

Aryal, Jeetendra Prakash

Working Paper

Contribution of agriculture to climate change and low-emission agricultural development in Asia and the Pacific

ADB Working Paper, No. 1340

Provided in Cooperation with:

Asian Development Bank Institute (ADBI), Tokyo

Suggested Citation: Aryal, Jeetendra Prakash (2022) : Contribution of agriculture to climate change and low-emission agricultural development in Asia and the Pacific, ADB Working Paper, No. 1340, Asian Development Bank Institute (ADBI), Tokyo, <https://doi.org/10.56506/WDBC4659>

This Version is available at:

<https://hdl.handle.net/10419/272883>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/3.0/igo/>



ADB Working Paper Series

**CONTRIBUTION OF AGRICULTURE TO
CLIMATE CHANGE AND LOW-EMISSION
AGRICULTURAL DEVELOPMENT
IN ASIA AND THE PACIFIC**

Jeetendra Prakash Aryal

No. 1340
September 2022

Asian Development Bank Institute

Jeetendra Prakash Aryal is a consultant at the International Maize and Wheat Improvement Center, Texcoco, Mexico.

The views expressed in this paper are the views of the author and do not necessarily reflect the views or policies of ADBI, ADB, its Board of Directors, or the governments they represent. ADBI does not guarantee the accuracy of the data included in this paper and accepts no responsibility for any consequences of their use. Terminology used may not necessarily be consistent with ADB official terms.

Working papers are subject to formal revision and correction before they are finalized and considered published.

The Working Paper series is a continuation of the formerly named Discussion Paper series; the numbering of the papers continued without interruption or change. ADBI's working papers reflect initial ideas on a topic and are posted online for discussion. Some working papers may develop into other forms of publication.

The Asian Development Bank refers to "China" as the People's Republic of China and "Korea" as the Republic of Korea.

Suggested citation:

Aryal, J. P. 2022. Contribution of Agriculture to Climate Change and Low-Emission Agricultural Development in Asia and the Pacific. ADBI Working Paper 1340. Tokyo: Asian Development Bank Institute. Available: <https://doi.org/10.56506/WDBC4659>

Please contact the authors for information about this paper.

Email: jeetenaryal@gmail.com, jeetaryal@yahoo.no

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

© 2022 Asian Development Bank Institute

Abstract

The agriculture sector in Asia and the Pacific region contributes massively to climate change, as the region has the largest share of greenhouse gas (GHG) emissions from agriculture. The region is the largest producer of rice, a major source of methane emissions. Further, to achieve food security for the increasing population, there has been a massive increase in the use of synthetic fertilizer and energy in agricultural production in the region over the last few decades. This has led to an enormous rise in nitrous oxide (N₂O; mostly from fertilizer-N use) and carbon dioxide (mostly from energy use for irrigation) emissions from agriculture. Besides this, a substantial increase in livestock production for meat and dairy products has increased methane emissions, along with other environmental problems. In this context, this study conducts a systematic review of strategies that can reduce emissions from the agriculture sector using a multidimensional approach, looking at supply-side, demand-side, and cross-cutting measures. The review found that though there are huge potentials to reduce GHG emissions from agriculture, significant challenges exist in monitoring and verification of GHG emissions from supply-side measures, shifting to sustainable consumption behavior with regard to food consumption and use, and the design and implementation of regulatory and incentive mechanisms. On the supply side, policies should focus on the upscaling of climate-smart agriculture primarily through expanding knowledge and improving input use efficiency in agriculture, while on the demand side, there is a need to launch a drive to reduce food loss and waste and also to move towards sustainable consumption. Therefore, appropriate integration of policies at multiple levels, as well as application of multiple measures simultaneously, can increase mitigation potential as desired by the Paris Agreement and also help to achieve several of the United Nations' SDGs.

Keywords: agriculture, climate change, low-emission agriculture, Asia and the Pacific

JEL Classification: Q15, Q18, Q24, Q54

Contents

1.	INTRODUCTION.....	1
2.	AFOLU SECTOR GHG EMISSIONS IN ASIA AND THE PACIFIC	2
2.1	Emissions from Agricultural Activities.....	2
2.2	Emissions from Livestock	6
2.3	Emissions from Forest and Land Use	8
3.	MITIGATION POTENTIAL IN THE AFOLU SECTOR	8
3.1	Supply-Side Mitigation Measures	9
3.2	Demand-Side Mitigation Measures	11
3.3	Cross-Cutting Issues.....	13
4.	CURRENT POLICIES AND IMPLICATIONS FOR LOW-EMISSIONS AGRICULTURAL DEVELOPMENT	13
5.	CONCLUSION AND WAY FORWARD	15
	REFERENCES	16

1. INTRODUCTION

The Asia and Pacific region accounts for almost 60% of the total global human population¹ and have the largest agricultural production share. With large areas under rice cultivation, increased use of synthetic fertilizer, and increased livestock production, this region substantially contributes to global greenhouse gas (GHG) emissions from the agriculture sector.² Over the last five decades, the regional emissions from agriculture (crops and livestock) have increased by 144% (i.e., from 1,006 million tons of CO₂ equivalent emissions in 1961 to 2,459 million tons of CO₂ equivalent emissions in 2012).³ Moreover, the demand for livestock products is predicted to double in developing countries by the year 2050 due to population growth.

The contribution of agriculture, forestry, and other land use (AFOLU) constituted nearly 24% of total global GHG emissions in 2010 (IPCC 2007, 2014). Of the total global GHG emissions from the AFOLU sector in 2010, the share of Asia (i.e., 44%) was the largest (IPCC 2014). During the same period, the share of the AFOLU sector in total GHG emissions was relatively much larger in some Southeast Asian countries (e.g., 39% in Malaysia, 71% in Indonesia, and 97% in the Lao People's Democratic Republic) (USAID 2017). In addition, Asia includes the two most populous and emerging economies of the world, India and the People's Republic of China (PRC), where agriculture is still one of the major sectors contributing significantly to their gross domestic product (GDP) and also to total GHG emissions (Huang et al. 2019; Aryal et al. 2020b). Therefore, a clear understanding of GHG emissions from this sector and its transformation towards low-emissions development is essential to reduce GHG emissions and to avert the worst impacts of future climate change.

Another crucial issue with AFOLU sector is that it has to address the challenges of climate change and the growing demand for food, fiber, and wood simultaneously (Smith et al. 2013). Emissions reduction in this sector, therefore, needs to be achieved such that the production of food, fiber, and wood products that are essential for human consumption is not compromised. Looking into future human population growth, dietary changes due to economic growth, and climate challenges, it is estimated that the total demand for crops and grass could increase by 35% to 165% between 2010 and 2100 (Bijl et al. 2017). More importantly, the global food demand scenarios show a strong increase in animal-based products, primarily in developing countries (Bodirsky et al. 2015). Accordingly, there is a need to assess multiple factors, including demand, supply, and other institutional factors, while transforming the AFOLU sector into a low-emissions development pathway (Sutton, Erisman, and Oenama 2007; Smith et al. 2013; Pradhan et al. 2017, 2019; Zeng et al. 2020).

The AFOLU sector is one of the major emitters of non-CO₂ GHGs, mainly nitrous oxide (N₂O) and methane (CH₄) (Sirohi and Michaelowa 2007; Chhabra et al. 2013; Zhang et al. 2013, 2021). Given that existing agriculture production practices are more carbon intensive, there is a substantial potential to reduce GHG emissions from this sector if proper policies to promote the use of less carbon-intensive production methods are applied (Huppmann et al. 2018; IPCC 2018). Responsible consumption and preventing food waste and loss can contribute immensely to avoiding the GHG emissions from agriculture (United Nations Environment Programme 2021a). Therefore, agriculture is one of the critical sectors in the climate change solution.

¹ <https://asiapacific.unfpa.org/en/node/15207>.

² <https://www.fao.org/resources/infographics/infographics-details/en/c/271649/>.

³ <https://www.fao.org/resources/infographics/infographics-details/en/c/271649/>.

After 1990, the relative share of GHG emissions from the AFOLU sector to total GHG emissions (including emissions from energy, transportation, industry, etc.) has declined. This is primarily due to the more rapid increase in emissions from other economic sectors, such as energy, and transport, as well as the declining rate of deforestation (FAO/IFA 2001; FAO 2013). Against this backdrop, this study has the following objectives: (i) to examine the trend of GHG emissions in the agriculture sector, primarily agriculture and livestock; (ii) to review the potential to reduce GHG emissions from agriculture and livestock; and (iii) to analyze critically how this sector can contribute to both climate change mitigation and food security goals simultaneously. This study uses data and information from many national and international organizations, including the Food and Agriculture Organization (FAO), World Bank, Asian Development Bank (ADB/ADBI), United Nations Framework Convention on Climate Change (UNFCCC), and Intergovernmental Panel on Climate Change (IPCC). Further, this paper extensively reviews the varied literature on climate change and agriculture to examine the challenges and prospects of agricultural GHG mitigation in Asia and the Pacific region.⁴

The remaining sections of the study are outlined as follows. The second section highlights the current status of GHG emissions from the AFOLU sector in Asia and the Pacific region. The third section reviews the potential of GHG mitigation from the AFOLU sector, while the fourth section presents the critical analysis/reviews of climate change mitigation policies and measures taken to reduce GHG emissions at multiple levels, with a focus on attaining both low-emissions agriculture (i.e., in line with the SDG of climate action) and also improving food security (i.e., in line with SDG of reducing poverty). The last section concludes the study with some key recommendations.

2. AFOLU SECTOR GHG EMISSIONS IN ASIA AND THE PACIFIC

This section presents the total GHG emissions from the AFOLU sector over the period 1960–2018 in Asia and the Pacific, and compares this with other regions of the world. Overall, this section presents the importance of reducing GHG emissions from the AFOLU sector to achieve the Paris climate goals of keeping the temperature rise to below 2°C and averting the catastrophic impacts of future climate change.

2.1 Emissions from Agricultural Activities

2.1.1 Methane Emissions from Paddy Rice

Countries in Asia and the Pacific region are the major producers and consumers of rice globally. About 90% of global rice is produced in this region, and the region accounts for nearly 87% of global rice consumption.⁵ Of the top ten rice-producing countries globally, the first nine countries belong to this region. The PRC is the largest producer of rice globally (about 30%), which is followed by India (24%), Indonesia (7%), Bangladesh (7%), Viet Nam (5%), Thailand (4%), about 1% each in Myanmar, Philippines, and Japan. In 2018–2019, the PRC produced 148.5 million metric tons of rice, and India produced 116.48 million metric tons. As methane emissions from

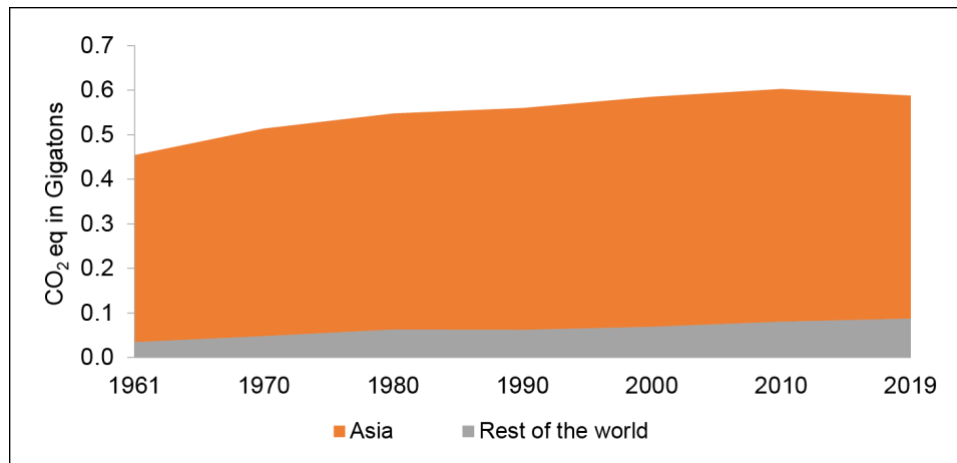
⁴ This study follows the definition set by the Asian Development Bank (ADB) while defining the region and countries under it.

