Opportunities and Challenges During Low-Carbon Transition: A Perspective From Asia’s Agriculture Sector

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OPPORTUNITIES AND CHALLENGES DURING LOW-CARBON TRANSITION: 
A PERSPECTIVE FROM ASIA’S AGRICULTURE SECTOR

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Abstract

Climate change because of greenhouse gas (GHG) emissions is a significant challenge facing humanity. Failure to take action to reduce GHG emissions would be catastrophic to life on earth, livelihood, and socioeconomic progress that humanities achieved so far. Agriculture is a victim as well as a perpetrator of climate change. The agricultural system depends on weather conditions; hence, agro-based livelihoods and food security are highly vulnerable to climate change. Agriculture, forestry, and other land use sectors contribute to about a quarter of GHG emissions, and Asia has the largest share of global agriculture, forestry, and other land use emissions. Therefore, agriculture and allied sectors should play an important role in the global efforts to achieve net zero carbon emissions. Numerous GHG mitigation strategies for the agricultural system are available, which include dietary changes, reducing food loss and waste, efficient use of resources (especially fertilizer), use of renewable energy in agriculture, soil carbon sequestration, reducing enteric fermentation, reducing methane emissions from rice cultivation, and managing manure to reduce GHG. However, the challenge is the investment that is required to scale up these strategies to more than 500 million smallholder farmers. Further, some of these strategies may adversely impact the yield, food security, livelihood loss, and foreign exchange export earnings of developing economies that are dependent on agriculture. Additionally, some government subsidies that are not climate-, environment-, and natural resources-friendly should be reallocated into sustainable and climate-smart agriculture. Therefore, the agriculture sector’s net zero carbon emission strategy in developing economies should be driven by technology and implemented gradually with financial and knowledge support from the government and international organizations.

Note

In this report, “$” refers to United States dollars.
EXECUTIVE SUMMARY

Agriculture is both a victim and a culprit of climate change, yet it has the potential to play a critical role in the fight against climate change. It has been noted that climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition. An increase in frequency, intensity, and severity of droughts, floods, heatwaves, and continued sea level rise will increase risks to food security in vulnerable regions, calling for an urgent need to invest in greenhouse gas (GHG) mitigation options and adaptation to climate change.

GHG emission from agriculture, forestry, and other land use (AFOLU) includes nitrous oxide from the application of synthetic fertilizer, manure to soils and dropped on pastures, and from manure management, methane (CH$_4$) from rice cultivation, enteric fermentation, and manure management, carbon dioxide emissions from above- and below-ground biomass changes and dead organic matter related to land use changes and forest management, as well as soil carbon emissions from deforestation/afforestation.

Mitigation strategies, including dietary changes, reducing food loss and waste, sustainable intensification, improving nitrogen management, enteric fermentation management, carbon sequestration in agricultural systems, methane emissions from rice cultivation, and clean energy use in agriculture, could play a crucial role in reducing GHG emission from the agriculture sector. Some of these strategies act as mitigation as well as adaptation strategies, thereby helping cope with climate risk and reducing GHG emissions. Soil carbon sequestration is a double-sword strategy as it helps reduce GHG emissions and improve agricultural production.

The direct cost of implementing the strategy and the lack of skills, knowledge, and capacity among smallholder farmers are major constraints for scaling these climate change (GHG emissions) mitigating technologies. Some of these climate change mitigating technologies can adversely affect agricultural production, which could further impact food and nutritional security, rural livelihoods and income, food price, agro-based industry, and the export earnings of the economies that are dependent on agriculture.
Some government subsidies that are not climate-, environment-, and natural resources-friendly should be reallocated into sustainable and climate-smart agriculture.

The impact of GHG mitigation on agricultural production and food security varies across economies and regions. Therefore, while selecting the strategies for GHG mitigation, it is important to identify the strategy with a high marginal effect on reducing GHG emission and less negative marginal impact on food production.

The faith in the agriculture sector is very precarious. Our inaction will intensify and accelerate climate change which will destroy the agricultural system and food security, while the implementation of GHG mitigation strategies is associated with some direct and indirect costs associated with it. Though the benefit of implementing GHG mitigation strategies outweighs the cost, several challenges remain, such as financing, the disruption of food supply and raw materials for agro-based industries, livelihood loss, foreign exchange earning loss, increase in hunger, increase in nutritional and insecurity, and poverty.

Strategies for net zero carbon emission should extensively test the technology in the experimental and farmers’ fields to ensure that the adverse effect on yield is minimal and sustainable, while reducing the GHG emission substantially. It is crucial to build confidence in the technology among all the stakeholders as smallholder farmers are poor, and mal-technology could put generations into a debt and poverty trap. Further, farmers do not have the resources and luxury to change such technology annually. Therefore, given the critical linkages between the agriculture sector, food security, and poverty, we must tread this path carefully and cautiously.
I. INTRODUCTION

Climate change because of greenhouse gas (GHG) emissions is a significant threat to the future of humanity. In recent years, we have experienced more frequent extreme climate events, such as an increase in temperature, drought, erratic rainfall, glacial melting, increase in pests and diseases, increase in flooding, seal level rise, and salination, thereby highlighting the urgency to reduce GHG emissions and attain net zero carbon emissions. Failure to act quickly would jeopardize the progress achieved so far.

