Low Carbon Footprint Agriculture

REENA SINGH | ASHOK GULATI

Low Carbon Footprint Agriculture

REENA SINGH | ASHOK GULATI

Low Carbon Footprint Agriculture

Authors

1. **Reena Singh**, Senior Fellow, Indian Council for Research on International Economic Relations, New Delhi (rsingh@icrier.res.in).
2. **Ashok Gulati**, Distinguished Professor, Indian Council for Research on International Economic Relations, New Delhi (agulati115@gmail.com; agulati@icrier.res.in)

ISBN Number: 978-81-954132-9-4

Published by: **Indian Council for Research on International Economic Relations (ICRIER)**
Core-6A, 4th Floor, India Habitat Centre, Lodhi Road, New Delhi – 110003

Disclaimer: Opinions and recommendations in the report are exclusively of the author(s) and not of any other individual or institution including ICRIER. This report has been prepared in good faith on the basis of information available at the date of publication. All interactions and transactions with sponsors and their representatives have been transparent and conducted in an open, honest, and independent manner as enshrined in ICRIER Memorandum of Association. ICRIER does not accept any corporate funding that comes with a mandated research area which is not in line with ICRIER's research agenda. The corporate funding of an ICRIER activity does not, in any way, imply ICRIER's endorsement of the views of the sponsoring organization or its products or policies. ICRIER does not conduct research that is focused on any specific product or service provided by the corporate. sponsor.

TABLE OF **CONTENTS**

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXURES

LIST OF BOXES

LIST OF ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
APEDA	Agricultural and Processed Food Products Export Development Authority
AWD	Alternate Wetting and Drying
C	Carbon
CACP	Commission for Agricultural Costs and Prices
CAG	Comptroller and Auditor General of India
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon-dioxide
CO_2 eq	Carbon-dioxide Equivalent
COP	Conference of the Parties
DES	Directorate of Economics and Statistics
DSR	Direct Seeded Rice
DST	Department of Science and Technology
EF	Emission Factor
FAI	fertiliser Association of India
FAO	Food and Agriculture Organization
FCI	Food Corporation of India
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GDP, PPP	Gross Domestic Product based on Purchasing Power Parity
Gg CO_2 eq	Gigagram carbon-dioxide Equivalent
GHG	Green-House Gas
GoI	Government of India
GWP	Global Warming Potential
Ha	Hectare
IARI	Indian Agricultural Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
Kg	Kilogram
Kg/ha	Kilogram per hectare
Kg/t	Kilogram per tonne
KII	Key Informant Information

LiFE	Lifestyle for the Environment
LGP	Lower Gangetic Plains
LULUCF	Land Use, Land Use Change and Forestry
LT-LEDS	Long-Term Low Emission Development Strategy
MGP	Middle Gangetic Plains
M ha	Million Hectare
MMT	Million metric tonnes
Mt CO_2 eq	Million tonnes Carbon Dioxide Equivalent
MoEFCC	Ministry of Environment, Forest, and Climate Change
MoES	Ministry of Earth and Sciences
MoP	Ministry of Power
MSP	Minimum Support Price
N	Nitrogen
N_2O	Nitrous Oxide
NDC	Nationally Determined Contribution
NO_3	Nitrate
NOx	Nitrogen Oxides
NMHCs	Non-Methane Hydrocarbons
NICRA	National Innovations on Climate Resilient Agriculture
NMSA	National Mission on Sustainable Agriculture
PAU	Punjab Agricultural University
PDS	Public Distribution System
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan
RBI	Reserve Bank of India
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
SRI	System of Rice Intensification
SO_2	Sulphur Dioxide
T	Tonne
TIFAC	Technology Information Forecasting and Assessment Council
TGP	Trans-Gangetic Plains
TPDS	Targeted Public Distribution System
UGP	Upper Gangetic Plains
UNFCCC	United Nations Framework Convention on Climate Change
UTs	Union Territories

GLOSSARY

Term	Definition
Low carbon footprint	Low carbon footprint refers to the reduction of the amount of carbon dioxide and other Green House Gas (GHG) emissions associated with the activities of the entity.
Nationally Determined Contribution	A nationally determined contribution (NDC) or intended nationally determined contribution (INDC) is a non-binding national plan highlighting climate change mitigation, including climate-related targets for GHG emission reductions.
Green-House Gases	Greenhouse gases (also known as GHGs) are gases in the earth's atmosphere that trap heat.
Mitigation	Climate change mitigation refers to efforts to reduce or prevent emission of GHG.
Adaptation	Climate change adaptation is the process of adjustment to actual or expected climate and its effects.
Global Warming	Global warming is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning that increases heat-trapping GHG levels in the Earth's atmosphere.
Climate Change	Climate change refers to changes in the Earth's climate, at local, regional, or global scales, and describes anthropogenic or human-caused climate change.
Net Zero	Net zero means cutting GHG emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, by oceans and forests.
Carbon-dioxide equivalent	A carbon dioxide equivalent or CO_2 equivalent, abbreviated as CO_2-eq is a metric measure to compare the emissions from various GHG on the basis of their Global Warming Potential (GWP) by converting amounts of other gases to the equivalent amount of carbon dioxide with the same GWP.
Global Warming Potential	This index measures its radiative forcing following an emission of a unit mass of the specific gas, accumulated over a specific time period using carbon dioxide as a reference. Carbon dioxide has a GWP of 1.

Foreword

Globally, high temperature records are routinely breaking and the frequency of climate-related disasters are increasing, underscoring the imperative to stabilise global temperatures. This requires transformations both at production and consumption levels to lower the green-house gas (GHG) emissions. Transition in industry and transport sector towards cleaner, less intensive energy systems has been the focus to date. Recent research implies that the agriculture and food systems also need to be aligned with the climate fight across the board to achieve the long-term goals of the Paris Agreement of keeping global warming below 2°C, preferably to 1.5°C, above pre-industrial levels. Much of this lies on the agriculture sector's large contribution to climate change. The sector contributes to approximately 22 percent (13 billion tonnes CO_2 eq) of the total anthropogenic GHG emissions (IPCC 2023). This includes emissions from land-use, land-use change, and forestry sector due to deforestation and land-clearing activities. If emissions associated with pre- and post-production activities in the global food system are included, the emissions are estimated to be 21–37 percent of the total net anthropogenic GHG emissions (IPCC 2021).

India's development pathway is dependent on climate-sensitive sectors - agriculture, fisheries, forestry and limited natural resources - which puts enormous challenge in coping with the impacts of climate change. With the current level of technology adoption by farmers, reduction in all India wheat yield by -7.7 percent (2050) and -6.5 percent (2080) is projected due to climate change as compared to the mean yield of 2010-2015 period. Even with the achievement of more ambitious nationally determined contribution (NDC) targets proposed by countries, the total economic value of crop loss (including both food and non-food crops) in India are projected to be $ 28.6 to 54.8 billion during 2030–2050, and $ 612 to 1,014 billion during 2050–2100 (MoEFCC 2023). While climate change is staring at us, Indian policy makers have to ensure food and nutrition security of the most populous country on this planet. This requires agriculture policies to be aligned such that it can give us climate resilience and take us towards low carbon agriculture footprint. This report lays the groundwork for a way forward and brings together comprehensive state-wise analysis of emissions from agriculture sector, examples of proven mitigation and adaptive technologies and practices, and lessons learned, recognizing that this is only a part of a larger and more complex set of issues of food systems and their transformation for sustainability.

Deepak Mishra
Director & Chief Executive
ICRIER

Preface

India is looking at accelerating decarbonisation across the board and is working towards achieving net zero emissions by 2070 and the Paris Agreement's goals. As part of its initial NDCs, India committed to decreasing the GHG emission intensity of its economy by 33-35 percent from 2005 levels by the year 2030. In August 2022, the Indian government updated its NDCs, increasing its target to a 45 percent reduction in GHG emission intensity from 2005 levels by 2030. In view of the requirement for the country to meet its ambitious climate goals, a robust national framework for Indian Carbon Market (ICM) through a reliable national carbon credit electronic platform is being developed. ICM Framework has two key mechanism – Compliance mechanism which aims to address the emissions from its energy use and industrial sectors and offset mechanism to incentivize the voluntary actions from entities (not covered under compliance) for GHG reduction, thus providing a comprehensive approach to decarbonisation of the economy.

The role of agriculture in generating GHG emissions – and how to reduce those emissions – is becoming increasingly clear. Low carbon footprint agriculture is a method of sustainable food production focused on reducing agriculture's environmental and climate impacts. The carbon footprint of agriculture encompasses the total greenhouse gases (measured in carbon dioxide equivalent units) emitted through various farming activities, including fuel usage, inputs, field emissions, and livestock. Although agriculture sector of the country has been kept away from emission reduction targets but, it has been listed under offset.

As per national GHG inventory, India's agriculture sector accounted for 421 million tonnes of carbon-dioxide equivalent (CO_2 eq) in 2019, which is 13.44 percent of the total GHG emissions of India (MoEFCC 2023). The fundamental step to evaluate the offset potential in agriculture is to measure baseline emissions and scrutinize the primary sources of these emissions, considering the differences in land use and production systems in different states. Based on this analysis, identification of emission hot spots and suitable mitigation strategies can be crafted, considering the technical options available. This knowledge can effectively guide policy decisions that align with national goals for food security, economic development, and environmental sustainability. Keeping this in backdrop, this report examines the case for promoting strategies and policies for low carbon footprint agriculture in India.

The report is organized into seven broad sections. Section 1 sets the context and objectives of the report. Section 2 provides details of the data and methodology for calculating state-wise agriculture emissions from various sources in 2022-23. Section 3 presents state-wise GHG emissions from rice cultivation. Rice fields in India are intensively managed, and provide ample opportunities to enforce practices (e.g., alternate wetting and drying, direct seeding or system of rice intensification, promotion of laser levelling of fields, micro-irrigation) that reduce net emission of GHGs. Section 4 presents state-wise GHG emissions from livestock. Approaches for mitigating these emissions were identified under the four broad categories: feed and nutrition, measures at animal level, manure management and grassland management. Section 5 presents state-wise GHG emissions from agriculture soils. Approaches for mitigation include fertigation, super-granule urea, slow-release fertilisers, and precision agriculture. Section 6 presents state-wise GHG emissions due to electricity consumption in agriculture. Section 7 lays out policy recommendations.