⁵ <https://ricepedia.org/rice-as-a-crop/who-grows-rice>.

global rice cultivation account for almost 50% of all crop-related GHG emissions, Asia and the Pacific contribute significantly to global anthropogenic methane emission (Kritee et al. 2018).

Global warming may increase methane emissions from rice paddies in the future (van Groenigen, van Kessel, and Hungate 2013; Zhang et al. 2020). The PRC's share of GHG emissions from agriculture is thus expected to increase with higher methane emissions from paddy rice (Yue et al. 2017). Figure 1 presents the methane emissions from rice production (in CO₂eq) in Asia and the rest of the world. It shows that about 87% of the methane emissions from rice cultivation come from Asia.

Figure 1: Emissions from Rice Cultivation in Asia and the Rest of the World

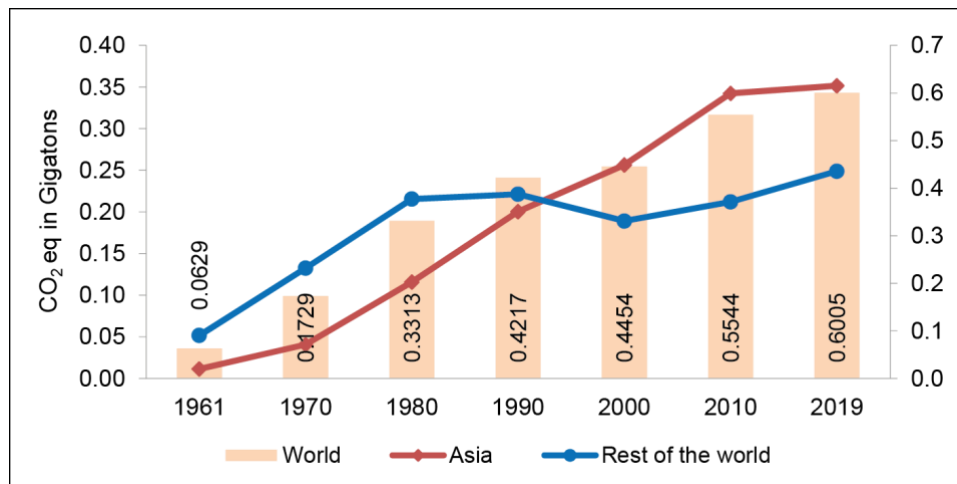


Source: Author's compilation from FAOSTAT.

2.1.2 Emissions from Inorganic Fertilizer Use

Inorganic fertilizer use is accountable for almost 30% of N₂O emissions from the agriculture sector (IPCC 2014). A large quantity of GHGs, including CO₂, CH₄, and N₂O, are also emitted during the manufacturing and transportation of inorganic fertilizer (Tian et al. 2020; Cui et al. 2021; Liang et al. 2021). In total, agriculture contributes around 60% of global N₂O emissions (Foley et al. 2011). As excessive use of inorganic fertilizer in agriculture is a major source of N₂O emissions from agriculture (Lu and Tian 2017; Aryal et al. 2021a), its proper use is essential for achieving climate goals stated in UN SDGs and the target of the Paris Agreement to remain below a 2°C warming threshold.

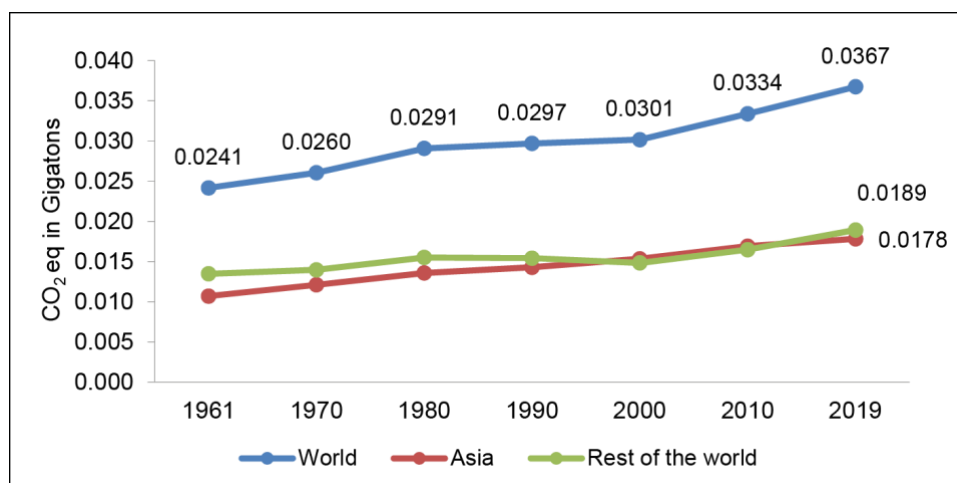
Emissions from inorganic fertilizer vary with management factors and variations in climatic and edaphic factors (Chen et al. 2015). The loss of applied nutrients into the environment during agricultural production results in fertilizer-induced N₂O emission (Sutton, Erismann, and Oenema 2007). Almost 60% of the nitrogen pollution that emanates from crop production is related to nitrogen fertilizer application (Sapkota et al. 2018). In Asia and the Pacific, India and the PRC are the largest emitters, as they are responsible for about 70% of total fertilizer-related N₂O emissions (Lassaletta et al. 2014). The GHG emissions (CO₂eq) from synthetic fertilizer increased by 9.5 times from 0.0629 gigatons in 1961 to 0.6005 in 2019, primarily due to an increase in the use of synthetic fertilizer in Asia. Until 1990, GHG emissions from synthetic fertilizer in Asia were lower than those in the rest of the world, but after 1990, emissions were greater than in the rest of the world (see Figure 2).

Figure 2: Synthetic Fertilizer Emissions in Asia and the Rest of the World

Source: Author's compilation from FAOSTAT.

2.1.3 Emissions from Burning of Crop Residues

Burning crop residues on farms contributes substantially to CO₂ emissions and air pollution in many countries of Asia (Streets et al. 2003; Lohan et al. 2018; Wu et al. 2020; Bajracharya, Mishra, and Maharjan 2021; Shen et al. 2021). In 2017–2018, nearly 116 million tons of crop residue were burned in India, which emitted 176.1 Tg of CO₂, 313.9 Gg of CH₄, and 8.14 Gg of N₂O (Venkatramanan et al. 2021). In 2003, it was estimated that about 110 Tg of crop residue were burned in the PRC, which is almost 44 % of all crop residues burned in Asia in that year (Streets et al. 2003). GHG emissions from residue burnings of rice, wheat, and corn comprise more than 85% of the total crop residue burned (Zhang et al. 2019). Figure 3 shows that emissions from crop residue burning increased from 0.0241 gigatons to 0.0367 gigatons over the last six decades, and the trend of growth is comparatively similar in Asia and the rest of the world.

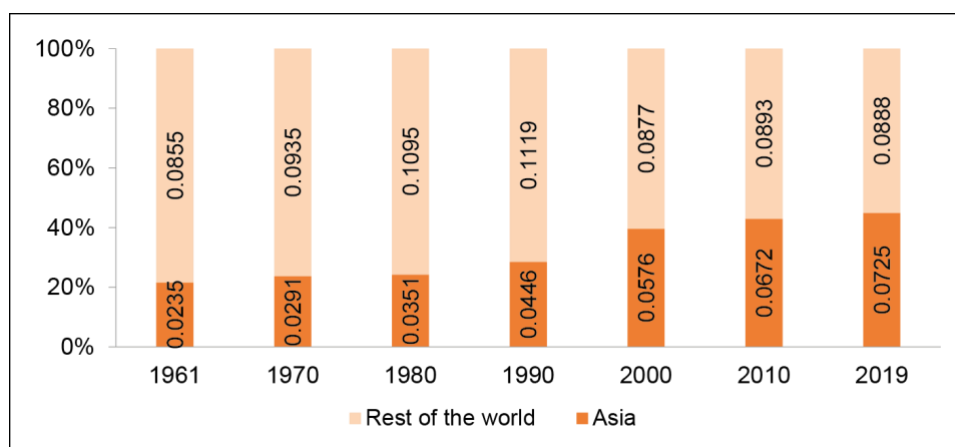
Figure 3: Emissions from Crop Residue Burning in Asia and the Rest of the World

Source: Author's compilation from FAOSTAT.

2.1.4 Emissions from Manure Left on Pasture and Manure Management

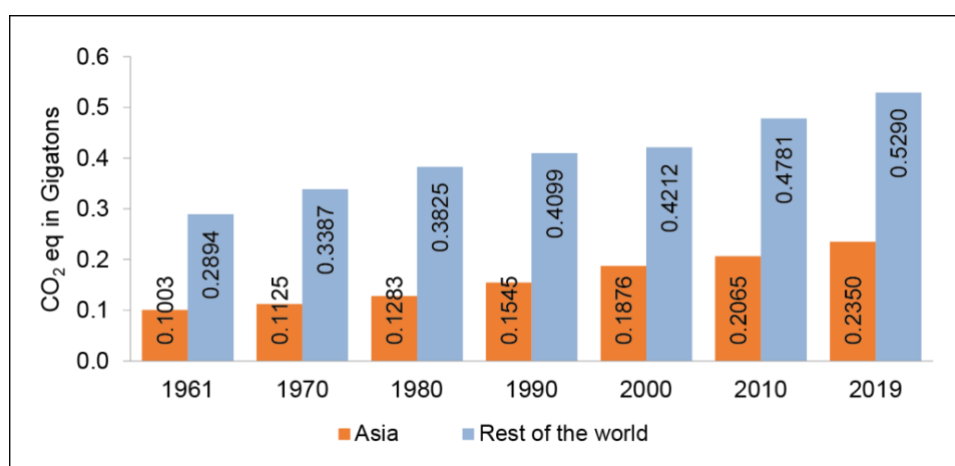
Manure left on pasture and manure management emit large amounts of methane and N₂O, which jointly account for almost 18% of total agricultural emissions (almost equivalent to the emissions from synthetic fertilizer use in agriculture⁶). The emissions factors and inventory from manure management differ by region and management system, due to the multitude of microbial activities in the manure environment. For instance, in India, methane emissions from bovine manure management varied from 0.8 to 3.3 kghead⁻¹year⁻¹, while the N₂O emissions varied from 3 to 11.7 mghead⁻¹year⁻¹ from solid storage of manure (Gupta et al. 2007). In Asia and the Pacific region, manure management has become a major problem due to more intensive production of livestock (Petersen et al. 2013).

Figure 4: Emissions from Manure Applied to Soil in Asia and Rest of the World



Source: Author's compilation from FAOSTAT.

Figure 5: Emissions from Manure Left on Pasture in Asia and the Rest of the World



Source: Author's compilation from FAOSTAT.

⁶ <https://www.fao.org/resources/infographics/infographics-details/en/c/271649/>.

Figures 4 and 5 show emissions from manure applied to soil and manure left on pasture, respectively, in Asia and the rest of the world. Manure applied to soil increased from 0.11 gigatons in 1961 to 0.16 gigatons in 2019, while the share of application in Asia increased from 22% to 45%. Emissions from manure left on pasture increased from 0.39 gigatons in 1961 to 0.76 gigatons in 2019, and Asia is responsible for 69% of the total emissions from manure left on pasture.