Agriculture is both a victim and a culprit of climate change, yet it has the potential to play a critical role in the fight against climate change. It has been noted that climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition (Shukla et al. 2019). Continuous increases in the frequency, intensity, and severity of droughts, floods, heatwaves, and sea level rise will increase food security risk, especially in vulnerable regions (climate hotspots). Without efforts to adapt to climate change, at 2°C or higher global warming level in the midterm, food security risks because of climate change will be more severe, leading to malnutrition and micro-nutrient deficiencies, especially in low-income and middle-income economies (Pörtner et al. 2022). The recent United Nations Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) has reported that, across Shared Socioeconomic Pathways (SSP)\(^1\) 1, 2, and 3, global crop and economic models projected a 1%–29% cereal price increase in 2050 because of climate change (RCP 6.0), which would impact consumers globally through higher food prices (Shukla et al. 2019). An additional 20%–36% population may face hunger in 2050 under high emissions and 11%–33% under low emissions scenarios (Hasegawa et al. 2021).

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\(^1\) SSP1: Low challenges for mitigation (resource efficiency) and adaptation (rapid development); SSP3: High challenges for mitigation (regionalized energy/land policies) and adaptation (slow development); SSP4: Low challenges for mitigation (global high-tech economy), high for adaptation (regional low-tech economies); SSP5: High challenges for mitigation (resource/fossil fuel intensive) and low for adaptation (rapid development).
Nelson et al. (2018) found that an additional 65 million people (10% more) will experience food insecurity because of climate change in 2050, and there will be a reduction of average energy intake by 5% in low-income and 2% in the highest-income economies.

Because of the expansion of agricultural production and limited/lack of crop intensification, land requirements are expected to increase from 1.5 billion hectares to 1.7 billion hectares between 2012 and 2050 (FAO 2018). However, there is limited or no space for the expansion of agricultural land and further, because of soil erosion and environmental degradation, soil health is depleting, which could further increase the risk of food insecurity.

In 2019, GHG emissions from agriculture, forestry, and other land use (AFOLU sector were an estimated 10.6 gigatons (Gt) of carbon dioxide equivalent (C02e) as shown in Figure 1. Total emissions from agriculture, i.e., generated within the farm gate and at the farm boundary with natural ecosystems, remained relatively constant over the entire 1990–2019 period\(^2\) (FAO 2021). A total of 7.2 Gt CO2e was generated within the farm gate in 2019 (FAO 2021); the most significant emission came from enteric fermentation in the digestive systems of ruminant livestock, followed by emissions from the use of fertilizers on agricultural soils.

Farm gate emissions increased by about 10% over the period 1990–2019, from 6.6 Gt CO2e to 7.2 Gt CO2e, while the emissions from land use change decreased by 25%, from 4.7 Gt CO2e to 3.5 Gt CO2e (FAO 2021). Total emissions from agriculture remained virtually unchanged over the last 30 years because of improvements in the efficiency of agricultural production processes and reductions in land conversions, mainly deforestation (FAO 2021).

On the other hand, forestland mitigates climate change by removing GHG from the atmosphere through biomass growth. The contribution of forests to carbon sequestration was about 2.4 Gt in 2019 (decreased from 3.2 Gt in 1990), nearly counterbalancing emissions from net forest conversion (FAO 2021). At the same time, fires in other forests added a relatively small amount of non-carbon dioxide (CO2) emissions, in the order of 0.2 Gt CO2e in 2019 (FAO 2021).

\(^2\) The underlying data uncertainty is about 30%, which stems from uncertainties in both the activity data and in the emissions factor coefficients applied for the emissions estimates (Tubiello et al. 2013).
This suggests that the annual net emissions of AFOLU were slightly below 8.15 Gt. IPCC’s AFOLU classification does not consider the emission produced from food waste.  

Figure 1: Annual Greenhouse Gas Emissions from Agriculture, Forestry, and Other Land Use: Asia and the Pacific, 1990–2019

FAOSTAT = Food and Agriculture Organization Corporate Statistical Database. 
Note: These categories follow FAOSTAT domain emissions totals. Methodological note released June 2021. Farm gate emissions include burning crop residues, drained organic soils, enteric fermentation, manure applied to soils, manure left on pasture, manure management, rice cultivation, savanna fires, synthetic fertilizers, and on-farm energy use. Forestland emission (sink) includes forest fires and forestland. Land use change emissions include fires in organic soils, net forest conversion in 2021. Source: FAOSTAT (2022a).

The largest contributor of emissions within farm-gate emissions from enteric fermentation in the digestive systems of ruminant livestock was the largest contributor (2.8 Gt CO₂e) (FAO 2022a). In the region, 77% of enteric fermentation emissions come from cattle, 14% from buffalo, and the rest from small ruminants (sheep and goats). The largest emitters of enteric fermentation in the region are India (0.39 Gt), the People’s Republic of China (PRC) (0.18 Gt), and Pakistan (0.13 Gt).

GHG emissions resulting from energy use in processing, trade, and consumption of food is about 3.4 Gt (FAO, 2016). Apart from the abovementioned emissions on agricultural land, another source of emissions is food waste. FAO had estimated that, each year, about one third of all food produced for human consumption in the world is lost or wasted, which is estimated to be 1.6 Gt of “primary product equivalents”, while the total wastage for the edible part of food is 1.3 Gt (FAO 2013).
Despite being a major livestock producer, Australia has relatively low enteric fermentation emissions at 0.06 Gt, which has decreased from 0.07 Gt since 1990.