A core concept of this report is that achieving climate stability is as critical a human need as the other functions of agriculture. By reducing GHG emissions while increasing soil carbon stores, agricultural operations can make a substantial contribution to India's commitment of reducing carbon footprint of the country.

Reena Singh

Ashok Gulati

Acknowledgement

This report is a part of ICRIER's work on promoting sustainable agriculture. We are grateful to a number of people who have contributed in various ways, from deep dive discussions to providing insights into rice farming and livestock economy, to commenting on our initial drafts to financially supporting it that gave us an opportunity to carry out this study.

We would like to thank Mr. D. Narain, Former President, Bayer South Asia and Global Head of Smallholder Farming, Mr. Rajvir Rathi, Director, Agricultural Affairs & Policy IBSL, and Ms. Sangeeta, Mendiratta, Lead - Government Affairs, Public Affairs and Sustainability, IBSL of Bayer for several rounds of discussion on rice economy, and supporting our work whole heartedly. Special thanks are due to Ms. Shilpa Divekar Nirula, and Mr. Rakesh Dubey of Monsanto (formerly) for financial assistance. We also thank Dr. Nalin Kishore, formerly with World Bank, for critically reviewing this report that has helped to improve the flow of the report. We sincerely thank Dr. Tapan Kumar Adhya, Director, South Asia Nitrogen Centre, Co-Director (Science) UKRI-GCRF South Asia Nitrogen Hub, Professor, KIIT & Former Director, Central Rice Research Institute, Cuttack, Dr. Bijay Singh, INSA Honorary Scientist & Former ICAR National Professor, Punjab Agriculture University (PAU), Ludhiana and Dr. Bharat R. Sharma, Former Senior Visiting Fellow, ICRIER & Scientist Emeritus (Water Resources), International Water Management Institute (IWMI), New Delhi for reviewing the rice-related aspects of this report and sharing their comments and suggestions. We would also like to thank Dr. P.K. Aggarwal, Asia Program Leader of CGIAR Research Program on Climate Change, Agriculture and Food Security, Borlaug Institute for South Asia, Dr. Arti Bhatia, Principal Scientist, CESCRA, Indian Agricultural Research Institute, Dr. O. P. Chaudhary, Head of Department, Soil Science, PAU, Dr. Gurmeet Singh Dheri, Assistant Soil Chemist, PAU, Dr. Ajmer Singh Brar, Principal Agronomist, PAU and Dr. Prabhjyot Kaur Sidhu, Principal Scientist, Agrometeorology, PAU for discussions during the preparation of this report. We acknowledge Dr. G.S. Cheema (Retired Associate Professor, PAU) and Dr. Daler Singh (Former, District Agriculture Officer, Punjab) for sharing farmer's insights and facilitating interactions with farmers.

We acknowledge ICRIER's APSI team for their insights and comments during internal review presentations of the study. We also thank Ms Shibani Chattopadhyay, Communication Officer, ICRIER for copy editing of this report. The help of Mr. Rahul Arora, ICRIER for the preparation of maps using the QGIS software and the final proof-reading of the report is duly acknowledged. Needless to say, the responsibility of facts, figures, analysis, and views expressed in this paper fully rests with the authors.

Abstract

Agriculture and allied sector has shown a resilient growth (though undulating) during the last two decades (2005-06 to 2024-25 period) with the average annual growth rate of 3.9 percent. The sector employs 46.1 percent of the workforce and contributed to 18 percent of the country's Gross Value Added (GVA) in 2024-25. This sector also has the responsibility to feed 1.4 billion populations. India is the world's largest producer of milk, pulses, and jute, and ranks as the second largest producer of rice, wheat, sugarcane, groundnut, vegetables, fruit, and cotton. Long-term changes in average temperatures, rainfall, and climate variability is a threat to agricultural production, food security, and the livelihoods of farming communities in India. While adaptation of Indian agriculture to climate change is necessary to assure food security and safeguarding livelihoods of poor farmers, mitigation of GHG emissions can abate the extent of climate change and future adaptation needs. This report estimated state-wise agriculture GHG emissions for 2022-23 using Tier 2 methodology of Intergovernmental Panel on Climate Change (IPCC) (IPCC 2006) with country specific emission factors. The activity data was obtained from 'cost of cultivation survey', 'fertiliser statistics', 'land-use statistics', 'agriculture statistics at a glance' and the '20th livestock census', published literature and government reports.

During 2022-23, the total methane (CH_4) and nitrous oxide (N_2O) emissions from production of crops (includes emissions related to rice cultivation, agriculture soils and residue burning) and livestock (includes emissions related to enteric fermentation and manure management) were estimated to be 490 Million Tonnes (Mt) equivalent of carbon dioxide (CO_2 eq). After including the emissions related to electricity consumption in agriculture, the total agriculture emissions amounted to 688 Mt CO_2 eq. The sector has the potential to mitigate 130-150 Mt CO_2 eq GHG emissions, through water management in rice, conservation agriculture, fertiliser use efficiency, balanced ration diet and feed additives for livestock, and solarisation of agriculture. By mitigating these emissions, farmers can earn carbon credits and profit by its trade. The Energy Conservation (Amendment) bill of December 2022 proposed a domestic carbon credits market, which can act as a thrust for decarbonising agriculture. The centre and state governments could align existing natural farming, regenerative farming, organic farming, sustainable agriculture, crop diversification, livestock programs and agriculture solarisation schemes to encourage farmers to participate in carbon credit programmes along with the associated organizations. To ensure quality credits from agriculture, government should fix minimum floor price of $ 20 per credit. Agriculture sector does not have emission reduction targets so the smart move is to begin by offering other sectors and domestic entities to offset their emissions by purchasing carbon credits from farmers.

Executive Summary

1. Introduction

At the core of the Sustainable Development Goals (SDGs) is "Target 2 Zero Hunger" that aims to end hunger, achieve food security, improve nutrition and promote sustainable agriculture. Food security in India has come a long way from 'ship to mouth' in 1960s to the Food Security Act of 2013 and Pradhan Mantri Garib Kalyan Anna Yojana (PMGKAY) of 2020. It continues to be high on its list of development priorities for India. Each year, more than 800 million people receive free food-grains through Public Distribution System (PDS) - the largest food subsidy program in the world. Climate change - increasing frequency of climate-related disasters – is an emerging threat to India's long-term food security challenges as it can affect food production.

Until a few decades ago, changes in the global climate occurred naturally, across centuries or millennia, now, human activities are altering the world's climate by increasing the atmospheric concentration of GHGs, thereby amplifying the natural "greenhouse effect" that is making the Earth warmer. These GHGs comprise, primarily, carbon dioxide (CO_2) (mostly from fossil fuel combustion), methane (CH_4) (from rice cultivation, animal husbandry, and oil extraction), nitrous oxide (N_2O) (from fertilisers), and various human-made halocarbons. Global net emissions of GHGs have continued to rise from 38 billion tonne carbon dioxide equivalent (Bt CO_2 eq) (in 1990) to 59 Bt CO_2 eq (in 2019) (IPCC 2023). As a result, global surface temperatures rose above pre-industrial levels (1850-1900) by +1.1-°C in the last century. The average global average temperature breached the 1.5 degrees' celsius mark consecutively for 2023 and 2024. The temperature increase is not uniform though across regions and countries.

1.1 India is facing climate change risks

During 1950-2018, average temperatures in the country have increased by 0.70 C while the summer monsoon precipitation (June to September) over India has declined by around 6 percent from 1951 to 2015, with notable decreases over the Indo-Gangetic Plains and the Western Ghats (MoES 2020). Increase in weather variability increased in the country, with temperatures recorded above 50°C in certain regions and the increased variability in monsoon season (in timing and quantity of rainfall). By the end of the 21st century, average temperature in the country is projected to rise by approximately 2.4°C and 4.4°C relative to the recent past (1976–2005 average), under intermediate emission scenario (RCP 4.5[1]) and high emission scenario (RCP 8.5) respectively (MoES 2020). Climate change is harming those sectors of the economy that are dependent on the weather such as agriculture (Singh & Gulati 2023a). Even with the achievement of more ambitious NDC targets

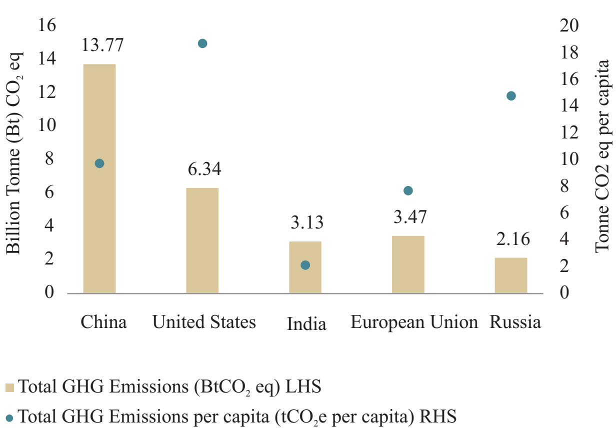
[1] Projections by climate models are based on multiple standardized forcing scenarios called Representative Concentration Pathways (RCPs). Each scenario is a time series of emissions and concentrations of the GHGs, aerosols, and chemically active gases, as well as land-use and land changes through the twenty-first century, characterized by the resulting Radiative Forcing* in the year 2100 (IPCC 2013). "'RCP 4.5" is an intermediate stabilization pathway that results in a Radiative Forcing of 4.5 W/m^2 in 2100) and "RCP8.5" is a high concentration pathway resulting in a Radiative Forcing of 8.5 W/m^2 in 2100). For the duration, 1901-2018, data reported is of the actual change.