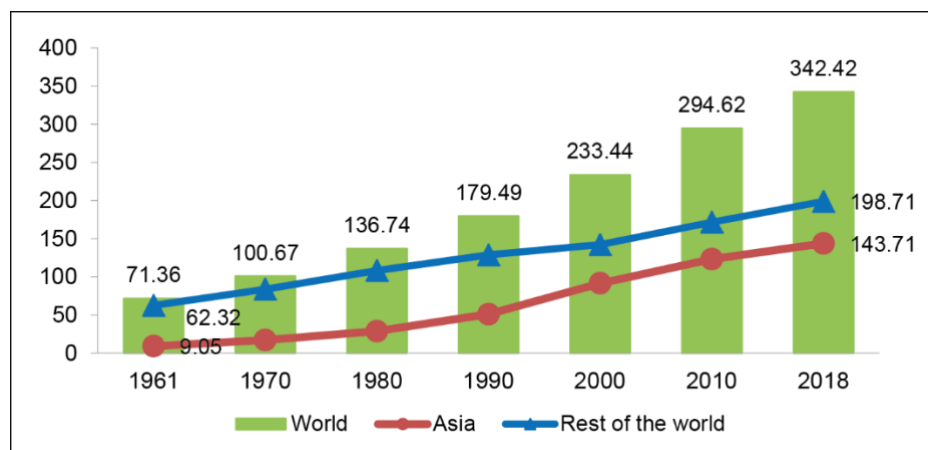
2.1.5 Emissions Due to Irrigation and Other Management Practices

Irrigation, input management practices, and energy use in farm operations affect the GHG emissions from agricultural production. Have the second largest quantity of irrigated land in the world, GHG emissions from irrigation in the PRC significantly influence the global mitigation potential. In 2010, it was estimated that agricultural irrigation in the PRC emitted 36.72–54.16 Mt of CO₂ equivalent emissions (Zou et al. 2015). Energy used for irrigation is responsible for about 70% of total emissions from energy activities in the agriculture sector (Wang et al. 2012; Zou et al. 2015). Nevertheless, irrigation strategies matter a lot for GHG emissions (Islam et al. 2020; Sapkota et al. 2020). Flood irrigation is the major source of methane emissions from rice, indicating that reduced irrigation would be an effective way to lower methane emissions. Conversely, the rate of CO₂ emissions is usually higher under low irrigation, whilst most studies found low N₂O emissions in continuously flooded irrigation (Sapkota et al. 2020). Between 1980 and 2015, the intensification of agriculture increased food production in India by 2.5 fold while it increased GHG emissions threefold (Benbi 2018).

2.2 Emissions from Livestock

Livestock constitutes an integral component of the agriculture sector in the Asia and Pacific region, though in varying degrees. It is also a major source of GHGs emissions. In East Asia, annual methane emissions from livestock in 2019 was 13.22 Tg, accounting for an increase of 231% since 1961 (Zhang et al. 2021). A major reason behind the increasing emissions from livestock is the rising demand for meat products in Asia over the past six decades. Figure 6 shows that meat production increased 4.8 times from 71.4 million tons in 1961 to 342.4 million tons in 2018. The share of Asia in global meat production increased from 12.7% to 42% during the same period.

Figure 6: Meat Production in Asia and the Rest of the World
(in million tons)



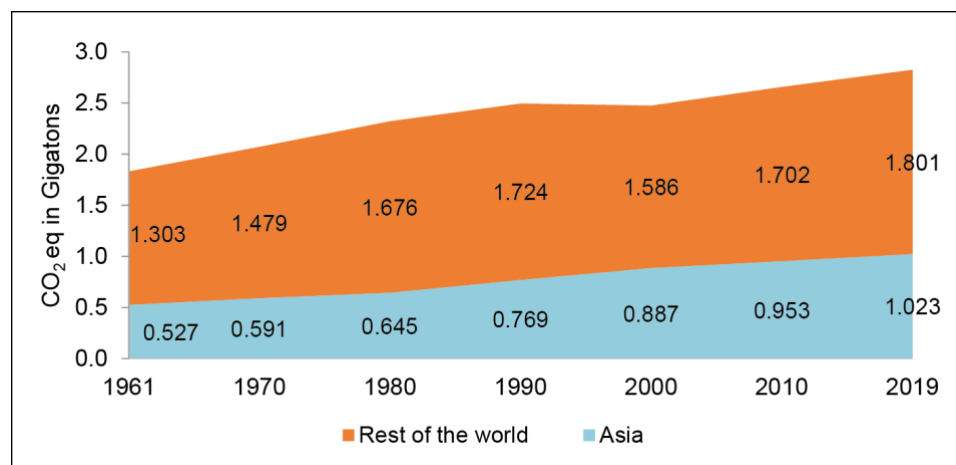
Source: Author's compilation from FAOSTAT.

2.2.1 Emissions from Enteric Fermentation

Emissions from enteric fermentation vary by region, age group, and animal breed. Methane emissions due to enteric fermentation is higher among ruminant livestock (cattle, buffalo, sheep, and goats) (Chang et al. 2019). In India, of the total methane emissions from livestock in 2003, enteric fermentation constituted nearly 91% (Chhabra et al. 2013). Cattle (55%) and buffalo (37%) are the major contributors to GHG emissions, and enteric CH₄ constituted almost 90% of the total GHG emissions from livestock (Patra 2017).

Figure 7 compares the emissions from enteric fermentation between Asia and the rest of the world. The emissions from enteric fermentation increased 1.5 times from 1.8 gigatons in 1961 to 2.8 gigatons in 2019, and the share of Asia in global enteric fermentation emissions increased from 29% to 36%.

Figure 7: Emissions from Livestock Enteric Fermentation in Asia and the Rest of the World



Source: Author's compilation from FAOSTAT.

2.2.2 Feed Management

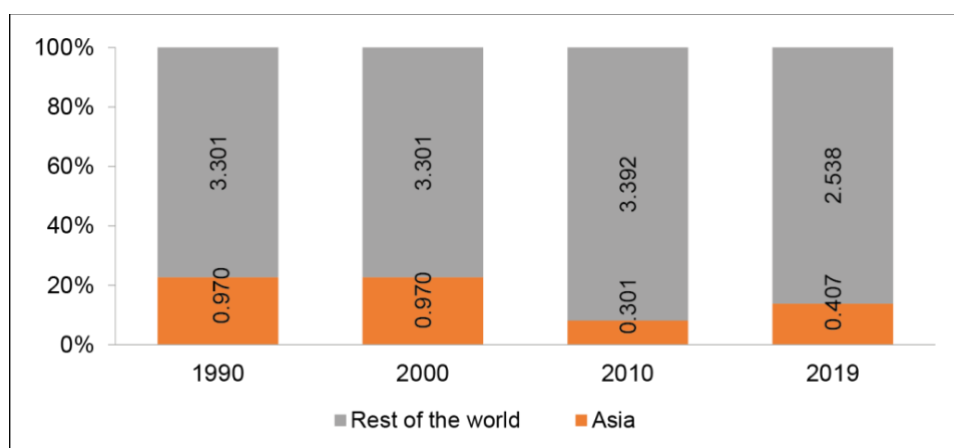
Feed efficiency is one of the key drivers of productivity, resource use, and GHG emissions intensities from the livestock sector; however, it varies largely across production systems, animal types, and animal products (Herrero et al. 2013). Therefore, application of better feed management measures in forage quality, feed processing, and precision feeding can help reduce methane emissions and prevent excessive nitrogen release into the environment by the livestock sector (Gerber et al. 2013).

Lower quality feeding practices explain why Asia has the highest share of enteric methane emissions compared to other regions in the world. For instance, the enteric methane emissions of producing nearly 46.3% of ruminant milk and meat energy by North America, Eastern and Western Europe, and the non-EU former Soviet states in 2005 was only 25.5%. Conversely, in the same year, Asia, Africa, and Latin America produced 47.1% of ruminant meat and milk energy, which was associated with 69% of enteric methane emissions (O'Mara 2011). The livestock sector has a large influence on global nitrogen flows and emissions, as it currently emits one-third of current human-induced nitrogen emissions (Uwizeye et al. 2020).

2.3 Emissions from Forest and Land Use

Deforestation and other land-use changes due to agricultural practices are projected to contribute about 17% of total global GHG emissions (IPCC 2007, 2014). Forest and other land uses were responsible for about 12% of emissions from 2000 to 2009 (IPCC 2014). Analyzing satellite observations of gross forest cover loss and a map of forest carbon stocks across tropical regions, it was estimated that 0.81 petagrams of carbon emissions per year are due to deforestation (Harris et al. 2012). Moreover, in the 1990s, the highest level of deforestation occurred in insular Southeast Asia, especially in humid tropical regions (Miettinen, Shi, and Liew 2011). Given that the forest ecosystems in insular Southeast Asia are an area with exceptionally high biodiversity and also with a large amount of carbon stored in forested peat lands, deforestation in this region has severe consequences for global GHG emissions and climate change. Figure 8 shows the emissions from net forest conversion to other land use in Asia and the rest of the world since 1990.

Figure 8: Emissions from Net Forest Conversion to Other Land Use in Asia and Rest of the World



Source: Author's compilation from FAOSTAT.

3. MITIGATION POTENTIAL IN THE AFOLU SECTOR

The AFOLU sector has a large potential to mitigate GHG emissions and also to sequester carbon in soils. To realize these potentials, we need to adopt improved technology in the farming system (Malla et al. 2005; Kahrl et al. 2010; Aryal et al. 2015; Hasegawa and Matsuoka 2015; Pradhan, Chaichaloempreecha, and Limmeechokchai 2019); better management of inputs such as water, energy, and fertilizer (Zhang et al. 2013); improved irrigation methods (Wang et al. 2012); better livestock management (Mottet et al. 2017; Enahoro et al. 2019); and better institutional arrangements (Aryal et al. 2020b). In the agricultural sector, livestock manure and enteric fermentation represent about 32% of emissions, and rice cultivation produces 8% of global anthropogenic emissions (United Nations Environment Programme 2021b). In addition to these supply-side mitigation measures in the AFOLU sector, the use of demand-side mitigation measures is also crucial if the target of keeping the temperature rise below 2°C is to be achieved. To achieve low-emissions agricultural development, it is essential to address the root cause of agricultural emissions, particularly the rising

demand for carbon-intensive agricultural products (Dickie et al. 2014). Both supply- and demand-side GHG mitigation measures in the agriculture sector are discussed below.

3.1 Supply-Side Mitigation Measures

3.1.1 Mitigation Options in Agriculture

The agriculture sector has a large potential to mitigate GHG emissions by employing efficiency-enhancing agricultural practices (Smith et al. 2008; Aryal et al. 2020b; Kiran Kumara, Kandpal, and Pal 2020). Conservation agriculture (CA), improved agronomic practices, appropriate nutrient management, reduced tillage and residue management, water management, and agro-forestry are some of the key management practices that have GHG mitigation potential (IPCC 2007).

Conservation Agriculture

Conservation agriculture (CA) is an agricultural practice that combines reduced or zero tillage with permanent soil cover and crop diversification, including legumes.⁷ Unlike conventional, tillage-based agricultural practices, CA contributes to GHG mitigation by increasing soil organic carbon (SOC) (Lal 1997) and also improving soil quality parameters compared to conventional agriculture (Page, Dang, and Dalal 2020). Yet, some studies report carbon sequestration potential under CA is much less than what is usually claimed (Powlson et al. 2016, 2014).

Practicing conventional, tillage-based rice-wheat cropping systems on one million hectares of the Indo-Gangetic Plains emits about 29 Mg CO₂yr⁻¹, while it would be 14 Mg CO₂yr⁻¹ if CA is applied to the same area of land (Grace et al. 2003). Grace et al. (2012) projected that following zero tillage in the rice-wheat system of India could sequester 44,100 Gg of carbon over 20 years. Shifting from a conventional, tillage-based wheat production system to a zero-tillage-based wheat production reduces GHG emissions by 1.5 Mg CO₂eq ha⁻¹ yr⁻¹ (Aryal et al. 2015), and following zero tillage with residue retention helps reduce GHG emissions from residue burning (Jat et al. 2021). Nevertheless, regional climate variation largely determine the carbon sequestration potential of CA (Sun et al. 2020). Residue retention in the CA system is crucial to SOC concentration (Zhang et al. 2014).