The second largest emissions are from drained organic soils (0.83 Gt). Organic soils, which are found in peatlands under waterlogged conditions, cover only a small portion (2.2%–3.0%) of the global terrestrial surface (Leifeld and Menichetti 2018; Tubiello et al. 2016), but hold a large proportion (more than one third) of the world’s soil organic carbon (Scharlemann et al. 2014; Yu et al. 2010). Large areas of peatland have been drained for AFOLU and peat mining. In the region, the largest emitters from drained organic soils are Indonesia (0.68 Gt), followed by Malaysia (0.096 Gt) and Papua New Guinea (0.064 Gt).

Another significant contributor to emissions is the application and management of livestock manure, which amounts to 1.31 Gt CO$_2$e (FAO 2022a). This includes emissions from pasture-based manure application by grazing animals (0.76 Gt), as well as the use of manure as organic fertilizer (0.16 Gt) and the management of manure (0.39 Gt). Globally, about 0.67 Gt of emissions is because of rice cultivation. Rice grown in flooded fields creates the perfect environment for bacteria to decompose organic matter (mostly rice straw residue) and release methane. The rice plant’s poor absorption of nitrogen-based fertilizers, frequently overused by farmers, leads to nitrous oxide emissions (Earth Security Group 2019). The Asia and Pacific region accounts for 87% of the global rice cultivation emissions, most of which are from the PRC (0.14 Gt), India (0.29 Gt), and Indonesia (0.06 Gt). Synthetic fertilizers contribute 0.60 Gt of emissions globally. of nitrogen fertilizer. When nitrogen fertilizer is applied to the soil, only a portion is up taken by the plants. Another portion is used by soil microorganisms, which produce nitrous oxide (N$_2$O) as a by-product of their metabolism, while another part of the nitrogen applied may end up leaching or volatilizing from the application site. Soil microbial activities release N$_2$O, a GHG with 265 times more global warming potential than CO$_2$ over 100 years period (Menegat et al. 2022). The Food and Agriculture Organization of the United Nations (FAO) has predicted that worldwide use of synthetic N fertilizers is expected to increase by 50% from the 2012 level by 2050 (FAO 2018). Larger emitters from synthetic fertilizers in the region are the PRC (0.16 Gt) and India (0.09 Gt), followed by Indonesia (0.016 Gt) and Pakistan (0.018).
Other sources of farm-gate emissions include on-farm energy use (0.53 Gt), savanna fires (0.21 Gt), crop residues (0.19 Gt), and burning crop residues (0.04 Gt). Similar to other sources of emissions from farm-gate, the PRC, India, and Indonesia are the largest emitters, with a notable exception from Iran, Japan, and Saudi Arabia, which emit large amounts of GHG emissions from on-farm energy use relatively.

In order to meet the goals of the Paris Agreement to limit the global temperature increase to below 2°C, and ideally to 1.5°C, the total remaining cumulative emissions should not exceed 400 Gt CO₂–1,000 Gt CO₂ by the end of the century (Millar et al. 2017). In light of the above discussion, the AFOLU sector needs to contribute significantly to achieve the climate change goals. GHG mitigation strategies in the agriculture sector should focus on both demand and supply. Notable mitigation strategies on the demand side include dietary change and reducing food waste and loss. On the supply side, mitigation strategies focus on agricultural practices which reduces GHG
emission, such as sustainable intensification, improving nitrogen management, reducing emission from enteric fermentation, carbon sequestration in the agricultural system, reducing methane emission from rice cultivation, and manure management.

However, the effort to net zero carbon emissions comes with a cost. First, investment is needed in designing, scaling, and implementing agricultural climate change mitigation strategies. Second, some of these strategies could have a detrimental effect on agricultural production, food security, rural livelihood, agro-based industries, and foreign exchange earnings for economies that are exporting agricultural products. For example, Frank et al. (2017) found that limiting global warming cost-efficiently across sectors to 1.5 °C will result in global food calorie losses ranging from 110 kilocalories (kcal)–285 kcal per capita per day in 2050, depending on the applied demand elasticities, which could translate into a rise in undernourishment of 80 million–300 million people in 2050. Similarly, Havlík et al. (2014) found that stringent climate policies (specifically livestock mitigation policies) might lead to reductions in food availability up to 200 kcal per capita per day globally.⁴ Fujimori et al. (2022) compared six global agroeconomic models using different factors of emissions reduction⁵ and carbon tax under 2°C climate-stabilization scenarios, and found that afforestation policies caused the greatest adverse side effects on food security, followed by non-CO₂ abatement policies, and that carbon taxes and mitigation actions in AFOLU would push the production costs, land rent, and commodity prices; consequently, calorie availability will decrease by 117 (19–142) kcal per capita per day, and the population at risk of hunger will increase by 117.7 (19.5–155.4) million in 2050, which grows over the period.

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⁴ Frank et al. (2019) and Havlík et al. (2014) both used GLOBUS model and compared to business-as-usual scenarios under SPS2.
⁵ Non-CO₂, bioenergy production, afforestation.
II EMISSIONS FROM THE AGRICULTURE SECTOR IN ASIA AND THE PACIFIC

Asia and the Pacific emitted 34% of the world’s GHG emissions from AFOLU, while the region emitted 44.3% of total GHG emissions in 2018 (Lamb et al. 2021). AFOLU sector represents the third largest share of emissions in the region (18.1%), after the energy systems (38.6%), industry (29.9%), followed by transport (8.4%) and buildings (4.9%) (Lamb et al. 2021). Therefore, Asia has to play a crucial role in reducing GHG emissions from all sectors, including the AFOLU sectors, in realizing net zero carbon emissions.