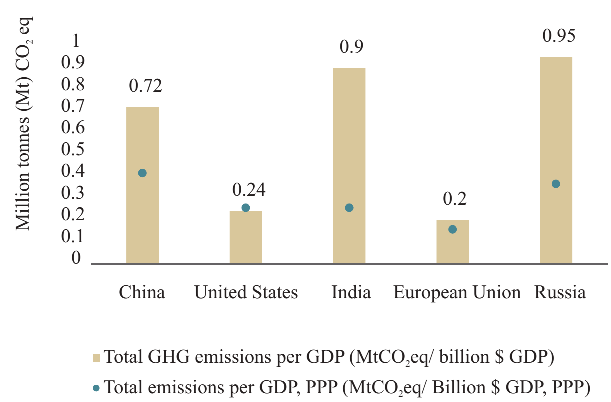
proposed by countries under intermediate emission scenario, the total economic value of crop loss (including food and non-food crops) in India are projected to be \$ 28.6 to \$ 54.8 billion during 2030–2050 and \$ 612 to \$ 1,014 billion during 2050–2100. In the high emission scenario, total losses for food crops could rise to \$ 70.0 to \$ 122.9 billion during 2030–2050 and \$ 1,436–\$ 2,691 billion during 2050–2100 (MoEFCC 2023). Those activities that drive climate change globally also tend to be significant producers of pollution locally, which has direct, negative impacts on individuals' health. Air Quality Life Index 2023 project research found that air pollution in India can shorten an average Indian's life expectancy by 5.3 years (and 11.9 years for the National Capital Territory of Delhi), relative to what it would be if the World Health Organization (WHO) air quality guideline was met (EPIC 2023).

1.2 India is the world's third largest GHG emitter, however in terms of emissions per capita it has the lowest amongst top emitters.

India ranks third in the total GHG emission and has emitted 3.13 Bt CO_2 eq in 2019 (MoEFCC 2023). European Union (EU-27) has marginally higher GHG emissions than India but, on per capita basis, India ranks very low. United States and China have respectively 8.6 and 4.5 times higher GHG emissions per capita. India also has a meagre 3 percent contribution to global historical cumulative GHG emissions (UNEP, 2022). Given India's modern economic development began considerably later; the emission intensity[2] (both with respect to GDP and GDP, PPP) of the country is higher than that of advanced economies – US and EU. The country emitted 0.9 million tonnes carbon-dioxide equivalent (Mt CO_2 eq) per billion \$ GDP and 0.2 Mt CO_2 eq per billion \$ GDP, PPP.

GHG emission in countries that are top emitters





Source: UNFCCC, IMF, MoEFCC 2023

[2] Emission intensity of the economy is the total amount of greenhouse gas emissions emitted for every unit increase of GDP

1.3 Under current policies, India's GHG emissions are on an upward trajectory, nevertheless the country is on track of reducing emission intensity

Historical emissions in the country have been slowly but steadily rising particularly since 2014 in line with economic development. India is conscious of this fact and has set NDC target of reducing emission intensity of its GDP by 45 percent by 2030 from 2005 level. India is well on track and has already achieved the reduction in emissions intensity of its GDP by 33 percent in 2019 from 2005 (MoEFCC 2023) and will reach this target with the existing policies. However, over the next 25 years, India has ambitious growth plans and is poised to achieve the status of developed country by 2047. While this development path is positive, it is anticipated, under current policies, that such a growth path will lead to increased GHG emissions.

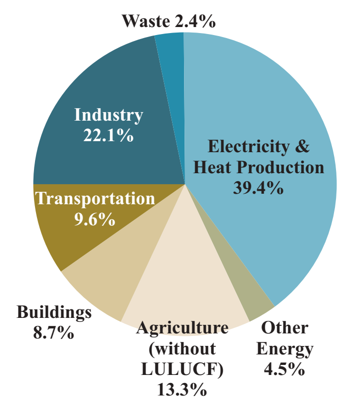
In 2019, India reported 3,132 Mt CO_2 eq GHG emissions (without LULUCF) in its third National Communication and initial Adaptation Communication to United Nations Framework Convention on Climate Change (UNFCCC). The power sector is the largest emitter in India, accounting for 39.4 percent of total GHG emissions, followed by the industry sector (22.1 percent), agriculture (13.3 percent), building (8.7 percent) and the transportation sector (9.6 percent) (MoEFCC 2023).

However, if we add the CO_2 emissions related to consumption of fertilisers, pesticides and electricity for agriculture[3], the share of agriculture-related GHG emissions would be as high as 18-20 percent. While a transition towards green energy in power generation and in industry and transport sector has been the focus to date, the role of agriculture in generating GHG emissions – and how to reduce those emissions – has not come up on similar priority. It may be due to perceived fear of negative impact on food production or the regulatory difficulty in measuring emissions at individual farm level in a small holder dominated agriculture, or it could be due to lack of political will. Given the future increase in demand for food and land use systems due to population and incomes growth, agriculture emissions in India, at least in absolute amount, are set to rise. Innovative low carbon solutions, be it in terms of products or policies, is the need of the hour. (Singh & Gulati 2023b). This report examines the case for promoting and re-aligning policies for low carbon agriculture in India.

2. Deciphering agriculture emissions and key drivers

Unlike energy and the transportation sector, agriculture is the anthropogenic source of atmospheric N_2O and CH_4, which are respectively 273 and 27.2 times more powerful than CO_2 for driving temperature increase in 100 years' time horizon (IPCC 2021). These GHG emissions are primarily from livestock's enteric fermentation, manures, agriculture soils, rice

India's GHG emission by economic sector



Source: MoEFCC 2023

[3] These CO_2 emissions related to agriculture sector are accounted in energy sector in national inventory

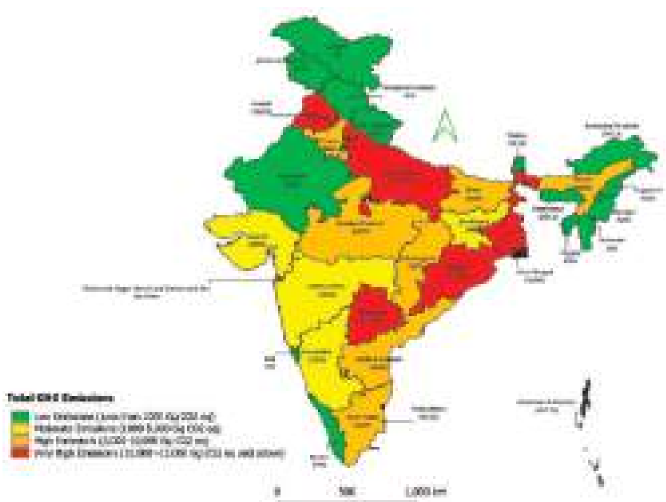
cultivation, and residue burning. Electricity consumption in agriculture is driving emissions in energy sector.

2.1 Rice cultivation areas in Punjab and Haryana, which are agro-climatically unsuitable for rice, leads to high emissions compared to other crops.

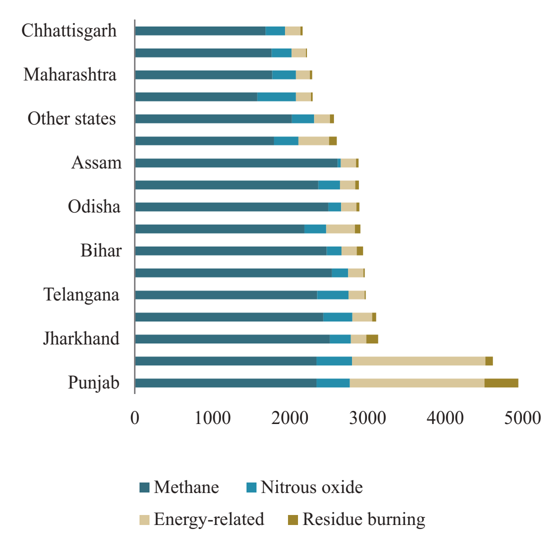
India is the second largest producer of rice after China. The area under rice crop was 30.81 million hectares (Mha) in 1950-51 which has increased to 49.53 Mha during 2022-23, and is the largest area under rice in the world. Assured procurement from government in some states and subsidised power for tube wells are the main factors for the increase in rice cultivation areas even in states like Punjab, which is agro-climatically more suitable to maize cultivation. Conventionally, farmers transplant rice seedlings after puddling the soil (intensive wet tillage) and keep the field continuously flooded for 30–40 days after transplanting. The after-math of rice cultivation is the emission of GHGs, from four sources: first, CH_4 emissions from continuous flooding; second, N_2O emissions from the use of nitrogenous fertilisers; third, CH_4 and N_2O from the burning of residue and finally, the release of CO_2 from energy sources used to pump groundwater for irrigation and for other mechanical operations. National GHG inventory for rice cultivation is based on methane emissions. In this study, we estimated all the four sources of GHG emissions from rice cultivation. During 2022-23, the total GHG emission from Indian rice cultivation was estimated to be 144,031 Gigagram (Gg) CO_2 eq (or 144.03 MtCO_2 eq) at 100-yr GWP. Uttar Pradesh (15,718 Gg CO_2 eq from 6.04 Mha), followed by Punjab (15,675 Gg CO_2 eq from 3.17 Mha) and West Bengal (15,384 Gg CO_2 eq from 5.19 Mha) emitted highest GHGs from rice cultivation. On per hectare basis, Punjab (5,040 Kg CO_2 eq/ha) and Haryana (4,715 Kg CO_2 eq/ha) were top emitters due to higher fertiliser & energy usage and residue burning. Rice cultivation also requires large amount of water (20-25 irrigations as compared to 4-5 in other crops), which is increasingly becoming scarce.

