet Nam has increased its mitigation target for agriculture under the Nationally Determined Contributions by 16 million tons of carbon dioxide equivalent ($MtCO_2e$) by 2030, equivalent to an annual reduction of 1.5 $MtCO_2e$. Also in Thailand, the project supported by Nationally Appropriate Mitigation Action aims to facilitate the country's transition to low-emission rice production through a combination of low-emission rice farming, the provision of climate change mitigation services, and the development of good agricultural practices to reduce emissions from rice cultivation.

Sources: CGIAR Research Program on Climate Change, Agricultural and Food Security (2020); Government of Viet Nam (2015).

IV. DISCUSSION AND PRIORITY AREAS OF ACTION

The increasing impacts of climate change threaten food production in the region, affecting the livelihoods of millions of farmers. While it is critical to strengthen the resilience of the farming system to the impacts of climate change through adaptation measures, there is a need to pursue

GHG emission reductions more effectively in agriculture to create synergies between adaptation and mitigation actions and achieve net-zero emissions from the agriculture sector. Achieving net-zero GHG emissions is more difficult than achieving net-zero CO_2 emissions because it is very difficult to reduce some sources of non-CO_2 emissions to zero, especially CH_4 and N_2O from agriculture.

Based on existing data, studies, and evidence, this paper examined various dimensions of emissions from the agriculture and land-use sectors in Asia and discussed potential mitigation pathways for Asia's transition to net zero. Below, we discuss some challenges that need to be considered and opportunities that can be pursued to achieve net zero in agriculture:

(i) Asia has one of the greatest potentials in the world to contribute effectively to achieving the net-zero target in agriculture and land use. The mitigation potential to achieve the net-zero target in Asian agriculture comes from various sources of emissions from agriculture and land-use change. However, how quickly and effectively the net-zero target can be achieved depends on the impacts of these mitigation channels and how they interact with (a) cost-effectiveness and benefits; (b) side effects and trade-offs with economic development, poverty, livelihoods, agricultural productivity, employment, and adaptation measures; (c) effective management of the transition and its impacts; (d) availability and affordability of mitigation technologies and potential for cost-effective and sustainable upscaling and out-scaling; (e) accounting for structural, economic, and social conditions at national and local levels; (f) availability of climate finance; (g) impacts on international trade; (h) political commitment; (i) emissions reductions from agricultural food supply chains; and (j) behavioral changes among producers and consumers.

(ii) To establish net-zero agricultural pathways, it is crucial that we create them with a pro-growth, pro-poor strategy that builds on the region's accomplishment of sustainable development. In addition to these issues, many countries in Asia are also dealing with inequality, unemployment, and poverty. It is critical to better achieve the goals of agriculture's net-zero transition in the fight against climate change.

(iii) Asia is a food-insecure region with 450 million smallholder farmers producing more than 80% of the region's food consumption. Smallholder farmers often work on plots of less than 2 ha and have limited access to many services. Achieving the net-zero target will not be possible in the region unless low-cost mitigation technologies are available to farmers in an accessible and convenient manner. Out-scaling and upscaling available and new low-cost mitigation technologies and increasing farmers' productivity and efficiency will be critical to achieving the net-zero transition. Careful consideration of the food security and nutrition dimension in designing policies to reduce emissions from agriculture and land use should be a priority.

(iv) Many countries in Asia are the largest producers of rice, wheat, cotton, tea, coffee beans, palm oil, milk, and meat. Countries such as India, Malaysia, Thailand, and Indonesia are net exporters of production-based land-use emissions in Asia. To promote the export of agricultural products, trade has led to the destruction of numerous carbon-dense and biodiverse ecosystems. The requirement for well-designed trade rules that guarantee that any additional costs incurred in preventing such a change in land use would first be met by (usually more developed) importing regions. To better understand the dynamics of trade and the support needed for policy, it is also necessary to gather trade- and emissions-related information at a more local level in Asia.

(v) Asia is highly vulnerable to the impacts of climate change, as the agriculture sector suffers high economic losses and is a major source of agricultural emissions. Although global climate finance is heavily focused on mitigation, progress in Asia has been slow in aligning financial flows with low GHG agricultural emissions pathways. New funding, innovative financing mechanisms, and effective economic incentives that leverage cost-effective mitigation options are essential. For example, in the livestock sector, where the potential for emissions reduction in Asia is high, the lack of funding for project implementation remains a major barrier. Currently, most investments in the AFOLU sector are dominated by public finance, and private investments in the AFOLU sectors face many barriers in Asia. There is an urgent need to rapidly scale up successful blended financing mechanisms in Asia.

(vi) Economic instruments such as prices and fiscal incentives are important factors affecting both agricultural production and emissions. A consensus is emerging that effective repurposing of agricultural subsidies from distortive and harmful types of support to agricultural producers to well-targeted, decoupled support for production of a particular crop or livestock and support that includes conditions to increase productivity and reduce negative environmental impacts can make a significant contribution to net-zero transition in Asia. However, this transition must occur without jeopardizing the food security of many low- and middle-income countries in Asia.

(vii) Regional collaboration among governments in Asia must be strengthened, with greater involvement of the private sector, civil society organizations, and multilateral organizations to ensure the successful implementation of national adaptation and mitigation measures.

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Asia's Transition to Net Zero
Opportunities and Challenges in Agriculture

While a large portion of the Asian population depends on agriculture for their livelihoods and food security, the agriculture sector is one of the main sources of greenhouse gas emissions in the region. In some Asian economies, it accounts for more than 40% of total emissions. This report reviews a variety of tools and technologies to alter emissions pathways in Asia and discusses the institutional, political, and economic challenges for achieving a cost-effective, inclusive, and resilient transition to net-zero agriculture.

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