**Figure 3: Greenhouse Gas Emission Decomposition**

AFOLU = agriculture, forestry, and other land use; GHG = greenhouse gas.
Note: Asia includes Asia-Pacific Developed, Eastern Asia, Eurasia, South-East Asia and Developing Pacific and Southern Asia. Other regions include Africa, Europe, Latin America and Caribbean, Middle East, North America.

Source: Lamb et al. (2021) data from 2018.

Almost one third of the AFOLU emissions is from enteric fermentation, while rice cultivation contributes to 17% and net forest conversion (12%), drained organic soils (12%), fires in organic

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6 Data of 2018 in the region (AR6-10R classification) of Southeast Asia and developing Pacific, Eurasia, Eastern Asia, Southern Asia, Asia and Pacific developed.
soils (13%), and synthetic fertilizers (10%). Trends from 1990 to 2019 suggest that total GHG emissions from AFOLU in the region increased by 32%, driven by increases in population.

Figure 3 shows that the PRC and India are the largest emitters from the farm gate, each emitting nearly 800 million tons of CO$_2$e in 2019 (FAO 2022a). Emissions from the PRC and India are because of enteric fermentation, the use of synthetic fertilizers, and rice cultivation. Indonesia, Myanmar, and Malaysia have high land use change emissions (657.6 million tons of CO$_2$e, 89.3 million tons of CO$_2$e, and 39.5 million tons of CO$_2$e each, respectively) (FAO 2022a). Indonesia’s high emission is mainly because of land use change emission (net forest conversion 19%, fires in organic soil 38%). Indonesia’s expansion of cropland (0.18 million square kilometers or 28%) was largely driven by international demand for palm oil, rubber, and plantation products (Austin et al. 2019; Xin et al. 2021). Pakistan’s emissions are mainly from enteric fermentation and manure left on the soil. More than 40% of Myanmar’s emissions are from net forest conversion, while enteric fermentation (17%) and rice cultivation (15%) are also big sources.

**Figure 4: Ranking of the Top Ten Asian Economies by Emissions from Agriculture and Land Use Change, 2019**

FAOSTAT = Food and Agriculture Organization Corporate Statistical Database, PRC = People’s Republic of China. Note: Farm gate emissions include emissions from enteric fermentation, livestock manure, manure management, burning of crop residues, crop residues, rice cultivation, drained organic soils, on-farm energy use, and savanna fires. Land use change emissions include emissions from fires in organic soils, and fires in humid tropical forests. These categories are following FAOSTAT Domain Emissions Totals. Methodological note, release June 2021. Per capita emissions are computed using the 2019 population of countries. Sources: FAOSTAT (2022a) and World bank databank (2022a).
Global diets are a key driver of production per capita, and thus land pressure and AFOLU emissions. As per capita incomes rise and populations urbanize, traditional diets emphasize starchy foods, legumes, and vegetable transition towards energy-intensive products such as refined sugars and fats, oils, and meat (Tilman and Clark 2014). However, at a certain point in national development, diets override population growth as the main driver of AFOLU emissions (Kastner et al. 2012). For example, the PRC and India have experienced rapid dietary westernization. A study by Kastners et al. (2014) found that using current western technologies to feed the world with western diets implies a need for almost twice the presently used cropland area.

Therefore, Asia and the Pacific should play a crucial role in reducing the GHG emission from the AFOLU sector, particularly by reducing enteric fermentation, N₂O, and manure management, reducing methane emissions from rice cultivation, use of clean energy, and preventing land use change.
III. IMPORTANCE OF THE AGRICULTURE SECTOR IN ASIA AND THE PACIFIC

Agricultural production has increased enormously in the last four decades, and Asia has been the engine of growth in the agriculture sector (Rahut et al. 2022). Growth in agricultural output not only increased the income of rural families, thereby uplifting millions of the population out of poverty and hunger, but it also supported the reduction of global food insecurity and hunger. Agriculture provides livelihood to a significant proportion of the rural population, and nearly half of the Asian population lives in rural areas.

Although the share of the agriculture sector to gross domestic product (GDP) in Asia has been declining over a period of time, it is still vital to the economy and employment, accounting for 13.4% of GDP, 4.2% of the total export, and employing 570 million people. Table 1 shows that half of the top emitters from the agriculture sector have a high agricultural output, share to GDP, and export earning share. In Myanmar, Indonesia, Pakistan, and Thailand, the share of agricultural and food export is relatively high (24.9%, 22.4%, 18.1%, and 14.1%). As agriculture plays a significant role in the economy, the low carbon transition in these economies will create pressure on the foreign currency balance, job market, and livelihood of smallholder farm households.
Table 1: Economic and Social Significance of Agriculture Sector in Top 10 CO₂ Emitters in Asia