GHG emissions from rice cultivation in India, 2022-23

Total Emissions (Gg CO_2 eq)



Source-wise emissions per ha basis (Kg CO_2 eq/ha)



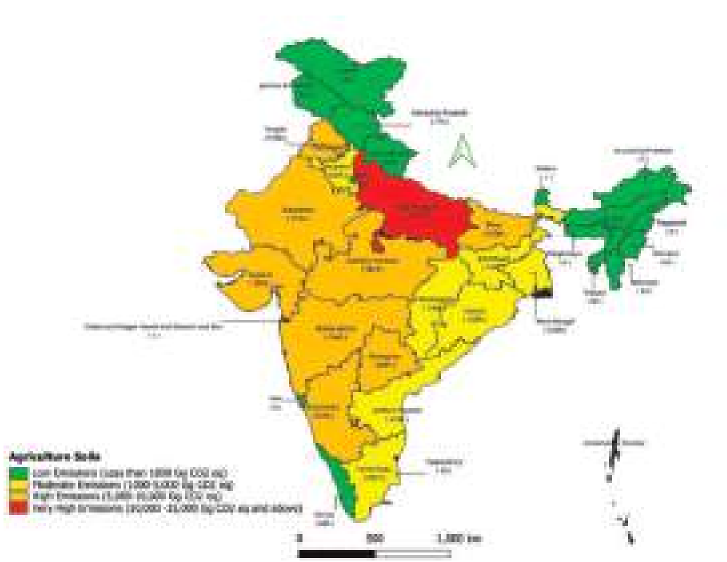
Source: Authors' calculations using LUS 2022-23, CoC Data 2021-22, DES 2024, TIFAC-IARI 2018

2.2 Consumption of synthetic nitrogenous (N) fertilisers in Indian croplands leads to N_2O emissions

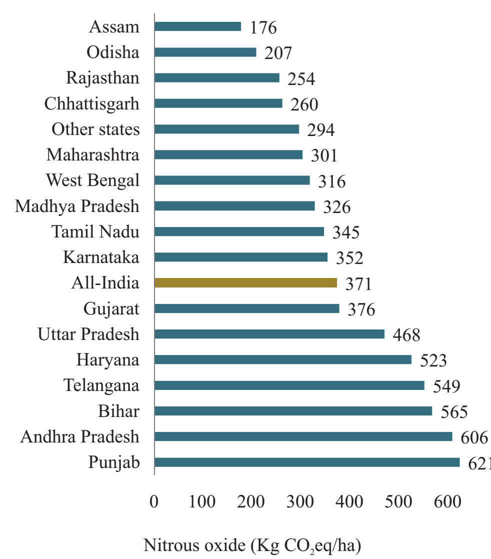
India is the second largest consumer of fertilisers in the world after China, with about 29.8 Mt of total N, phosphate (P_2O_5) and potash (K_2O) used by the agricultural sector in 2022-23 (Fertiliser Statistics 2022-23). Out of this, 20.24 Mt was N consumption. Hugely subsidized urea (often 85 to 90 percent of cost) encouraged higher consumption of N compared to phosphate and potash, with corresponding increase in N_2O emissions. In 2022-23, the N_2O emissions from synthetic fertilisers were estimated to be 53,571 Gg CO_2 eq (or 53.5 Mt CO_2 eq). Other sources of N_2O emissions from agricultural soils of India's gross cropped area (GCA) of 219 Mha are green manuring, production of legumes, forages, crop residue incorporation, mineralisation of soils and urine/dung from grazing livestock. The total emission from agriculture soils was estimated to be 67,552 Gg CO_2 eq (or 67.5 Mt CO_2 eq[4]). Uttar Pradesh emitted the highest N_2O emissions (13,218 Gg CO_2 eq) followed by Madhya Pradesh (9,819 Gg CO_2 eq) and Maharashtra (7,645 Gg CO_2 eq) due to larger area under cultivation and thus, total higher fertiliser application. On per-hectare basis, Punjab (621 Kg CO_2 eq/ha), Andhra Pradesh (606 Kg/CO_2 eq/ha) and Bihar (565 Kg CO_2 eq/ha) are the highest emitters due to high consumption of N-fertilisers.

Nitrous oxide emissions from agriculture soils in India, 2022-23

Total Emissions (Gg CO_2 eq)



Emissions per ha basis (Kg CO_2 eq/ha)



Source: Authors' calculations using LUS 2022-23, fertiliser Statistics 2022-23 DES 2024, 20th Livestock Census Data

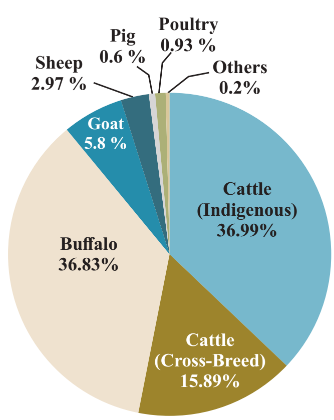
4 This does not include N_2O emission from rice cultivation as they were added in section 2.1

2.3 The large population of bovines is leading to high methane emissions from enteric fermentation.

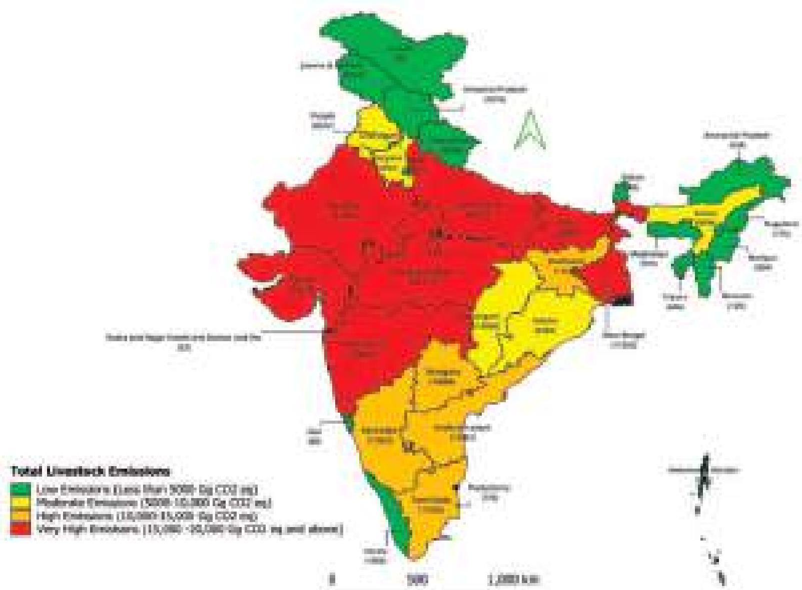
India is ranked first in milk production and possesses the world's largest livestock population of 536.76 million with 193.46 million cattle and 109.85 million buffalo (20th Livestock Census Data). This large bovine population has helped India increase milk production from 17 Mt in 1950-51 to 230.58 Mt in 2022-23 but is responsible for emission of GHGs through Enteric Fermentation (EF). EF is the digestive process of ruminants (largely buffaloes and cows in India) that creates CH_4, which animals release into the atmosphere through belching and exhalation. The CH_4 emission from EF by Indian livestock population was estimated to be 262,856 Gg CO_2 eq[5]. Bovines contribute a bulk of the methane emission from EF - indigenous cattle (37 percent), cross-bred cattle (16 percent) and buffalo (37 percent), followed by small ruminants like sheep (3 percent) and goat (6 percent), and a negligible emission of 0.5 percent from other categories. The emission from manure management of livestock accounts for small emission of 29,478 Gg CO_2 eq. Together, they accounted for 292,248 Gg CO_2 eq per year. Due to high bovine population, Uttar Pradesh (52.03 million), Rajasthan (27.63 million), Madhya Pradesh (29.05 million), and Bihar (23.11 million) are the top emitting states with 46,433 Gg CO_2 eq, 33,259 Gg CO_2 eq, 26,211 Gg CO_2 eq, and 20,283 Gg CO_2 eq emissions, respectively from livestock.

GHG emissions from livestock production in India, 2022-23

% share of emissions from livestock



Total Emissions (Gg CO_2 eq/ha)



Source: Authors' calculations using 20th Livestock Census Data

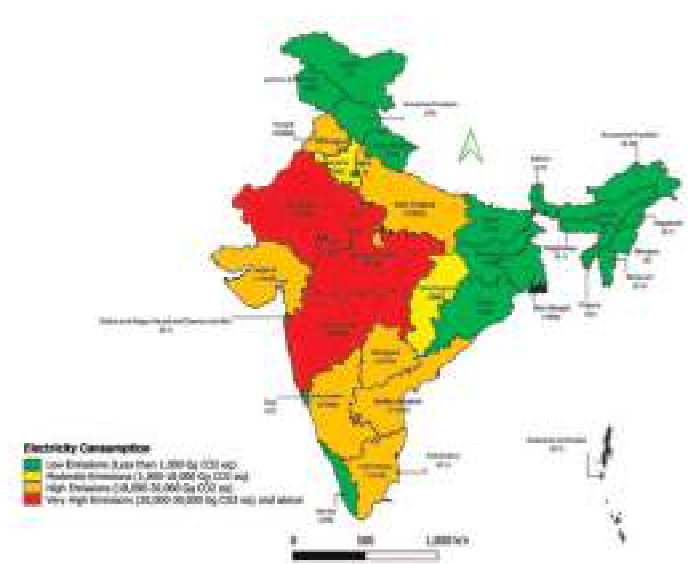
5 Estimated using the country specific methane emission coefficients based on IPCC Tier 2 methodology. 20th Livestock Census Data was used as the activity data.

2.4 Increased electricity consumption in agriculture sector leads to increased CO_2 emissions in energy sector

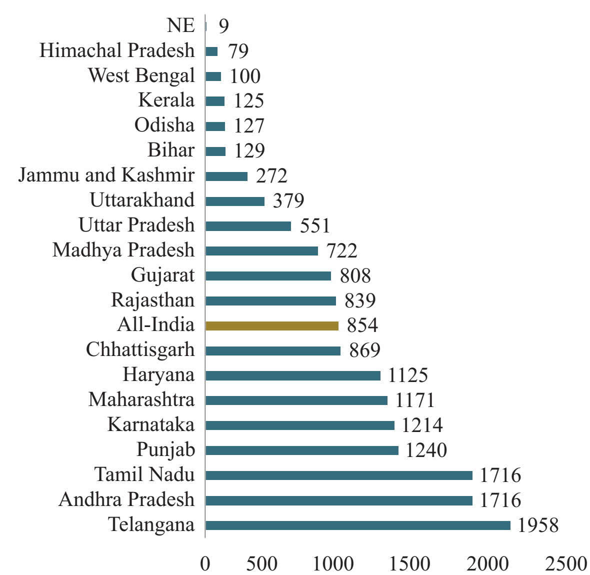
India uses 78 percent of its water resources (sourced from surface water through canals and tanks and groundwater) for irrigation. More than 63 percent of the irrigated area in India is dependent on groundwater (Central Ground Water Report 2021). Subsidised power and irrigation have led to growth in electricity and its consumption in agriculture, particularly for energising irrigation pump sets. During 2022-23, the electricity consumption in agriculture is 240.8 Billion Unit (BU), which is 17.2 percent of the total country's electricity consumption of 1403.4 BU (CERC 2023). This translates to 178,968 Gg CO_2 eq (or 178.9 Mt CO_2 eq[6]) emissions related to electricity consumption in agriculture. Maharashtra (29,727 Gg CO_2 eq) and Rajasthan (23,630 CO_2 eq) have the highest share but per hectare emissions from electricity consumption were highest in Telangana (1,958 Kg CO_2 eq per ha).