Site-Specific Nutrient Management

Soil nutrient management is a crucial factor associated with the GHG emissions from agriculture and, thus, has massive mitigation potential (Lenka et al. 2017). Proper use of chemical fertilizers is crucial to nutrient management. Studies on the North China Plain show that both cumulative and yield-scaled N₂O emissions from maize fields increase exponentially if fertilizer-N is applied above the optimum rate (Song et al. 2018). Site-specific nutrient management (SSNM) in rice helps reduce global warming potential by 2.5%, or about 12%–20% in wheat (Sapkota et al. 2021). Following nutrient expert (NE)-based fertilizer recommendations in the rice-wheat cropping system, India could produce more food with less synthetic fertilizer and reduce GHG emissions by about 5.34 Mt CO₂eq per year (Sapkota et al. 2021). In the northeast PRC, the adoption of the NE system in maize production has reduced reactive nitrogen losses by 47% and GHG emissions by 37.2% (Wang et al. 2020). Similarly, the adoption of NE in rice production has reduced reactive nitrogen losses by 10.1% and GHG emissions by 6.6% (Wang et al. 2020).

⁷ <https://www.fao.org/conservation-agriculture/overview/what-is-conservation-agriculture/en/>.

Laser Land Leveling

Laser land leveling (LLL) helps reduce irrigation water loss and thus energy use for irrigation. Compared to traditionally leveled and unleveled fields, LLL helps reduce total irrigation duration significantly—by about 70 h ha⁻¹ rotation⁻¹ (Aryal et al. 2015). Further, energy use for irrigation in the rice-wheat system is much lower in laser-leveled fields (almost 754 kWh less) compared to traditionally leveled fields (Aryal et al. 2015). Given the coal-dependent electricity generation system in India, LLL reduces about 0.15 Mg of CO₂eq of emissions per year if the rice-wheat system is followed in a hectare of land (Gill 2014). A study of Cambodia, the Philippines, Thailand, Viet Nam, and India showed that LLL saved energy of 3.0–6.9 GJ ha⁻¹, thereby decreasing GHG emissions by 1,151–1,186 Kg CO₂eq ha⁻¹ in rice production (Nguyen-Van-Hung et al. 2022).

Water Management

Water management practices like alternate wetting and drying (AWD) in rice, soil-water potential scheduling in crops, and alternative irrigation methods such as drip and sprinkler irrigation are crucial in mitigating GHG emissions from agriculture, along with maintaining production under water stress (Sibayan et al. 2018; Sapkota et al. 2020; Enriquez et al. 2021). At the global level, flooded rice accounts for approximately 12% of anthropogenic emissions from agriculture (Wassmann, Hosen, and Sumfleth 2009; Richards and Sander 2014). Although studies have shown variations in the reduction of methane emissions under AWD practices, most studies agree that it reduces methane emissions. For example, IPCC (2006) reports a 48% reduction in methane emissions under AWD practices; Richards and Sander (2014) report that it can be between 20% and 70%; and LaHue et al. (2016) showed that it reduces methane emissions by 60%–87%.

Soil and water potential (SWP) scheduling is another option to reduce N₂O and methane from rice production. Compared to AWD, seasonal N₂O emissions were significantly lower in the broadcast-SWP (by 64%) and liquid fertilizer-SWP (by 66%) treatments (Islam et al. 2020). Also, SWP reduced methane emissions by 34%. Water management and irrigation intensity considerably affect the GHG emissions from intensive vegetable production in the Republic of Korea (Kim et al. 2014). The global warming potential per unit of pepper fruit yield was reduced by almost 50% in a treatment that maintains soil water potential at 50 kPa through controlled irrigation. In the North China Plain, Mehmood et al. (2021) found that irrigation methods and irrigation scheduling levels affect cumulative CO₂ and methane emissions. Drip irrigation at 60% field capacity reduces global warming potential by 9% compared to the other irrigation methods examined (Mehmood et al. 2021).

Agroforestry System

The agroforestry system (AFS) contributes to GHG mitigation by storing carbon aboveground in the form of biomass and belowground in the form of soil organic carbon (Dhyani et al. 2020; Mayer et al. 2022). Compared to coniferous species, an AFS with broadleaf tree species sequesters more soil organic carbon (Mayer et al. 2022). Although the carbon sequestration potential of AFS can be improved and can vary by climatic zones, its basic potential is estimated to be 0.29–15.21 Mg ha⁻¹ year⁻¹ (Dhyani et al. 2020). The mitigation potentials of AFS in India and Pakistan are 25.4 MgC ha⁻¹ and 29.7 MgC ha⁻¹, respectively (Sathaye et al. 2001). Under the AFS, carbon sequestration aboveground is between 0.23 and 23.55 Mg C ha⁻¹ yr⁻¹ and belowground is from 0.03 to 5.08 Mg C ha⁻¹ yr⁻¹ (Kumar and Kunhamu 2021).

3.1.2 Mitigation Options for Livestock

Improving livestock management can reduce the emissions intensity of livestock production (Nugrahaeningtyas et al. 2018). Feed management, genetics, and animal health improvements; improved grazing management practices; and the use of energy-efficient livestock shelters are among the major strategies to reduce GHG emissions from livestock (Thornton and Gerber 2010; Thornton and Herrero 2010). Given that the livestock sector emits more GHG to the atmosphere than the entire global transportation sector (Gerber and FAO 2013; Rojas-Downing et al. 2017), improved livestock management is essential to reduce its environmental footprint (Tullo, Finzi, and Guarino 2019).

Feed management substantially reduces GHG emissions from livestock (Ouatahar et al. 2021). Nutrition and feeding approaches can reduce methane per unit of energy-corrected milk by 2.5%–15% (Knapp et al. 2014). Improved fodder management, along with better herd health and genetics, reduces methane intensity by almost 14.6%–43.2% and also increases milk yield (Habib and Khan 2018). In the case of lactating dairy cows, diet management can reduce enteric methane emissions by almost 60% (Roque et al. 2019). Similarly, a combination of hydrolysable tannin and condensed tannin at a concentration of 1.5% dietary dry matter helps reduce methane emissions from beef cattle without negatively affecting animal performance (Aboagye et al. 2018). Table 1 provides some estimates of methane emissions from improved feeding practice, dietary additives and animal breeding.

Table 1: Methane Emissions from Improved Livestock Management

Mitigation Potential	Dairy Cows	Beef Cattle	Sheep	Dairy Buffalo	Non-diary Buffalo
Improved feeding practice	0.04	0.02	0.02	0.04	0.02
Dietary additives	0.01	0.01	0.0005	0.01	0.002
Animal breeding	0.01	0.01	0.001	0.01	0.02

Note: all figures are in ($\text{MgCO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$).

Source: (Smith et al. 2007).

3.1.3 Mitigation Options in Forest and Other Land Use

Afforestation, reducing energy use in forestry, and better land-use planning are important GHG mitigation strategies. Forster et al. (2021) have shown that forest growth rate is crucial in determining cumulative mitigation. Non-forested degraded lands and forested degraded lands in India account for 93.68 mha and 35.89 mha, respectively, so there is a massive potential to sequester increased CO_2 through massive afforestation programs. For instance, converting 40 mha of the surplus degraded lands into forest area can mitigate approximately 3.32 Gt in the next 50 years (Singh and Lal 2000). Afforestation also improves soil organic carbon storage and reduces soil erosion (Shi et al. 2015). Edaphic properties and microbial attributes induced by land-use change can, however, influence the level of GHG mitigation (Chen et al. 2021).

3.2 Demand-Side Mitigation Measures

3.2.1 Reduce Food Loss and Waste

Reducing food loss and waste (FLW) can substantially help reduce GHG emissions from agriculture (FAO 2018). About 40% of all food produced is not consumed by human beings and is either lost or wasted. FLW accounts for about 10% of global GHG

emissions from food production (United Nations Environment Programme 2021a). Approximately 1.2 billion tons of food are lost on farms, while about 931 million tons are wasted at the retail and consumption stages.⁸

A recent study by Xue et al. (2021) has shown that nearly 27% of food annually produced is lost or wasted in the PRC. Their study also claims that the land, water, carbon, nitrogen, and phosphorus footprints associated with total FLW in the PRC is almost equivalent to the total carbon footprint of the United Kingdom. In 2013, South and Southeast Asia had the highest FLW-associated GHG emissions. Compared with other regions of the world, industrialized Asia has the highest FLW and the highest FLW-associated GHG emissions (Guo et al. 2020). More interestingly, the household-level average food waste ($\text{kgcapita}^{-1}\text{year}^{-1}$) is highest among the lower-middle-income countries ($91 \text{ kgcapita}^{-1}\text{year}^{-1}$), followed by high-income countries ($79 \text{ kgcapita}^{-1}\text{year}^{-1}$) and upper middle-income countries ($76 \text{ kgcapita}^{-1}\text{year}^{-1}$) (United Nations Environment Programme 2021a). This shows that reducing FLW is one of the possible alternatives to reduce GHG emissions. For this, there is a need to develop specific programs related to consumer awareness about the adverse impacts of FLW on overall human society.

3.2.2 Reduce Demand for Livestock Products or High Carbon-Intensity Food

Increasing demand for livestock products is one of the reasons behind the higher GHG emissions from agriculture. The contribution of livestock to total global GHG emissions is about 10% of global GHG emissions, and this reaches almost 18% if lifecycle assessment (i.e., including emissions occurring at input levels such as feed production, processing, and land-use change, and emissions related to processing and transportation) is followed (Gerber et al. 2011; O'Mara 2011; FAO 2013). For instance, as livestock units in the PRC have more than tripled in the last three decades, the GHG emissions from this sector have almost doubled, and nitrogen losses to watercourses have tripled (Bai et al. 2021). Such a massive change in the PRC has a global impact on GHG mitigation (Yue et al. 2017; Bai et al. 2021; Si, Aziz, and Raza 2021). As the production of a kilogram of cattle meat emits nearly 45 times more GHGs than producing the same amount of chicken meat,⁹ shifting from high- to low-carbon intensive food can substantially reduce GHG emissions. Although it is difficult to apply regulatory mechanisms to consumption behavior, it is possible to disseminate knowledge of how carbon-intensive food can deteriorate our environment and our existence. Some incentive mechanisms for the consumption of low-carbon intensive food can also be applied.

3.2.3 Reduce Emissions from Overall Food System

Existing food systems are accountable for one-third of global anthropogenic GHG emissions, so it is crucial to modify these food systems to reduce emissions (Clark et al. 2020). In 2015, food-system emissions was estimated to be 18 Gt CO_2eq globally (i.e., 34% of global GHG emissions); of total emissions, 71% was from agriculture and land-use change, and the remaining 29% was from supply chain activities (Crippa et al. 2021). Household consumption patterns and level of economic progress will largely determine the GHG emissions from the future food system. Therefore, lifestyle

⁸ <https://www.worldwildlife.org/press-releases/over-1-billion-tonnes-more-food-being-wasted-than-previously-estimated-contributing-10-of-all-greenhouse-gas-emissions>.

⁹ <https://www.fao.org/3/cb1329en/online/cb1329en.html#chapter-4>.

changes, including changes in food habits, are crucial to complement low-emissions development (Bjelle et al. 2021).

3.3 Cross-Cutting Issues

3.3.1 Agricultural Subsidies

The agriculture sector annually receives around US\$600 billion in government support worldwide (Laborde et al. 2021). Although agricultural subsidies can have heterogeneous effects on agricultural emissions (Guo et al. 2021), it can also incentivize high-emissions farming systems. Beef, dairy, and rice are three major agricultural products that account for over 80% of agricultural GHG emissions. In many Asian countries, the production of these emissions-intensive commodities is supported by subsidies and other government supports (Badiani, Jessoe, and Plant 2012; Aryal et al. 2015). For instance, the fertilizer subsidy policy has led to unbalanced fertilizer use in India, thereby increasing N₂O emissions from agriculture (Some, Roy, and Ghose 2019; Aryal et al. 2021a). Hence, reducing GHG emissions from agriculture requires careful management of subsidies and taxes on agricultural inputs (Luo et al. 2017).

3.3.2 Better Spatial Targeting and Informed Policy

Improved spatial targeting is essential to achieve GHG mitigation in agriculture. In mitigating soil N₂O emissions, accurate assessments of crop-specific mitigation potentials are crucial. Using modern technology such as geo-referenced-based field observations helps estimate precise emissions factors and design better management practices (Cui et al. 2021). About 30% of direct soil emissions of N₂O can be mitigated without compromising food production; however, almost 65% of this potential could be achieved in only 20% of the global harvested land area, which thus requires a spatially targeted policy for GHG mitigation (Cui et al. 2021, 2014; Tian et al. 2020).