<table>
<thead>
<tr>
<th>Country</th>
<th>Emissions from AFOLU (Gt/CO₂)</th>
<th>Agricultural GDP in Total GDP</th>
<th>Constant 2015 $ Million</th>
<th>%</th>
<th>Agriculture and Food Export</th>
<th>Total (million)</th>
<th>Male (million)</th>
<th>Female (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>8.15</td>
<td>4.3</td>
<td>3,795,594</td>
<td>8.5</td>
<td>2,771,062.4</td>
<td>883.3</td>
<td>559.1</td>
<td>324.4</td>
</tr>
<tr>
<td>Asia</td>
<td>3.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2,406,797&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>569,567.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>559.1&lt;sup&gt;d&lt;/sup&gt;</td>
<td>390.0&lt;sup&gt;d&lt;/sup&gt;</td>
<td>207.6&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1.15</td>
<td>13.3</td>
<td>139,182</td>
<td>22.4</td>
<td>65,067.5</td>
<td>37.3</td>
<td>23.6</td>
<td>13.7</td>
</tr>
<tr>
<td>PRC</td>
<td>0.14</td>
<td>7.3</td>
<td>1,173,103</td>
<td>2.2</td>
<td>101,322.3</td>
<td>194.3</td>
<td>120.2</td>
<td>74.2</td>
</tr>
<tr>
<td>India</td>
<td>0.73</td>
<td>16.8</td>
<td>445,276</td>
<td>11.6</td>
<td>58,652.0</td>
<td>199.6</td>
<td>147.7</td>
<td>52.1</td>
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<td>Pakistan</td>
<td>0.21</td>
<td>23.0</td>
<td>74,376</td>
<td>18.1</td>
<td>7,639.4</td>
<td>26.2</td>
<td>16.9</td>
<td>9.3</td>
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<td>Myanmar</td>
<td>0.21</td>
<td>23.5</td>
<td>15,809</td>
<td>24.9</td>
<td>8,008.2</td>
<td>11.8</td>
<td>7.7</td>
<td>4.1</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>0.12</td>
<td>11.6</td>
<td>34,899</td>
<td>1.9</td>
<td>1,014.7</td>
<td>25.7</td>
<td>14.2</td>
<td>11.5</td>
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<td>0.10</td>
<td>9.6</td>
<td>25,396</td>
<td>10.0</td>
<td>43,248.4</td>
<td>1.6</td>
<td>1.2</td>
<td>0.3</td>
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<td>8.5</td>
<td>37,980</td>
<td>14.1</td>
<td>58,994.9</td>
<td>12.1</td>
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<td>0.06</td>
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<td>34,394.7</td>
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<td>10.6</td>
<td>0.3</td>
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<td>10,019.1</td>
<td>10.1</td>
<td>7.7</td>
<td>2.4</td>
</tr>
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</table>

Data from: 2019 FAOSTAT 2022a, 2021 World Bank database 2022b, 2022c FAOSTAT 2022b, ILO 2022

AFOLU = agriculture, forestry, and other land use; CO₂ = carbon dioxide; FAOSTAT = Food and Agriculture Organization Corporate Statistical Database; Gt = gigaton; GDP = gross domestic product; ILO = International Labour Organization; PRC = People’s Republic of China, US = United States.

Note: <sup>a</sup> is for Asia and Oceania, <sup>b</sup> is for East Asia & Pacific and South Asia, <sup>c</sup> is the export of agricultural products, food excluding fish. <sup>d</sup> is Asia (excluding Oceania/Pacific)

Source: Authors’ computation.

Table 2 shows that, in 2019, about 398.2 million people were undernourished in Asia, 439.2 million were severely food insecure, 1,109.5 million were moderately or severely insecure, and 79 million children under 5 years were stunted. Further, Southeast Asian poverty levels are particularly high. Thus, Asia needs to increase agricultural production substantially to meet the food and nutritional needs of the growing population against the backdrop of rising climate change and environmental degradation.
Table 2: Nutrition in Asia and the Pacific, 3-Year Averages, 2019

<table>
<thead>
<tr>
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<td>9.0</td>
<td>702.7</td>
<td>10.7</td>
<td>830.2</td>
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<td>8.3</td>
<td>387.5</td>
<td>9.5</td>
<td>439.2</td>
</tr>
<tr>
<td></td>
<td>South Asia: 8.5**</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Indonesia</td>
<td>9.8</td>
<td>6.5</td>
<td>17.7</td>
<td>0.7</td>
<td>1.9</td>
</tr>
<tr>
<td>PRC</td>
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<td>&lt;2.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>India</td>
<td>21.9</td>
<td>16.3</td>
<td>224.3</td>
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<td>37.2</td>
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<td>18.8</td>
<td>10.7</td>
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<td>&lt;2.5</td>
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<td>Thailand</td>
<td>9.9</td>
<td>8.8</td>
<td>6.2</td>
<td>10.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Viet Nam</td>
<td>6.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>16.7</td>
<td>5.2</td>
<td>5.7</td>
<td>4.8</td>
<td>5.3</td>
</tr>
</tbody>
</table>


Source

World bank database 2022d
FAOSTAT 2022c

... = not available, avg = average, FAOSTAT = Food and Agriculture Organization Corporate Statistical Database, PRC = People’s Republic of China.

Note:* is the global poverty headcount ratio at $2.15 a day (2017 PPP) (% of the population), ** is East Asia & Pacific and South Asia population under $2.15 a day (2017 PPP) (% of the population). Otherwise, Asia includes Central Asia, East Asia, South Asia (excluding Oceania/Pacific).

Sources: Authors’ calculations.

Land-rich economies with extensive agriculture and large amounts of emissions from land use change, in particular, deforestation and forest degradation, can reduce emissions with limited trade-offs with food security (Frank et al. 2017). However, in the case of land-poor economies, it could adversely affect food security.
IV. GREENHOUSE GAS EMISSIONS MITIGATION STRATEGIES FROM THE AGRICULTURE SECTOR AND ITS IMPACT

Several strategies are available for GHG emissions mitigation strategies in the agriculture sector. Some smallholder farmers are already practicing some mitigation strategies, but it is widespread. Therefore, investment to create awareness, scale, and incentivize the adoption of GHG mitigation strategies is crucial.