GHG emissions related to electricity consumption for agriculture in India, 2022-23

Total emissions (Gg CO_2 eq/ha)



Emissions per ha basis (Kg CO_2 eq/ha)



Source: Authors' calculations using CERC 2022-23, LUS 2022-23

2.5 Total Agriculture production related emissions

In 2022-23, total CH_4 and N_2O emissions from production of crops (include emissions related to rice cultivation, agriculture soils and residue burning) and livestock (include emissions related to enteric fermentation and manure management) were

---

6 Calculated using carbon intensity of 0.82 $kgCO_2/kWh$ (as Central Electricity Authority, Ministry of Power, 2023). This does not include the emissions related to rice cultivation as they were added in section 1.

estimated to be 490 Mt CO_2 eq. After including the emissions related to electricity consumption in agriculture, the total agriculture emissions amounted to 688 Mt CO_2 eq. Of this, livestock emission comprised 292 Mt CO_2 eq (42.5 percent), followed by 178.9 Mt CO_2 eq (27.9 percent) from electricity consumption in agriculture, 144 Mt CO_2 eq (20.9 percent) from rice cultivation, 67.5 Mt CO_2 eq (9.8 percent) from agriculture soil and 5 Mt CO_2 eq (0.7 percent from residue burning).

3. Policy recommendation: aligning policies for a low-carbon footprint agriculture

3.1 Shift from price input subsidy to income subsidy on per hectare

Fertiliser and power subsidies have led to inefficient use of fertilisers (particularly urea), water and electricity with negative environmental consequences and higher GHG emissions. These subsidies are skewed towards rice cultivation, which receives the highest subsidy (₹ 38,973 per hectare in Punjab during 2023-24) amongst its kharif crop counterparts (Singh et al. 2024), even though this crop is GHG intensive (Section 2.1). These incentives need to be "crop neutral" and "input neutral" (Singh & Gulati 2024). By shifting from price subsidy to income subsidy to farmers on per hectare basis either through direct cash transfer or coupons with varying input options (including low-carbon products), farmers can purchase the inputs as per their requirement (including micronutrient fertilisers) and choice (that include bio-inputs, vermicompost, etc).

3.2 Premium support price for low-carbon crops

The Government of India (GoI) procures foodgrains (wheat and rice) at Minimum Support Price (MSP) for buffer stock requirements for PDS and other welfare schemes. Every year the Commission for Agricultural Costs and Price (CACP) recommends the MSP of various crops to the GoI. At present, CACP is not accounting carbon cost while recommending MSP for various commodities. In rice, cultivation practices like Direct Seeded Rice (DSR), Alternate Wetting and Drying (AWD), System of Rice Intensification (SRI) are reported to save up to 2-2.5 t CO_2 eq/ha (Sapkota et al. 2019). To encourage farmers to shift to low carbon footprint rice cultivation practices and low carbon crops such as legumes, and oilseeds, premium support price (which can be linked to the carbon price and can be recommended by

The case for policy alignment of agriculture and low carbon footprint goals

The country's policy direction to a low carbon footprint has so far eluded the agriculture sector. There is a range of instruments governments can take to reduce carbon footprint from agriculture.

- **Support measures:** Shift from price support to direct cash transfer, remunerate provision of soil carbon sequestration, premium support price for low-carbon crops.
- **Economic instruments:** Impose a price on carbon and other GHG gases through trading schemes for carbon emissions.
- **Research and development**: Increase public research and development on sustainable food and agriculture, promote private R&D.
- **Information, education, training and advice:** Increase public awareness for more sustainable patterns of consumption through certification and eco-labelling.
- **Enabling private investment in climate finance:** Strengthening financial incentives (or reducing risks/costs) for private sector investment in agriculture.
- **Solarization of agriculture:** Energy security of farmers need to be secured through solar energy.

CACP) should be offered to farmers. Since farmers respond to price signals through MSP, this measure will not only address food security objectives but will also encourage farmers to grow low carbon crops.

3.3 Performance-Linked Incentives (PLI) for industries that produce low carbon or climate resilient products or commodities for agriculture use

Technological interventions to reduce GHG emissions from agriculture sector would reduce the country's total emissions. Through PLI scheme, the government is supporting manufacturing of PV solar panels. The scheme should be extended to the manufacturers of agriculture-related products that has the potential to reduce emissions. For example, the feed additives for livestock for reducing emissions (e.g. Rumen8), biofertiliser products, nanoproducts, climate resilient seed varieties, etc.

3.4 Agriculture sector offers India the opportunity to lead carbon market for carbon farming credits

The country's agriculture contributes to 490 Mt CO_2 eq of CH_4 and N_2O emissions from agriculture sector and have significant scope for trading carbon under carbon trading system, where one carbon credit unit is equivalent to one tonne of CO_2 emissions. Carbon credits can allow farmers to earn an income for every unit of GHG reduction or sequester from the atmosphere. Indian agriculture has the potential to mitigate 85.5 $MtCO_2$ eq per year, 80 percent of which is delivered by cost-effective options (Sapkota et al. 2019). By mitigating the emissions, farmers can earn 3-5 credits per hectare. The value of one carbon credit depends upon the carbon market price. Farmers are generally paid $15 to $20 per ton of carbon saved/sequestered under agriculture companies' programs. Companies such as fertiliser producers, mining, oil companies, etc. who have higher carbon footprints and have opted for carbon neutrality goals, can offset their emissions by purchasing carbon credits from farmers. National and international companies can pitch in to offset their emissions from Indian croplands and livestock sector and can contribute to the global mission of net zero.

3.5 Complement adaptation with mitigation in agriculture

While innovation played a significant role in the increased gains of productivity of the second half of the 20th century, continuing to focus on productivity alone may lead to natural resource depletion and increased GHG emissions. A shift is needed in approach from increased productivity to sustainably increased productivity. Adaptation can reduce sensitivity and resilience against climate change while mitigation can reduce the rate and extent of the climate change. Therefore, response options to protect agriculture from effects of climate change should include both adaptation and mitigation. Together, they can reduce climate change risks. This will rely on the emergence of new technologies, climate resilient varieties and the adoption of innovative farming practices that encourages economic efficiency and climate performance. This will be possible through investment in agricultural innovation systems that include investments in technological improvements and in education, training and organizational improvements.

3.6 Enabling private investments towards climate financing

One of the key ways to address the rising environmental crisis is through climate financing, a fund meant to address the challenges of climate change through mitigation and climate action. Estimates put the cost of adaptation in a Business as Usual (BAU) scenario for India, to be ₹56.68 trillion till 2030, assuming 2023-24 as the base year of analysis. Climate induced damages could lead to an incremental cost of ₹15.5 trillion by 2030, and the requirements for building adaptation capital stock could be as high as ₹72 trillion after accounting for the country's developmental needs and climate-induced pressures (MoEFCC 2023). At COP15 (Copenhagen 2009), the developed countries had collectively committed to mobilising $100 billion per year by 2020, and at COP 21 (Paris 2015), it was re-emphasized and extended to 2025. During COP 29 (Bali 2024), climate finance agreement proposed triple finance to developing countries, from the previous goal of $ 100 billion annually, to $ 300 billion annually by 2035. This deal was rejected by India. There is a huge gap between the requirement and the allocation of climate funds. In this climate change crisis, the country should enable private sector to invest in building the infrastructure and innovations for mitigation and adaptation for agriculture sector. Of the total country's agriculture R&D expenditure, private sector R&D expenditure in agriculture sector is a mere 11 percent (Year 2020-21, DST 2023), whereas the overall R&D expenditure by private sector in the country comprise the share of 40 percent. Financial incentives (or reducing risks/costs) for private sector investment in agriculture can be encouraged through public finance instruments such as blended finance, credit enhancement, and other targeted risk reduction or revenue-boosting measures, undertaking public-private partnerships for green agricultural research with focus on climate mitigation and adaptation.

3.7 Solarisation of agriculture

Given the sector accounts for 17.2 percent of all the power used in the country, energy security for farmers needs to be secured through solar energy, which will ease financial stress on Distribution Companies (DISCOMS) and reduce emissions. The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PK-KUSUM) scheme is an effort in this direction that aims deploying 10 GW of solar capacity through installation of small solar power plants of capacity up to 2 MW, installing 2 million standalone solar powered agriculture pumps, and solarizing agricultural feeders for 1.5 million grid connected pumps. Diesel and electric pumps for ground water extraction emit 45.3–62.3 Mt CO_2 per year (Rajan et al. 2020). These emissions can be mitigated by replacing them with solar pumps, though it will over-exploit ground water.

In conclusion, it is possible to counter climate change shocks and turn crisis into opportunity. The first step is to cope successfully with climate change, by adapting and building climate resilience in agriculture using climate resilient varieties and practices. India needs to mitigate GHG emissions from agriculture sector. That means cutting down GHGs, ensuring low-carbon agriculture growth, and using new techniques and policies to “build back better.” The key: don't replicate the GHG-intensive practices and crops, but instead build toward improved low-carbon footprint agricultural practices and crops without compromising crop yields and farmer's income. Roughly 130-150 Mt CO_2 eq (85 Mt CO_2 eq from mitigating CH_4 and N_2O and 45-60 Mt CO_2 by replacing solar pumps) can be mitigated from the agriculture sector. The GoI and state governments could align existing natural farming, regenerative farming, organic farming and agriculture solarisation schemes to encourage farmers to participate in carbon credit programmes along with the associated organizations. To ensure quality credits from agriculture, government should fix minimum floor price of $ 20 per credit. Agriculture sector does not have emission reduction targets so the smart move is to begin by offering other sectors and domestic entities to offset their emissions indirectly by purchasing carbon credits from farmers.