3.3.3 Equitable Access to Improved Technology

Gender, caste, and class play important roles in defining the adoption of improved technologies that are crucial to GHG mitigation in agriculture (Paudyal et al. 2019; Aryal et al. 2020a, 2021b; Bryan et al. 2021). Regional disparity in clean technology has also been raised as a critical issue at the COP26. Transferring innovative technologies across countries to enhance the efficient use of agricultural resources, while acknowledging the need for policies that benefit both climate and social-environmental factors, can contribute largely to GHG mitigation initiatives in agriculture (Smith et al. 2007b, 2013; Gołasa et al. 2021).

4. CURRENT POLICIES AND IMPLICATIONS FOR LOW-EMISSIONS AGRICULTURAL DEVELOPMENT

Most countries have now acknowledged the critical role of the agriculture sector in mitigating GHG emissions and in achieving the target of keeping the global temperature rise below 2°C, as well as in attaining several SDGs. This has increased the scope for low-emissions agriculture in Asia and the Pacific region. In their nationally determined contributions submitted to the United Nations Framework on Climate Change (UNFCCC), many countries have mentioned the agricultural mitigation potential. This has been reflected in national climate policies also. There has been a massive transformation in the consideration of the AFOLU sector in international

climate change negotiations and priorities. In COP11 in 2005, the UNFCCC agreed to initiate a program to explore a variety of policy approaches for reducing emissions from deforestation and degradation (REDD), which was further strengthened in COP13 by considering REDD as an option to GHG mitigation in developing countries (Corbera, Estrada, and Brown 2010). Although the Bali Action Plan adopted at UNFCCC COP13 in 2007 acknowledged low-emissions development strategies through the concept of nationally appropriate mitigation actions (NAMAs), it did not mention agriculture specifically, and the NAMAs were discussed more as strategies to attain sustainable development (Wilkes, Tennigkeit, and Solymosi 2013). Issues related to GHG mitigation in agriculture were considered as an agenda for climate action only in COP17 in Durban. The UNFCCC's Subsidiary Body for Scientific and Technological Advice (SBSTA) included agriculture as an important sector for GHG mitigation in COP17, which was further defined in COP21 in Paris, and then in COP23 (Aryal et al. 2020b). Finally, COP23 in Bonn proved to be a milestone in prioritizing agriculture in climate action. It managed to establish the Koronivia Joint Work on Agriculture to design new strategies or address global climate change adaptation and mitigation actions in the agriculture sector (UNFCCC 2017).

Over the years, many countries in Asia have included GHG mitigation in agriculture in their climate plans, and some have developed NAMAs that explicitly mention GHG mitigation measures in agriculture sectors (Wilkes, Tennigkeit, and Solymosi 2013). For example, Cambodia included mitigation from the agriculture sector in its National Green Growth Roadmap of the year 2009; the PRC and the Republic of Korea followed with the National Climate Change Program (2007–2010) and National Strategies for Green Growth (2009), respectively. The Thai Rice NAMA is one of the major initiatives to reduce GHG emissions from rice production in Thailand.¹⁰ As rice farming in Thailand accounts for almost 60% of its total emissions from agriculture (i.e., the fourth largest emitter of rice-related GHG emissions globally), a shift from conventional to low-emissions rice farming could substantially reduce GHG emissions from rice in Thailand. Introduction of climate-smart rice farming in Viet Nam,¹¹ soil health card schemes for crop nutrient management in India,¹² and zero increases in chemical fertilizer use in 2020 in the PRC (Ji, Liu and Shi 2020) are some of the crucial steps taken by Asian nations toward GHG mitigation in the agriculture sector. In 2015, the PRC introduced an action plan proposing the goal of zero growth in fertilizer use. To facilitate this goal, the PRC set up a scientific fertilizer management technology system that improves fertilizer use efficiency; this program has been successful, and chemical fertilizer use in the PRC declined from 60.226 million tons in 2015 to 58.59 million tons in 2017 (Ji, Liu and Shi 2020).

Government policy alone may not solve the problem as expected. A glaring example of the policy-practice gap is observed in the case of crop residue burning in India (Kaushal 2020). Although crop residue burning is a crime under Section 188 of the Indian Penal Code and the Air and Pollution Control Act of 1981, a lack of effective implementation is apparent across the country (Porichha et al. 2021), which indicates a need to explore cost-effective alternatives to burning to manage crop residues.

¹⁰ <https://www.nama-facility.org/projects/thailand-thai-rice-nama/>.

¹¹ <https://www.cgiar.org/annual-report/performance-report-2020/low-emission-technologies-transform-vietnams-rice-sector/>.

¹² <https://www.soilhealth.dac.gov.in/>.

National policies targeting GHG mitigation can have a differential impact across economic sectors. For instance, the potential impact of the GHG mitigation policies under the nationally determined contributions in Indonesia is estimated to reduce GDP by 1.7% by 2030 compared to the business as usual (BAU) scenario. Furthermore, there are likely to be large negative impacts on agricultural GDP in Indonesia (by about 13.4% compared to BAU) due to GHG mitigation policies, while the share of the energy sector in GDP is more likely to have positive impacts (+3.5% compared to BAU) (Malahayati and Masui 2021). Although agriculture has the highest potential to follow a path of low-emissions development, there are multiple barriers to implementing these strategies (Norse 2012; Ghosh et al. 2020; Li et al. 2021).

5. CONCLUSION AND WAY FORWARD

The agriculture sector in the Asia and Pacific region emits a large amount of GHGs. Rice production, use of nitrogen fertilizer, use of energy for agricultural production, and livestock production are the four major supply-side sources of GHGs emissions from agriculture. Several agronomic measures and improved technologies and practices are found to have a high potential to make agriculture less carbon intensive on the supply side. On the demand side, rising demand for livestock products and increasing FLW are key issues for increasing GHG emissions from the agriculture sector. Thus, GHG mitigation in agriculture needs an assessment of not only agricultural production but also agricultural value chains and consumption patterns. Although there is huge potential to reduce GHG emissions from agriculture, there are crucial challenges to monitoring and verifying emissions from supply-side measures. Similarly, on the consumption side, though it has very high potential to avoid GHG emissions, its effectiveness is more constrained by regulatory mechanisms on human consumption behavior. Overall, the transformation of agriculture to a low-emissions pathway requires the integration of policies at multiple levels to enhance the adoption of better agricultural technologies and practices, to encourage consumption of less carbon-intensive food, and to reduce FLW.

Achieving low-emissions agriculture requires policy change in multiple directions. On the supply side, agricultural policies should focus on upscaling climate-smart agriculture, primarily through expanding knowledge and improving input use efficiency in agriculture, such as through more incentives to use site-specific nutrient management can reduce fertilizer use without compromising crop yield. On the demand side, dissemination of knowledge on sustainable consumption and the use of both regulatory and incentive mechanisms are essential. Increasing people's knowledge and awareness of the adverse impacts of their consumption behavior on the natural environment may help reduce such behavior. Therefore, governments need to mobilize multiple organizations and civil society to transform human behavior to food consumption and to reduce FLW along the value chains.

REFERENCES

- Aboagye, I.A., M. Oba, A.R. Castillo, K.M. Koenig, A.D. Iwaasa, and K.A. Beauchemin. 2018. Effects of Hydrolyzable Tannin With or Without Condensed Tannin on Methane Emissions, Nitrogen Use, and Performance of Beef Cattle Fed a High-forage Diet. *Journal of Animal Science* 96: 5276–5286. <https://doi.org/10.1093/jas/sky352>.
- Aryal, J.P., C.R. Farnworth, R. Khurana, S. Ray, T.B. Sapkota, and D.B. Rahut. 2020a. Does Women's Participation in agricultural Technology Adoption Decisions Affect the Adoption of Climate-Smart Agriculture? Insights from Indo-Gangetic Plains of India. *Review of Development Economics* 24: 973–990. <https://doi.org/10.1111/rode.12670>.
- Aryal, J.P., M. Mehrotra, M. Jat, and H. Sidhu. 2015. Impacts of Laser Land Leveling in Rice-Wheat Rotations of the North-western Indo-Gangetic Plains of India. *Food Security* 7: 725–738. <https://doi.org/10.1007/s12571-015-0460-y>.
- Aryal, J.P., D.B. Rahut, T.B. Sapkota, R. Khurana, and A. Khatri-Chhetri. 2020b. Climate Change Mitigation Options Among Farmers in South Asia. *Environment, Development and Sustainability* 22: 3267–3289. <https://doi.org/10.1007/s10668-019-00345-0>.
- Aryal, J.P., T.B. Sapkota, M.L. Jat, and D.K. Bishnoi. 2015. On-farm Economic and Environmental Impact of Zero-Tillage Wheat: A Case of North-West India. *Experimental Agriculture* 51: 1–16. <https://doi.org/10.1017/S001447971400012X>.
- Aryal, J.P., T.B. Sapkota, T. Krupnik, D.B. Rahut, M.L. Jat, and C. Stirling. 2021a. Factors Affecting Farmers' Use of Inorganic Fertilizers and Manure in South Asia. Preprint. <https://doi.org/10.21203/rs.3.rs-206349/v1>.
- Aryal, J.P., T.B. Sapkota, D.B., Rahut, P. Marennya, and C.M. Stirling. 2021b. Climate Risks and Adaptation Strategies of Farmers in East Africa and South Asia. *Scientific Reports* 11: 10489. <https://doi.org/10.1038/s41598-021-89391-1>.
- Badiani, R., K.K. Jessoe, and S. Plant. 2012. Development and the Environment. *Journal of Environment and Development* 21: 244–262.
- Bai, Z., W. Ma, L. Ma, G.L. Velthof, W. Zhibiao, et al. 2021. China's Livestock Transition: Driving Forces, Impacts, and Consequences. *Science Advances* 4: eaar8534. <https://doi.org/10.1126/sciadv.aar8534>.
- Bajracharya, S.B., A. Mishra, and A. Maharjan. 2021. Determinants of Crop Residue Burning Practice in the Terai Region of Nepal. *PLoS One* 16: e0253939.
- Benbi, D.K. 2018. Carbon Footprint and Agricultural Sustainability Nexus in an intensively Cultivated Region of Indo-Gangetic Plains. *Science of the Total Environment* 644: 611–623. <https://doi.org/10.1016/j.scitotenv.2018.07.018>.
- Bijl, D.L., P.W. Bogaart, S.C. Dekker, E. Stehfest, B.J.M. de Vries, and D.P. van Vuuren. 2017. A Physically-Based Model of Long-Term Food Demand. *Global Environmental Change* 45: 47–62. <https://doi.org/10.1016/j.gloenvcha.2017.04.003>.
- Bjelle, E.L., K.W. Wiebe, J. Többen, A. Tisserant, D. Ivanova, et al. 2021. Future Changes in Consumption: The Income Effect on Greenhouse Gas Emissions. *Energy Economics* 95: 105114. <https://doi.org/10.1016/j.eneco.2021.105114>.