A. Demand-Side Greenhouse Gas Emissions Mitigation Strategies

Two important demand-side GHG emissions mitigation strategies include dietary changes and reducing food waste and loss.

1. Dietary Changes

Consuming food with a lower carbon footprint will reduce GHG emissions. Dietary changes would include consuming foods with a lower carbon footprint, such as consuming less meat, and substituting meat with fruit and vegetable and meat with a lower footprint, such as eggs, fish, and chicken. Dietary changes are an individual choice and cannot be imposed. Dietary intake is also a habit that has been developed over a period of time, and it is not easy to change in the short term. The United Nations Framework Convention on Climate Change (UNFCC) has suggested five ways to reduce GHG emissions from the supply side: buy locally, grow your own, avoid excessive packaging, eat less meat, and measure what you eat. The dietary changes would result in a mismatch between the supply and demand of food products, which may increase the price of a commodity with more demand and could contribute to inflation, food, and nutritional insecurity. However, dietary changes do not happen at an accelerated rate; hence, the farming community may have the time and capacity to adjust the food supply to meet the slowly changing food basket. The only cost for the dietary changes would come from the investment needed to create awareness and hence demand (change in the food basket) and provide inputs to farmers to change their production basket and, therefore, the supply.
2. Reducing Food Waste and Loss

Food loss and waste (FLW) contribute to GHG emissions. Hence, reducing FLW would contribute to the global communities’ effort to achieve net zero carbon emissions, reduce stress on land and natural resources, and improve food security. FLW happens at different stages, such as post-harvest, distribution, and consumption. Schemes and technology to reduce FLW at various stages would increase food availability and reduce GHG emissions. Scaling treatments, packaging, training, and technologies will help reduce a post-harvest loss. To reduce food loss in the distribution stage, cold storage, packaging, and efficient distribution system are some of the strategies. Awareness, storing correctly, preserving food, donating food, composting, innovative food labeling and dynamic pricing, buying ‘imperfect’ fruit and vegetable, use food-sharing apps are some strategies to reduce food waste. Besides contributing to net zero carbon emission, reducing FLW would increase food availability and hence the food security of millions. The only cost of reducing food loss is the investment required to scale the technology and improve awareness.

There are numerous agricultural production side GHG mitigation strategies. In this note, we have summarized a few common options based on the studies by Dickie et al. (2014).

3. Sustainable Intensification

Sustainable intensification of agriculture is an important strategy to reduce GHG emissions. In sustainable intensification, farmers produce the same output level, if not more, using fewer resources. It involves the use of high-yielding varieties, inputs, and practices, thus improving production. Sustainable intensification has a potentially positive impact on overall production. However, it would mean an increase in the cost of production, which may increase the food price, thereby adversely affecting poor families. Second, smallholder farmers, particularly the poor, vulnerable, and female farmers, may be unable to afford the technology. The third is the accessibility to the technology. Any disruption in the input supply chain could adversely affect production. Such negative shocks may lead to an increase in inequality and food and nutritional insecurity.
4. **Improving Nitrogen Management**

Nitrogen fertilizer is crucial for food production, but manufacturing and application could release N$_2$O, which is 300 times more powerful than CO$_2$ as a GHG. Therefore, the programs which test soil health conditions recommend the correct use of fertilizer, and its management is crucial for reducing the emission of N$_2$O. Further, the N$_2$O fertilizer application should be optimal, appropriately timed, use diagnostic tools to manage the rate, precision agriculture, and reduce the nitrogen loss process. Introduce crop rotation and intercropping with legume for natural nitrogen fixation. However, nitrogen management requires training, skills, and knowledge. Therefore, extensive and committed extension services are crucial for scaling this technique. The failure to properly implement nitrogen management could result in a decline in production, adversely affecting income, livelihood, and food security. Direct impact would also be the cost of implementing improved nitrogen management, which would increase the cost of food production and food price.

5. **Enteric Fermentation Management**

Enteric fermentation is a natural part of the digestive process in ruminant animals such as cattle, sheep, goats, and buffalo. Enteric fermentation releases methane gas, which is 28 times greater than CO$_2$ and lasts more than a 100-year period (Aldhafeeri et al. 2020). The strategy to reduce emissions from enteric fermentation in the agriculture sector includes improving the quality and digestibility of feed, providing supplements and additives to reduce methane, and optimizing the health and reproductive capacity of the herds (Ntinyari and Gweyi-Onyango 2021). Emissions intensities can vary significantly between different production units, even within the same production system. Interventions to reduce emissions often involve technologies and practices that improve production efficiency at the animal and herd level. These may include using higher-quality feed and better feed balancing to decrease enteric and manure emissions, as well as improving breeding and animal health to reduce the size of the unproductive portion of the herd and related emissions.

6. **Manure Management Practices**

Manure management practices that ensure the recovery and recycling of nutrients and energy contained in manure, and improvements in energy use efficiency along supply chains can
contribute further to mitigation. Sourcing low-emission intensity inputs (feed and energy in particular) is a further option. An FAO study in 2013 found that a 30% reduction of GHG emissions would be possible, for example, if producers in a given system, region, and climate adopted the technologies and practices which are currently used by the 10% of producers with the lowest emission intensity (Gerber et al. 2013).