1

Introduction

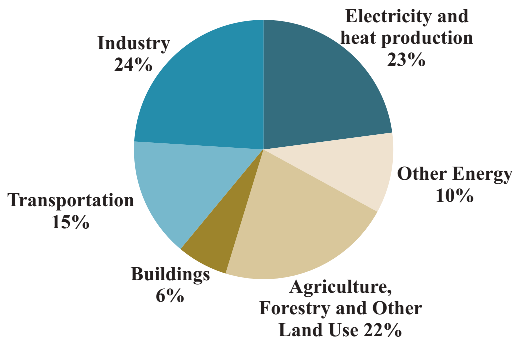
The greenhouse effect is essential to life on Earth, but human-made emissions in the atmosphere are trapping and slowing heat loss to space. Four key GHGs are CO_2, N_2O, CH_4, and chlorofluorocarbons (CFCs). Global net emissions of GHGs have continued to rise from 38 Bt CO_2 eq (in 1990) to 59 Bt CO_2 eq (in 2019) (IPCC 2023). As a result, global surface temperatures rose above pre-industrial levels (1850-1900) by +1.1 °C in the last century. In the last two consecutive years 2023 and 2024, global average temperatures breached the 1.5 °C mark for the first time and climate change was identified as the "biggest threat modern humans have faced". The adverse effects of climate change are already being experienced in the form of increased heatwaves, droughts and floods, mass mortalities in species such as trees and corals, climate migrants and damage to infrastructure.

Amidst current international debate on global warming and climate action, it is noteworthy that United Nations and the international community took some two generations to reach this point. The IPCC, a forum for the exploration of greenhouse warming and global climate change, was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988. IPCC identified climate change as a specific and urgent issue. As a result, significant global efforts started shaping up (**Box 1.1**).

The current global food system is both a major driver of climate change, and increasingly vulnerable to it (from production, transport, and market activities). The link between agriculture and climate change, has been acknowledged since the Rio Declaration in 1992, where food production is Chapter 14 of Agenda 21, to the Paris Agreement of 2015, the preamble of which recognizes the priority to safeguard food security and hunger to the adverse impacts of climate change. This growing prominence of food is reflected in reports of Intergovernmental Panel on Climate Change (IPCC), including its Special Report on Climate Change and Land in 2019, where food security is discussed in Chapter 5. Many countries have included food systems in their mitigation and adaptation plans as found in their NDCs for the Paris Agreement. Climate action is also embodied in the UN's Sustainable Development Goal (SDG) 13.

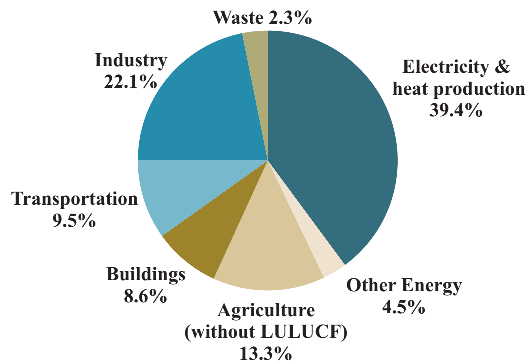
Agriculture, Forestry and Other Land Use (AFOLU) sector contributes 22 percent of total anthropogenic GHG Emissions (IPCC 2023) (**Figure 1.1**). If emissions associated with pre- and post-production activities in the global food system are included, the emissions are estimated to be 21–37 percent of total net anthropogenic GHG emissions (IPCC 2021). In India, land-use and land-use change has been stabilized with non-significant land clearing and deforestation activities. GHG emissions from Indian agriculture primarily comprise crop and livestock production and account for 13.44 percent (421 Mt CO_2 eq) of India's total GHG emissions of 3,132 Mt CO_2 eq (excluding LULUCF) (**Figure 1.2**) (MoEFCC 2021).

Figure 1.1: Global GHG emission by economic sector



Source: IPCC 2023

Figure 1.2: India's GHG emission by economic sector



Source: MoEFCC 2023

Box 1.1

International Approach on Climate Change

International Panel on Climate Change (IPCC) - a forum for the exploration of GHG warming and global climate change, was established in 1988 by the UNEP and the WMO.

United Nations Framework Convention on Climate Change (UNFCCC) - 158 states (including India) signed this framework during Rio de Janeiro, Brazil (Earth Summit) in 1992 to stabilize atmospheric concentrations of GHGs. As of 2025, UNFCCC has universal membership, comprising 198 parties.

Conference of Parties (COP) - the apex decision-making body of UNFCCC. COP members have been meeting every year since 1995 and till date, 29 COP meetings have been organized.

Kyoto Protocol - aimed to reduce the industrialized countries' overall emissions of CO_2 and other GHGs by at least 5 percent below the 1990 levels in the commitment period of 2008 to 2012. The protocol with 192 parties was adopted in 1997 and entered into force in 2005.

Green Climate Fund (GCF) - was established in 2010 within the framework of the UNFCCC as an operating entity of the Financial Mechanism to assist developing countries to counter climate change.

Paris Agreement - 175 countries (now 194 Parties including India) pledged in 2015 to "GHG emission reductions to limit global warming to no more than 2 °C from preindustrial levels and pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels". The UN Countries that have not formally joined the Paris Agreement are Iran, Libya and Yemen. US withdraw from the Paris Agreement during January 2025, the move will be effective in January 2026.

Net-zero Target - As of November 2023, 145 countries had announced or are considering net zero targets, covering a close to 90 percent of global emissions. Among these are China, the EU, the USA and India, who jointly represent more than half of the global GHGs. 137 Countries have pledged to cut carbon emissions and reach net zero by 2050. India has net-zero pledge set for 2070. Eight Countries have already achieved net zero. They are Bhutan, the Comoros, Gabon, Guyana, Madagascar, Nine Panama and Suriname.

Global Methane Pledge - 150 countries in 2022 agreed to reduce global methane emissions at least 30 percent from 2020 levels by 2030, which could eliminate over 0.2°C warming by 2050. India stayed away from this pledge. Currently, 159 countries and European Commission have signed this pledge.

Declaration on Sustainable Agriculture, Resilient Food Systems and Climate Action - 159 countries in 2023 signed declaration to include agriculture and food systems into National Adaptation Plans, NDCs, Long-term Strategies, National Biodiversity Strategies and Action Plans, and other related strategies. India stayed away from this declaration.

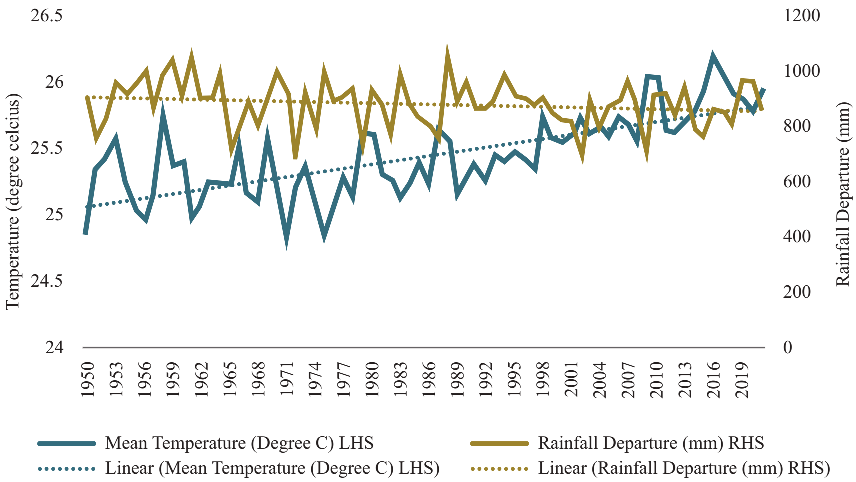
Carbon Markets Agreement - Government-to-government carbon markets agreement under Article 6 of the Paris Agreement has been finalized in 2024. This framework includes Article 6.2 for regulating bilateral carbon trading between countries, where emissions reductions are discounted from national climate plans and Article 6.4 for establishing a global crediting mechanism, allowing nations to sell emissions reductions. India aims to launch its carbon trading market by fiscal year 2027.

1.1 Climate Change Impacts in India

During 1950-2018, average temperatures in the country increased by 0.7°C while the summer monsoon precipitation (June to September) has declined by around 6 percent, with notable decreases over the Indo-Gangetic Plains and the Western Ghats (**Figure 1.3**; MoES 2020). Increase in weather variability with temperatures recorded above 50°C in certain regions and the increased variability in monsoon season (in timing and quantity of rainfall). By the end of the 21st century, average temperature in the country is projected to rise by approximately 2.4°C and 4.4°C relative to the recent past (1976–2005 average), under intermediate emission scenario (RCP 4.5[7]) and high emission scenario (RCP 8.5) respectively.

[7] Projections by climate models are based on multiple standardized forcing scenarios called Representative Concentration Pathways (RCPs). Each scenario is a time series of emissions and concentrations of the GHGs, aerosols, and chemically active gases, as well as LULUC through the 21st century, characterized by the resulting Radiative Forcing in 2100 (IPCC 2013). "'RCP 4.5" is an intermediate stabilization pathway that results in a Radiative Forcing of 4.5 W/m^2 in 2100) and "RCP8.5" is a high concentration pathway resulting in a Radiative Forcing of 8.5 W/m^2 in 2100). During 1901-2018, the data reported is of the actual change.

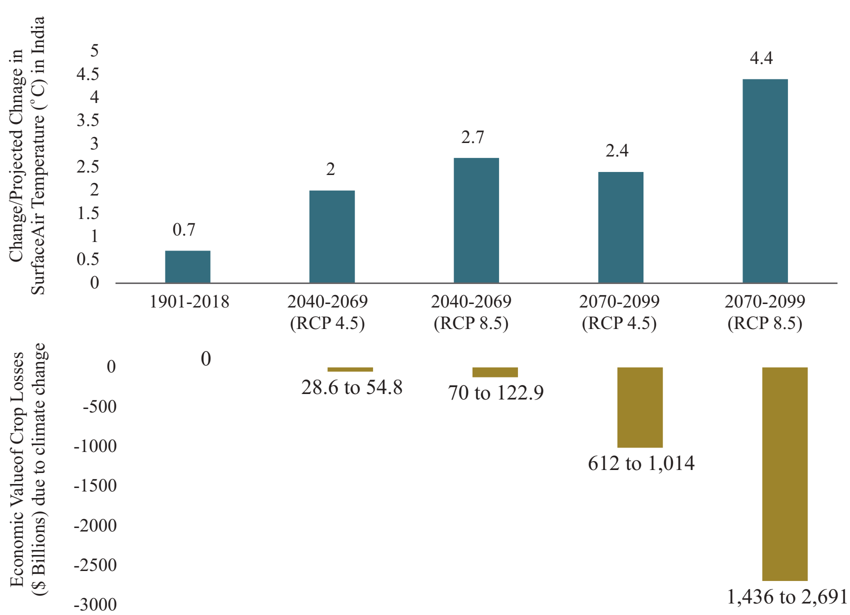
Figure 1.3: Climate Change in India



Source: India Meteorological Department (IMD)

Climate change is harming sectors of the economy that are dependent on the weather such as agriculture (Singh & Gulati 2023a). Despite the achievement of more ambitious NDC targets proposed by countries under intermediate emission scenario, the total economic value of crop loss (including food and non-food crops) in India are projected to be $28.6 to $54.8 billion during 2030–2050, and $612 to $1,014 billion during 2050–2100. In the high emission scenario, total losses for food crops could rise to $70.0 to $122.9 billion during 2030–2050 and $1,436–$2,691 billion during 2050–2100 (MoEFCC 2023) (**Figure 1.4**).