- Bodirsky, B.L., S. Rolinski, A. Biewald, I. Weindl, A. Popp, and H. Lotze-Campen. 2015. Global Food Demand Scenarios for the 21st Century. *PLoS One* 10: e0139201.
- Bryan, E., E. Kato, and Q. Bernier. 2021. Gender Differences in Awareness and Adoption of Climate-Smart Agriculture Practices in Bangladesh. In *Gender, Climate Change and Livelihoods: Vulnerabilities and Adaptations*, edited by J. Eastin and K. Dupuy. Wallingford: CABI, pp. 123–142.
- Chang, J., S. Peng, P. Ciais, M. Saunois, S.R.S. Dangal, et al. 2019. Revisiting Enteric Methane Emissions from Domestic Ruminants and Their $\delta^{13}\text{CCH}_4$ Source Signature. *Nature Communications* 10: 3420. <https://doi.org/10.1038/s41467-019-11066-3>.
- Chen, J., W. Cao, Y. Li, D. Cao, and F. Wang. 2015. Estimating Nitrous Oxide Emission Flux from Arable Lands in China Using Improved Background Emission and Fertilizer-Induced Emission Factors. *Atmospheric Pollution Research* 6: 343–350. <https://doi.org/10.5094/APR.2015.038>.
- Chen, Q., C. Long, J. Chen, and X. Cheng. 2021. Differential Response of Soil CO_2 , CH_4 , and N_2O Emissions to Edaphic Properties and Microbial Attributes Following Afforestation in Central China. *Global Change Biology* 27: 5657–5669. <https://doi.org/10.1111/gcb.15826>.
- Chhabra, A., K.R. Manjunath, S. Panigrahy, and J.S. Parihar. 2013. Greenhouse Gas Emissions from Indian Livestock. *Climate Change* 117: 329–344. <https://doi.org/10.1007/s10584-012-0556-8>.
- Clark, M.A., N.G. Domingo, C. Kimberly, S.K. Thakrar, Tilman, D. et al. 2020. Global Food System Emissions Could Preclude Achieving the 1.5° and 2°C Climate Change Targets. *Science* 70(6517): 705–708. <https://doi.org/10.1126/science.aba7357>.
- Corbera, E., M. Estrada, and K. Brown. 2010. Reducing Greenhouse Gas Emissions from Deforestation and Forest Degradation in Developing Countries: Revisiting the Assumptions. *Climate Change* 100: 355–388. <https://doi.org/10.1007/s10584-009-9773-1>.
- Crippa, M., E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F.N., Tubiello, and A. Leip. 2021. Food systems Are Responsible for a Third of Global Anthropogenic GHG Emissions. *Nature Food* 2: 198–209. <https://doi.org/10.1038/s43016-021-00225-9>.
- Cui, X., F. Zhou, P. Ciais, E.A. Davidson, F.N. Tubiello, et al. 2021. Global Mapping of Crop-Specific emission Factors Highlights Hotspots of Nitrous Oxide Mitigation. *Nature Food* 2: 886–893. <https://doi.org/10.1038/s43016-021-00384-9>.
- Cui, Z.L., L. Wu, Y.L., Ye, W.Q. Ma, X.P. Chen, and F.S. Zhang. 2014. Trade-offs Between High Yields and greenhouse Gas Emissions in Irrigation Wheat Cropland in China. *Biogeosciences* 11: 2287–2294. <https://doi.org/10.5194/bg-11-2287-2014>.
- Dhyani, S.K., A. Ram, R. Newaj, A.K. Handa, and I. Dev. 2020. Agroforestry for Carbon Sequestration in Tropical India. In *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems*, edited by P.K. Ghosh, S.K. Mahanta, D. Mandal, B. Mandal, and S. Ramakrishnan. Singapore: Springer, pp. 313–331. https://doi.org/10.1007/978-981-13-9628-1_19.

- Dickie, A., C. Streck, S. Roe, M. Zurek, F. Haupt, and A. Dolginow. 2014. Strategies for Mitigating Climate Change in Agriculture: Abridged Report. San Francisco: Climate Focus and California Environmental Associates. Available at: www.agriculturalmitigation.org.
- Dixon, R.K. 1995. Agroforestry Systems: Sources of Sinks of Greenhouse Gases? *Agroforestry Systems* 31: 99–116. <https://doi.org/10.1007/BF00711719>.
- Enahoro, D., D. Mason-D'Croz, M. Mul, K.M. Rich, T.P. Robinson, et al. 2019. Supporting Sustainable Expansion of Livestock Production in South Asia and Sub-Saharan Africa: Scenario Analysis of Investment Options. *Global Food Security* 20: 114–121. <https://doi.org/10.1016/j.gfs.2019.01.001>.
- Enriquez, Y., S. Yadav, G.K. Evangelista, D. Villanueva, M.A. Burac, and V. Pede. 2021. Disentangling Challenges to Scaling Alternate Wetting and Drying Technology for Rice Cultivation: Distilling Lessons From 20 Years of Experience in the Philippines. *Frontiers in Sustainable Food Systems* 5:194. <https://doi.org/10.3389/fsufs.2021.675818>.
- FAO/IFA. 2001. Global Estimates of Gaseous Emissions of NH₃, NO and N₂O from Agricultural Land. Rome: FAO and IFA.
- FAO. 2018. Save Food for a Better Climate: Converting the Food Loss and Waste Challenge into Climate Action. Rome: FAO.
- . 2013. Tackling Climate Change Through Livestock a Global Assessment of Emissions and Mitigation Opportunities. Rome: FAO.
- Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S., Gerber, et al. 2011. Solutions for a Cultivated Planet. *Nature* 478: 337–342. <https://doi.org/10.1038/nature10452>.
- Forster, E.J., J.R. Healey, C. Dymond, and D. Styles. 2021. Commercial Afforestation Can Deliver Effective Climate Change Mitigation Under Multiple Decarbonisation Pathways. *Nature Communications* 12: 3831. <https://doi.org/10.1038/s41467-021-24084-x>.
- Gerber, P., T. Vellinga, C. Opio, and H. Steinfeld. 2011. Productivity Gains and greenhouse Gas Emissions Intensity in Dairy Systems. *Livestock Science* 139: 100–108. <https://doi.org/10.1016/j.livsci.2011.03.012>.
- Gerber, P.J. and FAO, 2013. Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities. Rome: FAO.
- Gerber, P.J., A.N. Hristov, B. Henderson, H. Makkar, J. Oh, et al. 2013. Technical Options for the Mitigation of Direct Methane and Nitrous Oxide Emissions from Livestock: A Review. *Animal* 7: 220–234. [https://doi.org/DOI: 10.1017/S1751731113000876](https://doi.org/DOI:10.1017/S1751731113000876).
- Ghosh, A., S. Misra, R. Bhattacharyya, A. Sarkar, A.K. Singh, et al. 2020. Agriculture, Dairy and Fishery farming Practices and Greenhouse Gas Emission Footprint: A Strategic Appraisal for Mitigation. *Environmental Science and Pollution Research* 27: 10160–10184. <https://doi.org/10.1007/s11356-020-07949-4>.
- Gill, G.J. 2014. An Assessment of the Impact of Laser-Assisted Precision Land Leveling Technology as a Component of Climate-Smart Agriculture in the State of Haryana, India. New Delhi, India: International Maize and Wheat Improvement Center (CIMMYT).

- Gołasa, P., M. Wysokiński, W. Bieńkowska-Gołasa, P. Gradziuk, M. Golonko, et al. 2021. Sources of Greenhouse Gas Emissions in Agriculture, with Particular Emphasis on Emissions from Energy Used. *Energies* 14(13): 3784. <https://doi.org/10.3390/en14133784>.
- Grace, P.R., J. Antle, P.K. Aggarwal, S. Ogle, K. Paustian, and B. Basso. 2012. Soil Carbon Sequestration and Associated Economic Costs for Farming Systems of the Indo-Gangetic Plain: A Meta-analysis. *Agriculture, Ecosystems and Environment* 146: 137–146. <http://dx.doi.org/10.1016/j.agee.2011.10.019>.
- Grace, P.R., M.C. Jain, L. Harrington, G.P. Robertson, J. Antle, et al. 2003. Long-Term Sustainability of the Tropical and Subtropical Rice-Wheat System: An Environmental Perspective. In *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact*, edited by J.K. Ladha, J. Hill, R.K. Gupta, J. Duxbury, and R.J. Buresh. Madison: ASA Special Publications 65, pp. 1–18. <http://dx.doi.org/10.1016/j.agee.2011.10.019>.
- van Groenigen, K.J., C. van Kessel, and B.A. Hungate. 2013. Increased Greenhouse-Gas Intensity of Rice Production Under Future Atmospheric Conditions. *Nature Climate Change* 3: 288–291. <https://doi.org/10.1038/nclimate1712>.
- Guo, L., H. Li, X. Cao, A. Cao, and M. Huang. 2021. Effect of Agricultural Subsidies on the Use of Chemical Fertilizer. *Journal of Environmental Management* 299: 113621. <https://doi.org/10.1016/j.jenvman.2021.113621>.
- Guo, X., J. Broeze, J.J. Groot, H. Axmann, and M. Vollebreg. 2020. A Worldwide Hotspot Analysis on Food Loss and Waste, Associated Greenhouse Gas Emissions, and Protein Losses. *Sustainability* 12(18): 7488. <https://doi.org/10.3390/su12187488>.
- Gupta, P.K., A.K. Jha, S. Koul, P. Sharma, V. Pradhan, et al. 2007. Methane and Nitrous Oxide Emission from Bovine Manure Management Practices in India. *Environmental Pollution* 146: 219–224. <https://doi.org/10.1016/j.envpol.2006.04.039>.
- Habib, G. and A.A. Khan. 2018. Assessment and Mitigation of Methane Emissions from Livestock Sector in Pakistan. *Earth Systems and Environment* 2: 601–608. <https://doi.org/10.1007/s41748-018-0076-4>.
- Harris, N.L., S. Brown, S.C. Hagen, S.S. Saatchi, S. Petrova, et al. 2012. Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. *Science* 336: 1573–1576. <https://doi.org/10.1126/science.1217962>.
- Hasegawa, T. and Y. Matsuoka. 2015. Climate Change Mitigation Strategies in Agriculture and Land Use in Indonesia. *Mitigation and Adaptation Strategies for Global Change* 20: 409–424. <https://doi.org/10.1007/s11027-013-9498-3>.
- Herrero, M., P. Havlík, H. Valin, A. Notenbaert, M.C. Rufino, et al. 2013. Biomass Use, Production, Feed Efficiencies, and Greenhouse Gas Emissions from Global Livestock Systems. *Proceedings of the National Academy of Sciences* 110: 20888–20893. <https://doi.org/10.1073/pnas.1308149110>.
- Huang, X., X. Xu, Q. Wang, L. Zhang, X. Gao, and L. Chen. 2019. Assessment of Agricultural Carbon Emissions and Their Spatiotemporal Changes in China, 1997–2016. *International Journal of Environmental Research and Public Health* 16: 3105. <https://doi.org/10.3390/ijerph16173105>.

- Huppmann, D., J. Rogelj, E. Kriegler, V. Krey, and K. Riahi. 2018. A new Scenario Resource for Integrated 1.5°C Research. *Nature Climate Change* 8: 1027–1030. <https://doi.org/10.1038/s41558-018-0317-4>.
- IPCC, 2018. Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, edited by V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, et al. Cambridge: Cambridge University Press.
- . 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, et al. Cambridge: Cambridge University Press.
- . 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
- Islam, S.F., B.O. Sander, J.R. Quilty, A. de Neergaard, J.W. van Groenigen, and L.S. Jensen. 2020. Mitigation of Greenhouse Gas Emissions and Reduced Irrigation Water Use in Rice Production Through Water-Saving Irrigation Scheduling, Reduced Tillage and Fertiliser Application Strategies. *Science of the Total Environment* 739: 140215. <https://doi.org/10.1016/j.scitotenv.2020.140215>.
- Jat, H.S., A. Datta, M. Choudhary, P.C. Sharma, and M.L. Jat. 2021. Conservation Agriculture: Factors and Drivers of Adoption and Scalable Innovative Practices in Indo-Gangetic Plains of India—a review. *International Journal of Agricultural Sustainability* 19: 40–55. <https://doi.org/10.1080/14735903.2020.1817655>.
- Jat, M.L., J.C. Dagar, T.B. Sapkota, Yadvinder-Singh, B. Govaerts, et al. 2016. Climate Change and Agriculture: Adaptation Strategies and Mitigation Opportunities for Food Security in South Asia and Latin America. *Advances in Agronomy* 137: 127–235. <https://doi.org/10.1016/bs.agron.2015.12.005>.
- Ji, Y., H. Liu, and Y. Shi. 2020. Will China's Fertilizer Use Continue to Decline? Evidence from LMDI Analysis Based on Crops, Regions and Fertilizer Types. *PLoS One* 15: e0237234.
- Kahrl, F., Y. Li, Y. Su, T. Tennigkeit, A. Wilkes, and J. Xu. 2010. Greenhouse Gas Emissions from Nitrogen Fertilizer Use in China. *Environmental Science and Policy* 13: 688–694. <https://doi.org/10.1016/j.envsci.2010.07.006>.
- Kaushal, L.A. 2020. Examining the Policy-Practice Gap- The Issue of Crop Burning Induced Particulate Matter Pollution in Northwest India. *Ecosystem Health and Sustainability* 6: 1846460. <https://doi.org/10.1080/20964129.2020.1846460>.
- Kim, G.-Y., H.-C. Jeong, Y.-K. Sonn, S.Y. Kim, J.-S. Lee, and P.J. Kim. 2014. Effect of Soil Water Potential on Methane and Nitrous Oxide Emissions in Upland Soil During Red Pepper Cultivation. *Journal of the Korean Society for Applied Biological Chemistry* 57: 15–22. <https://doi.org/10.1007/s13765-013-4228-9>.
- Kiran Kumara, T.M., A. Kandpal, and S. Pal. 2020. A Meta-analysis of Economic and Environmental Benefits of Conservation Agriculture in South Asia. *Journal of Environmental Management* 269: 110773. <https://doi.org/10.1016/j.jenvman.2020.110773>.