7. Carbon Sequestration in Agricultural Systems
Farming practices result in the release of GHG into the atmosphere. Hence, it is crucial to practice farming methods that either reduce the release of GHG or sequester carbon. First, techniques such as minimum or no tillage, cover crop, contour farming, and contour strip cropping would decelerate organic matter decomposition and prevent soil erosion. Second, crop residue retention and biochar can be applied to increase carbon in the soil. Third, agroforestry or silvopasture can help in carbon capture and reduce soil erosion, besides providing additional cash income. Fourth, biodiversity restoration can also be used to increase soil organic carbon storage. However, carbon sequestration in agricultural systems requires enormous investment, and there are uncertainties that are associated with food production, and thus income and food security.

8. Methane Emissions from Rice Cultivation
Globally, rice is among the three most important cereals after corn and wheat, and it is the number one cereal in Asia. Rice farming contributes to global methane emissions, accounting for about 8% of global methane emissions in 1995. It is projected that this figure will decrease to 5.9% in 2030 (US-EPA 2012). Thus, reducing methane emissions from rice cultivation is an important step toward achieving net zero carbon by 2050. Three types of strategies are recommended: (i) improved irrigation patterns, such as mid-season drainage and controlled irrigation (Bloom and Swisher 2010; Hou et al. 2010; Yang et al. 2012); (ii) improved straw management, such as abandoning straw application to rice fields and straw compost (Liang et al. 2007; Koga and Tajima 2011); and (iii) improved nutrition management which includes proper fertilizer and manure application, timing fertilizer applications, mulching cover crops, and soil testing. Further, these strategies also have implications for the production and farmers’ capacity to implement the practices to reduce emissions from rice cultivation. On the one hand, a strategy like mid-season drainage can cause a rise in yield by 12%–14% (Wassmann et al. 2000). On the other hand, some
strategies also impose additional work for farmers, such as straw compost, and this limits farmers’ acceptance. Further alternate wetting and drying paddy farming could significantly reduce GHG emissions and save water usage, a scarce resource threatened by climate change.

9. Clean Energy Use in Agriculture
Farms use different energy sources, such as diesel, electricity, natural gas, gasoline, and liquefied petroleum gas, for irrigation, land management, drying, and transportation. To support the net zero carbon emission agenda, the agriculture and energy policy should support the farmers to switch from fossil fuels to clean fuels such as electricity. However, the availability of clean fuel and the cost poses a serious challenge for this transition. Moreover, limited battery capacity is also a serious obstacle.
V. CONCLUSION AND WAY FORWARD

Given the threat posed by climate change because of global warming, every country is committed to net carbon emissions. As the AFOLU sector contributes to a quarter of GHG emissions, AFOLU must do its part to reduce GHG emissions to help global communities attain net zero emissions and save the planet. Besides, it is also worth noting that agriculture is responsible for feeding 8.6 billion people in 2030, 9.8 billion in 2050, and 11.2 billion in 2100, while even today, 721.7 million are undernourished, and 2.2 billion are moderate to severely food insecure. Globally, agriculture contributes to about 14.5% of the GDP ($3.68 billion), and agricultural and food exports amount to $2.77 billion (8.5% of total exports), and it employs 883.3 million people. Therefore, unlike other sectors, climate change mitigation strategies in the agriculture sector should be cautiously implemented so that it does not disrupt the food product supply. Further, it should be supported by the government because there are 500 million small farm households globally that are poor and vulnerable.

There are several climate change mitigation strategies in the agriculture sector, such as dietary changes, reducing FLW, sustainable intensification, improving nitrogen management, enteric fermentation management, carbon sequestration in agricultural systems, methane emissions from rice cultivation, and transition to clean fuel use in agriculture. Some of these strategies improve yield and food security besides reducing GHG emissions, while other mitigation strategies could lead to a decrease in food production, leading to food insecurity, loss of income, and livelihood of rural households. Implementing these strategies requires enormous investment, which may increase food prices, hunger and poverty, and inequalities. In this line, globally coordinated efforts in targeting GHG hotspots is also an important factor in decreasing GHGs from AFOLU. Specifically, land-rich economies with extensive agriculture and large amounts of emissions from land use change, in particular deforestation and forest degradation, can reduce emissions limited trade-offs with food security.

It is also worth noting that agriculture is responsible for feeding 8.6 billion people in 2030, 9.8 billion in 2050, and 11.2 billion in 2100, while even today 721.7 million are undernourished and 2.2 billion are moderate to severely food insecure. Globally, agriculture contributes to about 14.
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Unlike other sectors, climate change mitigation strategies in the agriculture sector should be cautiously implemented so that it does not disrupt the food product supply. Further, it should be supported by the government as there are 500 million small farm households globally that are poor and vulnerable.
## Tables A1: Summary of net carbon emission