Figure 1.4: Projected Change in surface air temperature (°C) and economic value of crop losses over India under RCP 4.5 and RCP 8.5 emission scenario



Source: MoES (2020), MoEFCC (2023)

1.2 India's Approach to Climate Change

While agreeing to address climate change, India has maintained that "as a developing country, the principles of equity and common but differentiated responsibilities (CBDR) are central for us. India is asking for space for basic development for its people and poverty eradication,". India has argued that its per capita GHG emission levels are much below the levels of developed countries.

Nevertheless, India is actively engaged in multilateral negotiations under the UNFCCC and actions at the national level in terms of ambitious climate change policies under 2008 National Action Plan on Climate Change (NAPCC) with a consistent push for renewable energy, conservation of natural ecosystems, and initiatives for disaster risk reduction and climate change adaptation measures:

Rio to Kyoto Protocol (COP1 (1995) – COP6 (2000): India signed UNFCCC in 1992 and Kyoto Protocol in 2002. India took a strong position on climate justice and fair responsibility. Consequently, the 'Berlin Mandate' was adopted at COP 1 and CBDR became the core principle of UNFCCC.

Copenhagen Summit (COP 7 (2001) to COP 15 (2009): India called for adaptation funds at COP 7 and 'Climate adaptation' was prioritized in the Marrakech Accords. India embraced Clean Development Mechanism (CDM). At COP15, India worked closely through the alliance of BASIC countries - Brazil, South Africa, India and China that represent coalition of emerging economies to counter the increasing pressure that each of them was facing from a largely united US-led North. These developed nations often pressure BASIC countries to taken on greater responsibilities without adequate financial and technological support.

Building up to Paris Agreement (COP 16 (2010)-COP 21 (2015)): India re-emphasized the inclusion of 'loss and damage' into the new agreement. India was one of the pivotal voices at COP 21 and its position was in alignment with its balanced approach to meet its climate change goals while pursuing national interest. India ratified the Paris Agreement in October 2016.

Deliverables to UNFCCC (COP 22 (2016)-COP 27 (2022)): India submitted its NDCs to the secretariat of the UNFCCC shortly before COP 21 in 2015 and committed to

- reducing the emissions intensity of its GDP by 33-35 percent below 2005 levels by 2030,
- achieving 40 percent share of cumulative electric power installed capacity from non-fossil sources by 2030,
- and creating an additional carbon sink of 2.5-3.0 Bt CO_2 eq through additional forest and tree cover by 2030.

Building upon Prime Minister Modi's *Panchamrit* pledges (five nectar elements) at COP26 in Glasgow, including the target of net-zero emissions by 2070, India updated three of its NDCs in August 2022 with the following revised targets (MoEFCC, 2022; UNFCCC, 2022):

- meeting 50 percent of India's cumulative electric power installed capacity from non-fossil sources by 2030.
- reducing the emission intensity of the GDP by 45 percent below 2005 levels by 2030.
- putting forward and further propagating a healthy and sustainable way of living based on traditions and values of conservation and moderation, including through a mass movement for LiFE–Lifestyle for Environment as a key to combating climate change.

India submitted its Long-Term Low Emission Development Strategy (LT-LEDS) during COP 27 in Egypt and identified seven key transitions to low carbon development pathways (MoEFCC 2022): (i) Low carbon development of electricity systems consistent with development; (ii) Develop an integrated, efficient, inclusive low carbon transport system; (iii) Promote adaptation in urban design, energy and material-efficiency in buildings, and sustainable urbanisation; (iv) Promote economy-wide decoupling of growth from emissions and development of an efficient, innovative low emission industrial system; (v) CO_2 removal and related engineering solutions; (vi) Enhancing forest and vegetation cover consistent with socio-economic and ecological considerations; and (vii) Economic and financial aspects of low carbon development.

Climate Finance and intergovernmental carbon market (COP 28 (2023)-COP 29 (2024)):

At COP29, the focus was on setting a new climate finance target for developed countries to help climate-vulnerable nations beyond 2025. A consensus was reached to provide $300 billion annually by 2035, which is a notable rise from the current $100 billion. However, countries like India, Nigeria, Bolivia, and Cuba advocated for a significantly higher target of $1.3 trillion per year. This led to visible dissatisfaction, with the Alliance of Small Island States (AOSIS) and Least Developed Countries (LDCs). India rejected this finance deal.

COP29 reached an agreement on intergovernmental carbon markets as outlined in Article 6 of the Paris Agreement. India aims to launch its carbon trading market by fiscal year 2027.

1.3 Context and objectives of report

Agriculture is a biological production process where production and productivity are dependent on climatic conditions. Any disruption in climate change like in temperature, precipitation, drought, solar radiation, etc. affect the agriculture ecosystem. Emissions from agriculture have been rising on a yearly basis since 1994 (base year for calculating emissions). As per National Inventory, total agricultural emissions in India in 1994 (base year for GHG emissions calculations) was 344 million tonnes carbon-dioxide equivalent (Mt CO_2 eq), which rose to 356 CO_2 eq in 2000 and 421 Mt CO_2 eq in 2019, which is 13.44 percent of the country's total emissions (MoEFCC 2023). After adding the CO_2 emissions related to consumption of fertilisers, pesticides and electricity for agriculture, the share of agriculture-related GHG emissions are much higher.

As a result of agriculture's large footprint, relatively small changes in agricultural practices, which may have a modest impact per acre, can affect this sector's contribution to climate change if they are widely implemented. Small changes can also improve farmers' and cattlemans' ability to adapt to the changing climate. So far, agricultural emissions have not been addressed by India, owing to perceived fear of negative impact of food production and livelihood concerns. It may also be due to small holder nature of Indian agriculture, where promoting good agricultural practices (GAP) that lead to low carbon agriculture could be a challenge fuelled by lack of political will. Given the future increase in demand on food and land use systems due to growing population, GHG emissions from this sector will rise in the country. Identification of agriculture emission hotspots and mitigation options might help prioritize efforts to cut down emissions without compromising food and nutrition security.

This report estimates the agricultural emissions at the state level, reviews GHG mitigation opportunities in the agricultural sector, and presents recommendations. While we recognize that the boundaries between the forestry and agricultural sectors are permeable, we have focused ou GHG emission estimations for 2022-23 and recommendations on achieving emission reductions and removals within the agricultural sector at the state level, which are as follows:

1.3.1 | Crop sector emissions:

Rice cultivation

The anaerobic decomposition of organic material in flooded rice fields produces CH_4, which escapes to the atmosphere, mostly by transport through the rice plants. The CH_4 emissions depend on the number and duration of crops grown, water regimes before and during the cultivation period, and organic and inorganic soil amendments, soil type, temperature, and rice cultivar.

Soil management and soil amendments

Direct and indirect emissions of N_2O occur from soils following increases in available N from:

- Synthetic N fertilisers and organic fertilisers (e.g., animal manure, compost).
- Urine and dung that is deposited onto pastures and agriculture land.
- Incorporation of crop residues into soils and N-fixation by legumes.
- N mineralization.

Burning of crop residues

Crop residue burning releases CH_4 and N_2O.

1.3.2 | Livestock sector emissions

Enteric fermentation

CH_4 is produced in herbivores as a by-product of EF, where carbohydrates are broken down by bacteria in the digestive tract. The amount of CH_4 that is produced depends on:

- the type of animal - ruminant livestock (cattle and buffalo) foster extensive EF and high CH_4 emissions.
- quantity and composition of feed.
- age and size of livestock.

Manure management

Manure management releases CH_4 and N_2O. CH_4 is emitted during the storage and treatment of manure under anaerobic conditions. N_2O is emitted directly or indirectly from stored or treated manures.

1.3.3 | Electricity consumed

The associated emissions (mainly CO_2) will depend on the mix of fuel types and technologies used on the grid concerned.

Emissions related to rice cultivation, agriculture soils, burning of crop residues, EF and manure management are 'direct agricultural emissions', which are those emissions found in agricultural GHG emissions inventories of the country. These inventories include N_2O and CH_4 emissions. Emissions related to electricity consumption in agriculture are captured in the energy section of national emission inventories. This report focuses on the agriculture related emissions so we included it as a key component of the agriculture sector.

2

Methodological framework

This section describes the types of activity data, assumptions and approaches needed to calculate GHG fluxes from agricultural sector. The calculation approaches differ in how they map onto the various tiers defined by the IPCC for national inventory reporting (see Box 2). We used IPCC Tier 2 methodology, but it may not be very effective in capturing the geographical variation and farm management practices that underpin GHG fluxes. The emissions from pre-production (i.e. fertiliser production, pesticide production etc.) and post-production stages (i.e., transportation, supply chain, waste, etc.) are not included in this study.

Box 2.1

IPCC Methodologies for National GHG Emissions Inventories

The IPCC has developed a comprehensive set of methodologies - the 2006 IPCC Guidelines for National GHG Inventories - to guide the preparation of national inventories. The guidelines define three general tiers of methodologies based on their complexity and data requirements. The choice of tier depends on the significance of the emissions sources under consideration.

- **Tier 1:** Simple, emission factor-based approach. Tier 1 emission factors are international defaults, although they are based on studies conducted in a select few (mostly temperate) countries.
- **Tier 2:** More region-specific emission factors or more refined empirical estimation methodologies.
- **Tier 3:** Dynamic bio-geophysical simulation models using multi-year time series and context-specific parameterization.

These tiers provide a useful way to categorize and understand the likely accuracy of the different calculation methods available. Tier 3 methods are considered most accurate and Tier 1 methods are least accurate.