- Knapp, J.R., G.L. Laur, P.A. Vadas, W.P. Weiss, and J.N. Tricarico. 2014. Invited Review: Enteric Methane in Dairy Cattle Production: Quantifying the Opportunities and Impact of Reducing Emissions. *Journal of Dairy Science* 97: 3231–3261. <https://doi.org/10.3168/jds.2013-7234>.
- Kritee, K., D. Nair, D. Zavala-Araiza, J. Proville, J. Rudek, et al. 2018. High Nitrous Oxide Fluxes from Rice Indicate the Need to Manage Water for both Long- and Short-Term Climate Impacts. *Proceedings of the National Academy of Sciences* 115: 9720–9725. <https://doi.org/10.1073/pnas.1809276115>.
- Kumar, B.M. and T.K. Kunhamu. 2021. Carbon Sequestration Potential of Agroforestry Systems in India: A Synthesis. In *Agroforestry and Ecosystem Services*, edited by R.P. Udawatta and S. Jose. Cham: Springer, pp. 389–430. https://doi.org/10.1007/978-3-030-80060-4_15.
- Laborde, D., A. Mamun, W. Martin, V. Piñeiro, and R. Vos. 2021. Agricultural Subsidies and Global Greenhouse Gas Emissions. *Nature Communications* 12: 2601. <https://doi.org/10.1038/s41467-021-22703-1>.
- LaHue, G.T., R.L. Chaney, M.A. Adviento-Borbe, and B.A. Linquist. 2016. Alternate Wetting and Drying in High Yielding Direct-Seeded Rice Systems Accomplishes Multiple Environmental and Agronomic Objectives. *Agriculture, Ecosystems and Environment* 229: 30–39. <https://doi.org/10.1016/j.agee.2016.05.020>.
- Lal, R. 1997. Residue Management, Conservation Tillage and Soil Restoration for Mitigating Greenhouse Effect by CO₂-enrichment. *Soil Tillage Research* 43: 81–107. [https://doi.org/http://dx.doi.org/10.1016/S0167-1987\(97\)00036-6](https://doi.org/http://dx.doi.org/10.1016/S0167-1987(97)00036-6).
- Lassaletta, L., G. Billen, B. Grizzetti, J. Anglade, and J. Garnier. 2014. 50 Year Trends in Nitrogen Use Efficiency of World Cropping Systems: The Relationship Between Yield and Nitrogen Input to Cropland. *Environmental Research Letters* 9: 105011. <https://doi.org/10.1088/1748-9326/9/10/105011>.
- Lenka, S., N.K. Lenka, A.B. Singh, B. Singh, and J. Raghuwanshi. 2017. Global Warming Potential and Greenhouse Gas Emission Under Different Soil Nutrient Management Practices in Soybean–Wheat System of Central India. *Environmental Science and Pollution Research* 24: 4603–4612. <https://doi.org/10.1007/s11356-016-8189-5>.
- Li, W., J. Ruiz-Menjivar, L. Zhang, and J. Zhang. 2021. Climate Change Perceptions and the Adoption of low-Carbon Agricultural Technologies: Evidence from Rice Production Systems in the Yangtze River Basin. *Science of the Total Environment* 759: 143554. <https://doi.org/10.1016/j.scitotenv.2020.143554>.
- Liang, D., X. Lu, M. Zhuang, G. Shi, C. Hu, et al. 2021. China's Greenhouse Gas Emissions for Cropping Systems from 1978–2016. *Scientific Data* 8: 171. <https://doi.org/10.1038/s41597-021-00960-5>.
- Lohan, S.K., H.S. Jat, A.K. Yadav, H.S. Sidhu, M.L. Jat, et al. 2018. Burning Issues of Paddy Residue Management in North-West States of India. *Renewable and Sustainable Energy Reviews* 81: 693–706. <https://doi.org/10.1016/j.rser.2017.08.057>.
- Lu, C. and H. Tian. 2017. Global Nitrogen and Phosphorus Fertilizer Use for Agriculture Production in the Past Half Century: Shifted Hot Spots and Nutrient Imbalance. *Earth System Science Data* 9:181–192. <https://doi.org/10.5194/essd-9-181-2017>.

- Luo, Y., X. Long, C. Wu, and J. Zhang. 2017. Decoupling CO₂ Emissions from Economic Growth in Agricultural Sector Across 30 Chinese Provinces from 1997 to 2014. *Journal of Cleaner Production* 159: 220–228. <https://doi.org/10.1016/j.jclepro.2017.05.076>.
- Malahayati, M. and T. Masui. 2021. Potential Impact of Introducing Emission Mitigation Policies in Indonesia: How Much Will Indonesia Have to Spend? *Mitigation and Adaptation Strategies for Global Change* 26: 37. <https://doi.org/10.1007/s11027-021-09973-2>.
- Malla, G., A. Bhatia, H. Pathak, S. Prasad, N. Jain, and J. Singh. 2005. Mitigating Nitrous Oxide and Methane Emissions from Soil in Rice–Wheat System of the Indo-Gangetic Plain with Nitrification and Urease Inhibitors. *Chemosphere* 58: 141–147. <http://dx.doi.org/10.1016/j.chemosphere.2004.09.003>.
- Mayer, S., M. Wiesmeier, E. Sakamoto, R. Hübner, R., Cardinael, et al. 2022. Soil Organic Carbon Sequestration in Temperate Agroforestry Systems – A Meta-analysis. *Agriculture, Ecosystems and Environment* 323: 107689. <https://doi.org/10.1016/j.agee.2021.107689>.
- Mehmood, F., G. Wang, Y. Gao, Y. Liang, M. Zain, et al. 2021. Impacts of Irrigation Managements on Soil CO₂ Emission and Soil CH₄ Uptake of Winter Wheat Field in the North China Plain. *Water* 13(15): 2052. <https://doi.org/10.3390/w13152052>.
- Miettinen, J., C. Shi, and S.C. Liew. 2011. Deforestation Rates in Insular Southeast Asia Between 2000 and 2010. *Global Change Biology* 17: 2261–2270. <https://doi.org/10.1111/j.1365-2486.2011.02398.x>.
- Mottet, A., B. Henderson, C. Opio, A. Falcucci, G. Tempio, et al. 2017. Climate Change Mitigation and Productivity Gains in Livestock Supply Chains: Insights from Regional Case Studies. *Regional Environmental Change* 17: 129–141. <https://doi.org/10.1007/s10113-016-0986-3>.
- Nguyen-Van-Hung, C. Balingbing, J. Sandro, S. Khandai, H. Chea, et al. 2022. Precision Land Leveling for Sustainable Rice Production: Case Studies in Cambodia, Thailand, Philippines, Vietnam, and India. *Precision Agriculture* 23: 1633–1652. <https://doi.org/10.1007/s11119-022-09900-8>.
- Norse, D. 2012. Low Carbon Agriculture: Objectives and Policy Pathways. *Environmental Development* 1:25–39. <https://doi.org/10.1016/j.envdev.2011.12.004>.
- Nugrahaeningtyas, E., C.-Y. Baek, J.-H. Jeon, H.-J. Jo, and K.-H. Park. 2018. Greenhouse Gas Emission Intensities for the Livestock Sector in Indonesia, Based on the National Specific Data. *Sustainability* 10(6): 1912. <https://doi.org/10.3390/su10061912>.
- O'Mara, F.P. 2011. The Significance of Livestock as a Contributor to Global Greenhouse Gas Emissions Today and in the Near Future. *Animal Feed Science and Technology* 166–167: 7–15. <https://doi.org/10.1016/j.anifeedsci.2011.04.074>.
- Ouatahar, L., A. Bannink, G. Lanigan, and B. Amon. 2021. Modelling the Effect of Feeding Management on Greenhouse Gas and Nitrogen Emissions in Cattle Farming Systems. *Science of the Total Environment* 776: 145932. <https://doi.org/10.1016/j.scitotenv.2021.145932>.

- Page, K.L., Y.P. Dang, and R.C. Dalal. 2020. The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. *Frontiers in Sustainable Food Systems* 4: 31. <https://doi.org/10.3389/fsufs.2020.00031>.
- Patra, A.K. 2017. Accounting Methane and Nitrous Oxide Emissions, and Carbon Footprints of Livestock Food Products in Different States of India. *Journal of Cleaner Production* 162: 678–686. <https://doi.org/10.1016/j.jclepro.2017.06.096>.
- Paudyal, B.R., N. Chanana, A. Khatri-Chhetri, L. Sherpa, I. Kadariya, and P. Aggarwal. 2019. Gender Integration in Climate Change and Agricultural Policies: The Case of Nepal. *Frontiers in Sustainable Food Systems* 3: 66. <https://doi.org/10.3389/fsufs.2019.00066>.
- Petersen, S.O., M. Blanchard, D. Chadwick, A. Del Prado, N. Edouard, et al. 2013. Manure Management for Greenhouse Gas Mitigation. *Animal* 7: 266–282. <https://doi.org/10.1017/S1751731113000736>.
- Porichha, G.K., Y. Hu, K.T. Rao, and C.C. Xu. 2021. Crop Residue Management in India: Stubble Burning vs. Other Utilizations including Bioenergy. *Energies* 14(14): 4281. <https://doi.org/10.3390/en14144281>.
- Powlson, D.S., C.M. Stirling, M.L. Jat, B.G. Gerard, C. a. Palm, et al. 2014. Limited Potential of No-till Agriculture for Climate Change Mitigation. *Nature Climate Change* 4: 678–683. <https://doi.org/10.1038/NCLIMATE2292>.
- Powlson, D.S., C.M. Stirling, C. Thierfelder, R.P. White, and M.L. Jat. 2016. Does Conservation Agriculture Deliver Climate Change Mitigation Through Soil Carbon Sequestration in Tropical Agro-Ecosystems? *Agriculture, Ecosystems and Environment* 220: 164–174. <https://doi.org/10.1016/j.agee.2016.01.005>.
- Pradhan, B.B., A. Chaichaloempreecha, and B. Limmeechokchai. 2019. GHG Mitigation in Agriculture, Forestry and Other Land Use (AFOLU) sector in Thailand. *Carbon Balance and Management* 14: 3. <https://doi.org/10.1186/s13021-019-0119-7>.
- Pradhan, B.B., R.M. Shrestha, N.T. Hoa, and Y. Matsuoka. 2017. Carbon Prices and Greenhouse Gases Abatement from agriculture, Forestry and Land Use in Nepal. *Global Environmental Change* 43: 26–36. <https://doi.org/10.1016/j.gloenvcha.2017.01.005>.
- Richards, M. and B.O. Sander. 2014. Alternate Wetting and Drying in Irrigated rice : Implementation Guidance for Policymakers and Investors. Practice Brief on Climate-Smart Agriculture. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CAAFS).
- Rojas-Downing, M.M., A.P. Nejadhashemi, T. Harrigan, and S.A. Woznicki. 2017. Climate Change and livestock: Impacts, Adaptation, and Mitigation. *Climate Risk Management* 16:145–163. <https://doi.org/10.1016/j.crm.2017.02.001>.
- Roque, B.M., J.K. Salwen, R. Kinley, and E. Kebreab. 2019. Inclusion of Asparagopsis Armata in Lactating Dairy Cows' Diet Reduces Enteric Methane Emission by Over 50 Percent. *Journal of Cleaner Production* 234: 132–138. <https://doi.org/10.1016/j.jclepro.2019.06.193>.
- Sapkota, A., A. Haghverdi, C.C.E. Avila, and S.C. Ying. 2020. Irrigation and Greenhouse Gas Emissions: A Review of Field-Based Studies. *Soil Systems* 4(2): 20. <https://doi.org/10.3390/soilsystems4020020>.