<table>
<thead>
<tr>
<th>Mitigation strategies</th>
<th>Synthetic Fertilizers</th>
<th>Rice Cultivation</th>
<th>Manure Applied to Soils</th>
<th>LULUCF</th>
<th>Livestock (includes manure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission (%)</td>
<td>6%</td>
<td>8.27%</td>
<td>2%</td>
<td>32%</td>
<td>46%</td>
</tr>
<tr>
<td>Emission (CO₂e AR5 in 2019)</td>
<td>503,144.8</td>
<td>587,400.95</td>
<td>152,862.01</td>
<td>2,543,565.37</td>
<td>3,620,850.92</td>
</tr>
</tbody>
</table>
| Mitigation strategies | • Adjusting fertilization and matching N supply with demand  
• Selecting fertilizer/amendment, such as ammonium-based fertilizer and sulfates  
• Use of nitrification inhibitors or slow-release fertilizers  
• Use of a leaf color chart or photometer for determining time-dependent N demand | • Tillage permutation  
• Selection of rice cultivars with low CH₄ emission and higher resource use efficiency  
• Modifying cropping regime, e.g., direct-seeded rice technology  
• Modifying irrigation patterns, such as mid-season drainage and intermittent drainage | • Soil incorporation of fermented manures  
• Application of fermented biogas residue  
• Compost application | • Protection and sustainable management of existing production forest areas  
• Conservation of existing protection forests  
• Reforestation  
• Planting long-rotation large timber trees  
• Planting fast-growing trees for lumber  
• Planting short-rotation pulpwood forest  
• Growing long-rotation non-timber product forest | • Increase productivity by feed  
• Animal health and reducing mortality  
• Reduced age at harvest, herd composition, reduced herds  
• Genetic selection  
• Quality of pastures |
<table>
<thead>
<tr>
<th></th>
<th>Synthetic Fertilizers</th>
<th>Rice Cultivation</th>
<th>Manure Applied to Soils</th>
<th>LULUCF</th>
<th>Livestock (includes manure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely positive impact of the mitigation practices</td>
<td>• Induce technology innovation in precision agriculture &lt;br&gt;• Co-benefit for soil quality and water &lt;br&gt;• Conservative use of chemical fertilizer also positively impacts farmers’ health &lt;br&gt;• Reduce costs by saving on fertilizer &lt;br&gt;• Use of nitrate inhibitors can also bring a 24%–31% rise in rice yield</td>
<td>• Saving labor force: direct wet seeding is an economically viable technique as opposed to the labor-intensive transplanting. &lt;br&gt;• Mid-season drainage and alternate wetting and drying can also cause a rise in yield by 12%–14%. &lt;br&gt;• The CH₄-reducing effect of mid-season drainage could substantially be enhanced in conjunction with direct wet seeding (46%–57% reduction). &lt;br&gt;• Reduced tillage also improves long-term land quality. &lt;br&gt;• Using manipulated irrigation requires machinery, which helps the mechanization of agriculture.</td>
<td>• Induce the development of a fermented manure supply chain</td>
<td>• Positive impact on land quality and ecology</td>
<td>• Reducing herd size would push for more productivity gains per unit, thus decreasing greenhouse gas emissions. &lt;br&gt;• Pursuing a suite of intensive and extensive reproductive management technologies. Increasing animal health will decrease the demand for replacement animals and decrease the costs of veterinary services per farmer. This is also related to one health goals</td>
</tr>
<tr>
<td>Synthetic Fertilizers</td>
<td>Rice Cultivation</td>
<td>Manure Applied to Soils</td>
<td>LULUCF</td>
<td>Livestock (includes manure)</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------</td>
<td>-------------------------</td>
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<td>-----------------------------</td>
<td></td>
</tr>
<tr>
<td>Ammonium sulfate is more expensive than urea based on N content, e.g., the costs are about twice as high in the Philippines. Recent meta-analyses indicated that the response of CH₄ emissions might be N rate dependent, where N addition at low rates tends to stimulate CH₄ emissions but can potentially mitigate CH₄ emissions at high N rates. Requirement of technological innovation could result in inequality between small farmers and large farmers.</td>
<td>Some traditional varieties can reduce emissions but have a very low yield. Direct wet seeding technology could result in a significant decline in yield by 28% compared with transplanting. In the meantime, direct seeding is only recommended in a system with high organic inputs. And the supply of water in the method may also incur costs, such as pumping.</td>
<td>Compost will reduce yield by 15%, significantly. Cause more labor and time cost</td>
<td>Reduce farm size. For some strategies, the period is quite long, on average, taking 40 years. For some strategies, the cost of conduction is high,</td>
<td>Indigenous climate-resistant breeds may be lost. Shortage of meat products Ensuring the quality of pasture will require community-based actions, which may be a moral hazard to some pastoralists. Improving productivity, and fertility and decreasing mortality in many parts of the world, especially in developing countries, is related to inadequate nutrition. Increasing the amount of nutrition will put pressure on crop systems and rangelands.</td>
<td></td>
</tr>
</tbody>
</table>

LULUCF = land use, land-use change, and forestry.

### Tables A2: Summary of low carbon agriculture strategies and their perceived impact

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Rationale</th>
<th>Economic impacts</th>
<th>Social impacts</th>
<th>Environmental impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Food security</td>
<td>Production cost</td>
<td>Export</td>
</tr>
<tr>
<td>Demand-side</td>
<td></td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Dietary changes</td>
<td>Consuming food with a lower carbon footprint</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reducing food waste and loss</td>
<td>Reduce stress on land and natural resources and improve food security.</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Supply-side</td>
<td></td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Sustainable intensification</td>
<td>Produce the same output level using fewer resources, such as high-yielding varieties, inputs, and practices</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Improving nitrogen management</td>
<td>Soil condition test, precision agriculture, crop rotation, intercropping.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Enteric fermentation management</td>
<td>Improving the quality and digestibility of feed, providing supplements and additives</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carbon sequestration in agriculture</td>
<td>Minimum or no tillage, cover crop, contour farming, and contour strip cropping; crop residue retention and biochar; agroforestry or silvopasture</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Reduce methane emissions from rice cultivation</td>
<td>Improved irrigation, rice straw management, and nutrient management</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clean energy use in agriculture</td>
<td>Switch from fossil fuels to clean fuels</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Author’s review and research
Note: positive sign for production cost means the … increase in production cost; positive sign for supply chain means
REFERENCES