- Sapkota, T.B., J.P. Aryal, A. Khatri-Chhetri, P.B. Shirsath, P. Arumugam, and C.M. Stirling. 2018. Identifying high-Yield Low-Emission Pathways for the Cereal Production in South Asia. *Mitigation and Adaptation Strategies for Global Change* 23: 621–641. <https://doi.org/10.1007/s11027-017-9752-1>.
- Sapkota, T.B., M.L. Jat, D.S. Rana, A. Khatri-Chhetri, H.S. Jat, et al. 2021. Crop Nutrient Management Using Nutrient Expert Improves Yield, Increases Farmers' Income and Reduces Greenhouse Gas Emissions. *Scientific Reports* 11: 1564. <https://doi.org/10.1038/s41598-020-79883-x>.
- Sathaye, J.A., W.R. Makundi, K. Andrasko, R. Boer, N.H. Ravindranath, et al. 2001. Carbon Mitigation Potential and Costs of Forestry Options in Brazil, China, India, Indonesia, Mexico, the Philippines and Tanzania. *Mitigation and Adaptation Strategies for Global Change* 6: 185–211. <https://doi.org/10.1023/A:1013398002336>.
- Shen, Y., C. Jiang, K.L. Chan, C. Hu, and L. Yao. 2021. Estimation of Field-Level NO_x Emissions from Crop Residue Burning Using Remote Sensing Data: A Case Study in Hubei, China. *Remote Sensing* 13(3): 404. <https://doi.org/10.3390/rs13030404>.
- Shi, S., P. Han, P. Zhang, F. Ding, and C. Ma. 2015. The Impact of Afforestation on Soil Organic Carbon Sequestration on the Qinghai Plateau, China. *PLoS One* 10: e0116591.
- Si, R., N. Aziz, and A. Raza. 2021. Short and Long-Run Causal Effects of Agriculture, Forestry, and Other land Use on Greenhouse Gas Emissions: Evidence from China using VECM Approach. *Environmental Science and Pollution Research* 28: 64419–64430. <https://doi.org/10.1007/s11356-021-15474-1>.
- Sibayan, E.B., K. Samoy-Pascual, F.S. Grospe, M.E.D. Casil, T. Tokida, et al. 2018. Effects of Alternate Wetting and Drying Technique on Greenhouse Gas Emissions from Irrigated Rice Paddy in Central Luzon, Philippines. *Journal of Soil Science and Plant Nutrition* 64: 39–46. <https://doi.org/10.1080/00380768.2017.1401906>.
- Singh, R. and M. Lal. 2000. Sustainable Forestry in India for Carbon Mitigation. *Current Science* 78: 563–567.
- Sirohi, S. and A. Michaelowa. 2007. Sufferer and Cause: Indian Livestock and Climate Change. *Climate Change* 85: 285–298. <https://doi.org/10.1007/s10584-007-9241-8>.
- Smith, P., H. Haberl, A. Popp, K. Erb, C. Lauk, et al. 2013. How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology* 19: 2285–2302. <https://doi.org/10.1111/gcb.12160>.
- Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, et al. 2007a. Agriculture. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer. Cambridge: Cambridge University Press, pp. 499–541.
- . 2007b. Policy and Technological Constraints to Implementation of Greenhouse Gas Mitigation Options in Agriculture. *Agriculture, Ecosystems and Environment* 118: 6–28. <https://doi.org/http://dx.doi.org/10.1016/j.agee.2006.06.006>.

- . 2008. Greenhouse Gas Mitigation in Agriculture. *Philosophical Transactions of the Royal Society B* 363: 789–813. <https://doi.org/10.1098/rstb.2007.2184>.
- Some, S., J. Roy, and A. Ghose 2019. Non-CO₂ Emission from Cropland Based Agricultural Activities in India: A Decomposition Analysis and Policy Link. *Journal of Cleaner Production* 225: 637–646. <https://doi.org/10.1016/j.jclepro.2019.04.017>.
- Song, X., M. Liu, X. Ju, B. Gao, F. Su, et al. 2018. Nitrous Oxide Emissions Increase Exponentially When Optimum Nitrogen Fertilizer Rates Are Exceeded in the North China Plain. *Environmental Science and Technology* 52: 12504–12513. <https://doi.org/10.1021/acs.est.8b03931>.
- Streets, D.G., K.F. Yarber, J.-H. Woo, and G.R. Carmichael. 2003. Biomass Burning in Asia: Annual and seasonal Estimates and Atmospheric Emissions. *Global Biogeochemical Cycles* 17: 1099. <https://doi.org/10.1029/2003GB002040>.
- Sun, W., J.G. Canadell, Lijun Yu, Lingfei Yu, W. Zhang, et al. 2020. Climate Drives Global Soil Carbon Sequestration and Crop Yield Changes Under Conservation Agriculture. *Global Change Biology* 26: 3325–3335. <https://doi.org/10.1111/gcb.15001>.
- Sutton, M.A., J.W. Erisman, and O. Oenema. 2007. Strategies for Controlling Nitrogen Emissions from Agriculture: Regulatory, Voluntary and Economic Approaches. Paper presented at IFA International Workshop on Fertilizer Best Management Practices, Brussels, Belgium, 7–9 March 2007.
- Thornton, P., and P. Gerber. 2010. Climate Change and the Growth of the Livestock Sector in Developing Countries. *Mitigation and Adaptation Strategies for Global Change* 15: 169–184. <https://doi.org/10.1007/s11027-009-9210-9>.
- Thornton, P.K., and M. Herrero. 2010. Potential for Reduced Methane and Carbon Dioxide Emissions from Livestock and Pasture Management in the Tropics. *Proceedings of the National Academy of Sciences* 107: 19667–19672. <https://doi.org/10.1073/pnas.0912890107>.
- Tian, H., R. Xu, J.G. Canadell, R.L. Thompson, W. Winiwarter, et al. 2020. A Comprehensive Quantification of global Nitrous Oxide Sources and Sinks. *Nature* 586: 248–256. <https://doi.org/10.1038/s41586-020-2780-0>.
- Tullo, E., A. Finzi, and M. Guarino. 2019. Review: Environmental Impact of Livestock Farming and Precision Livestock Farming as a Mitigation Strategy. *Science of the Total Environment* 650: 2751–2760. <https://doi.org/10.1016/j.scitotenv.2018.10.018>.
- UNFCCC. 2017. Land Use and Climate Change. http://unfccc.int/land_use_and_climate_change/items/8792.php (accessed 9 April 2018).
- United Nations Environment Programme (UNEP). 2021a. Food Waste Index Report 2021. Nairobi: UNEP.
- . 2021b. Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: UNEP.
- USAID. 2017. Assessment of Business Models for Low Emission Land-Use Management in Asia. Bangkok: USAID/RDMA Regional Environmental Office.
- Uwizeye, A., I.J.M.de Boer, C.I. Opio, R.P.O. Schulte, A. Falcucci, et al. 2020. Nitrogen Emissions Along Global Livestock Supply Chains. *Nature Food* 1: 437–446. <https://doi.org/10.1038/s43016-020-0113-y>.

- Venkatramanan, V., S. Shah, A.K. Rai, and R. Prasad. 2021. Nexus Between Crop Residue Burning, Bioeconomy and Sustainable Development Goals Over North-Western India. *Frontiers in Energy Research* 8: 392. <https://doi.org/10.3389/fenrg.2020.614212>.
- Wang, J., S.G.S.A. Rothausen, D. Conway, L. Zhang, W. Xiong, et al. 2012. China's Water–Energy Nexus: Greenhouse-Gas Emissions from Groundwater Use for Agriculture. *Environmental Research Letters* 7: 14035. <https://doi.org/10.1088/1748-9326/7/1/014035>.
- Wang, Y., C. Li, Y. Li, L. Zhu, S. Liu, et al. 2020. Agronomic and Environmental Benefits of Nutrient Expert on Maize and Rice in Northeast China. *Environmental Science and Pollution Research* 27: 28053–28065. <https://doi.org/10.1007/s11356-020-09153-w>.
- Wassmann, R., Y. Hosen, and K. Sumfleth. 2009. Reducing methane Emissions from Irrigated Rice. 16(3). Washington DC: International Food Policy Research Institute.
- Wilkes, A., T. Tennigkeit, and K. Solymosi. 2013. National Integrated Mitigation Planning in Agriculture: A Review Paper. Rome: FAO.
- Wu, J., S. Kong, F. Wu, Y. Cheng, S. Zheng, et al. 2020. The Moving of High Emission for Biomass Burning in China: View from Multi-year Emission Estimation and Human-Driven Forces. *Environment International* 142:105812. <https://doi.org/10.1016/j.envint.2020.105812>.
- Xue, L., X. Liu, S. Lu, G. Cheng, Y. Hu, et al. 2021. China's Food Loss and Waste Embodies Increasing Environmental Impacts. *Nature Food* 2, 519–528. <https://doi.org/10.1038/s43016-021-00317-6>.
- Yue, Q., X. Xu, J. Hillier, K. Cheng, and G. Pan. 2017. Mitigating greenhouse Gas Emissions in Agriculture: From Farm Production to Food Consumption. *Journal of Cleaner Production* 149: 1011–1019. <https://doi.org/10.1016/j.jclepro.2017.02.172>.
- Zeng, Y., T.V. Sarira, L.R. Carrasco, K.Y. Chong, D.A. Friess, et al. 2020. Economic and social Constraints on Reforestation for Climate Mitigation in Southeast Asia. *Nature Climate Change* 10: 842–844. <https://doi.org/10.1038/s41558-020-0856-3>.
- Zhang, G., X. Xiao, J. Dong, F. Xin, Y. Zhang, et al. 2020. Fingerprint of rice Paddies in Spatial–Temporal Dynamics of Atmospheric Methane Concentration in Monsoon Asia. *Nature Communications* 11: 554. <https://doi.org/10.1038/s41467-019-14155-5>.
- Zhang, H.-L., R. Lal, X. Zhao, J.-F. Xue, and F. Chen. 2014. Chapter One – Opportunities and Challenges of Soil Carbon Sequestration by Conservation Agriculture in China. *Advances in Agronomy* 124: 1–36. <https://doi.org/10.1016/B978-0-12-800138-7.00001-2>.
- Zhang, L., H. Tian, H. Shi, S. Pan, X. Qin, et al. 2021. Methane Emissions from Livestock in East Asia During 1961–2019. *Ecosystem Health and Sustainability* 7: 1918024. <https://doi.org/10.1080/20964129.2021.1918024>.
- Zhang, W., Z. Dou, P. He, X.-T. Ju, D. Powlson, et al. 2013. New Technologies Reduce Greenhouse Gas Emissions from Nitrogenous Fertilizer in China. *Proceedings of the National Academy of Sciences* 110: 8375–8380. <https://doi.org/10.1073/pnas.1210447110>.

- Zhang, X., Y. Lu, Q. Wang, and X. Qian. 2019. A High-Resolution Inventory of Air Pollutant Emissions from Crop Residue Burning in China. *Atmospheric Environment* 213: 207–214. <https://doi.org/10.1016/j.atmosenv.2019.06.009>.
- Zou, X., Y. Li, K. Li, R. Cremades, Q. Gao, et al. 2015. Greenhouse Gas Emissions from Agricultural Irrigation in China. *Mitigation and Adaptation Strategies for Global Change* 20: 295–315. <https://doi.org/10.1007/s11027-013-9492-9>.