Source: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

2.1 Methodological framework for estimating GHG emissions from rice cultivation

India is reporting CH_4 related emission factors for rice cultivation within the national inventories submitted to United Nations. The aftermath of rice cultivation is the emission of GHGs, from four sources: first, CH_4 emissions from continuous flooding; second, N_2O emissions from the use of nitrogenous fertilisers; third, CH_4 and N_2O from the burning of residue and finally, the release of CO_2 from energy sources used to pump groundwater for irrigation and for other mechanical operations. National GHG inventory for rice cultivation is based on CH_4 emissions. This study focuses on the total emissions related to rice cultivation so we estimated all the four sources of GHG emissions for understanding the complete picture.

2.1.1 | Methane emission

Anaerobic decomposition of organic material in flooded rice fields produces CH_4 that is produced through two major pathways (Takai, 1970; Conrad 1989):

- Reduction of CO_2 with H_2, with fatty acids or alcohols as hydrogen donor,

  $CO_2\,(aq.) + 4H_2 = CH_4 + 2H_2O$

- Transmethylation of acetic acid or methanol by methane-producing bacteria

  $CH_3COO- + H_2O = CH_4 + H\,CO-$

The following steps were used to compute methane emission inventory for 2022-23.

2.1.1.1 Harvest paddy area under IPCC rice water regimes

The water regime in the rice growing season is continuous flooding, single drainage period, multiple drainage periods, flood-prone rain-fed, drought-prone rainfed, deep water and upland (**Table 2.1**).

Table 2.1: Water regime in the rice growing season

Variable	Description	
Upland	Fields are never flooded for the significant period of time.	
Irrigated fields are flooded for a significant period of time and the water regime is fully controlled	Continuous flooding	Fields have standing water throughout the rice growing season and may only dry out for harvest (end-season drainage).
	Single drainage period	Fields have a single drainage event and period during the cropping season at any growth stage, in addition to the end of season drainage.
	Multiple drainage periods	Fields have more than one drainage event and period of time without flooded conditions during the cropping season, in addition to an end of season drainage, including alternate wetting & drying.

Variable	Description	
Rainfed and deep water Fields are flooded for a significant period of time with water regimes that depend solely on precipitation.	Rainfed, regular/flood-prone	Fields are flood prone and the water level may rise up to 50 cm during the cropping season.
	Rainfed, drought-prone	Fields are drought-prone and the drought period occurs during every cropping season.
	Deep water	In fields, the water level rises to more than 50 cm above the soil for a significant period of time during the cropping season.

Source: 2019 Refinement to IPCC 2006 guidelines, IPCC 2019

The total state-wise paddy harvested area was taken from LUS 2024. Based on the published studies of IRRI (1997), Gupta et al. (2008) and IARI (Pathak et al. 2010; Bhatia et al. 2013), state-wise rice harvested area was divided into upland, irrigated, rain-fed and deep-water rice area[8]. The irrigated rice area in each state was subdivided into irrigated continuously flooded, irrigated single drainage period and irrigated multiple-drainage periods. Rain-fed area in each state was divided into rain-fed drought-prone and rain-fed flood-prone. The study included a scoping visit to Ludhiana, Punjab where discussions with agronomists, soil scientists, rice breeders and climate scientists of Punjab Agriculture University (PAU) and farmer groups were held during June 2022 to understand their views regarding the water regimes of rice cultivation in Punjab.

2.1.1.2 Emission coefficients for methane

India specific emission factor of each water management regime was used for calculating CH_4 emissions for the particular rice ecosystem in a state (**Table 1.2**).

---

[8] Data for different water management regimes for rice cultivation in India is not documented. Assumptions have been made based on published studies that are a bit outdated and not based on surveys. It is recommended that detailed survey regarding rice water regime areas across states needs to be carried out for accurate estimation of methane inventory.

Table 2.2: Emission factors for different water regimes

Rice Cultivation	Water Regimes	Emission (Kg CH_4/ha)
Irrigated	Continuously Flooded	162 Kg CH_4 /ha
	Single Aeration (Drainage Period)	66 Kg CH_4 /ha
	Multiple Aeration (Drainage Periods)	18 Kg CH_4 /ha
Rain-fed	Drought prone	66 Kg CH_4 /ha
	Flood prone	190 Kg CH_4 /ha
Deep water	Deep water	190 Kg CH_4 /ha
Upland		0

Source: Gupta et al. 2008, Pathak et al. 2010, Bhatia et al. 2013, MoEFCC 2021

2.1.1.3 *Computation of methane emission inventory (total emissions and emissions per hectare)*

The total annual emissions were equal to the sum of emissions from each sub-unit of harvested area under different water management regime and were calculated as IPCC 2006 methodology (Tier 2, country specific) using the following equation (MoEFCC 2018):

$$E_{RC}\ \text{Rice} = \Sigma_{ijk}\, EF_{i,j,k} \cdot A_{i,j,k} \cdot 10^{-6}$$

where:

E_{RC} = CH_4 emissions from rice cultivation (Gg per year)

$E_{i,j,k}$ = a seasonal integrated country-specific emission factor for i, j, and k conditions, Kg CH_4 / ha

$A_{i,j,k}$ = annual harvested area of rice for i, j, and k conditions, ha per year

i, j, and k = represent different ecosystems, water regimes, under which CH_4 emissions from rice may vary

10^{-6}= to convert Kg into Gg.

The CH_4 emissions were estimated by multiplying the seasonal emission factors by the annual harvested areas. Harvested area for each sub-unit (state in our estimate) was multiplied by the respective emission factor that was representative of the water management regimes that define the states. Total emission (state-wise) was converted into Gg CO_2 eq by multiplying calculated CH_4 emissions by 27.2 (which is the 100-yr GWP as per the Sixth Assessment Report of IPCC (IPCC 2021). Emission per hectare (state-wise) was calculated by dividing the total emission of the state by total GCA of rice that was taken from LUS 2024.

2.1.2 | Nitrous oxide emission

Direct emissions of N_2O, from soils result from the following processes (IPCC 2006):

- **Nitrification:** The aerobic microbial oxidation of ammonium ions to nitrate through ammonium hydroxide and nitrite:

  NH_4^+ → NH_2OH → NO_2^- → No_3^-
  (Ammonia) (Ammonium hydroxide) (Nitrite) (Nitrate)

- **Denitrification:** The anaerobic microbial reduction of nitrate successively to nitrite and then to the gases NO, N_2O and N_2:

NO_3^- → NO_2^- → NO → N_2O → N_2

(Nitrate) (Nitrite) (Nitric oxide) (Nitrous oxide) (Nitrogen)

- **Chemo denitrification:** The chemical reduction of nitrite ion to N_2O by compounds such as amines present in soil organic matter, and by inorganic ions (Fe^2+, Cu^2+) (Granli and Bøckman, 1994).

Emissions of N_2O in rice cultivation result from anthropogenic N inputs (IPCC 2006) in soil through

- Direct pathway i.e., directly from the soils through synthetic fertilisers and compost, and
- Indirect pathways
  - through volatilization of ammonia (NH_3) & nitrogen oxide (NO_x) and the subsequent re-deposition of these gases & their products (NH_4 and NO_3) to soils
  - leaching and run off of N, mainly as No_3.

Calculations are based on the IPCC 2006 methodology (Tier 2, country specific) as mentioned in Pathak et. al. (2010), Bhatia et al. (2013) and MoEFCC (2018) described below:

2.1.2.1 Direct N_2O emissions

Data on state-wise N-fertiliser consumption by paddy (in kg/ha) was derived from the Cost of Cultivation data (2021-22) provided by the Ministry of Agriculture. By multiplying the crop- N-fertiliser consumption rates by the area under paddy cultivation (in hectares), the total N-fertiliser consumption (in kg) was estimated for paddy. In instances where fertiliser consumption data was unavailable for a particular state, the proxy data from neighbouring states was employed to facilitate the estimation process.

The total annual direct emissions were calculated using the following equation

N_2O direct –N = {(FSN + FON)* EF1}

where:

N_2O direct-N denotes direct N_2O-N emissions from rice cultivation (Gg per year).

FSN denotes the annual amount of un-volatilized and un-leached synthetic fertiliser N (Kg) applied to soil during rice cultivation.

FON denotes the annual amount of un-volatilized and un-leached organic N (from FYM) applied (Kg) to soil during rice cultivation.

Ef1 denotes country specific emission coefficient from N-fertilisers, kg N_2O-N/kg N.

Notes:

(I) We have not considered direct N additions due to rice residue returned to soil annually. The IPCC default value is 25 percent. In India, rice residues are used for fuel, feed and other domestic purposes, and in Punjab, Haryana and western Uttar Pradesh, majority of the rice straw is burnt. Very little of the crop residues are incorporated in the field (Bhatia et al. 2013) and we have assumed it to be insignificant for direct N_2O emissions.

(ii) We have considered direct N additions due to organic soils as zero. Organic soils contain more than 12–18 percent of organic carbon. In India, the highest range reported is 4.1 percent organic carbon (Bhatia et al. 2013). In the present estimation, area under organic soil for rice cultivation has been taken as zero. N_2O emission due to mineralization of organic N is calculated in relation to mineralization of C and since Indian soils are very poor (with less than 1 percent organic carbon range), we have assumed it to be insignificant for direct N_2O emissions.

2.1.2.2 In-Direct N_2O emissions

15 percent of the nitrogen loss per kg of urea and other N-fertilisers from volatilization of NH_3 and NOx was considered, instead of the IPCC fraction of 10 percent (Bhatia et al 2013., MoEFCC 2021). 10 percent of the N applied to the soil was considered to be lost through leaching (Bhatia et al.2013, MoEFCC 2021).

The total annual indirect emissions were calculated using the following equation:

N_2O Indirect –N = N_2O (V)-N + N_2O (L) –N

where:

N_2O Indirect - N denotes indirect N_2O-N emissions from rice cultivation (Gg per year).

N_2O (V) - N denotes the annual amount of N_2O–N produced from atmospheric deposition of N volatilized from rice fields, kg N_2O–N per year.

N_2O (L) – N denotes the annual amount of N_2O-N produced from leaching and runoff of applied fertiliser and animal manure N from rice fields, kg N_2O–N per year.

N_2O (V) – N = [(FSN * $Frac_{SNV}$) + ((FON + $Frac_{ONV}$)] * EF2

where:

$Frac_{SNV}$ denotes the fraction of synthetic fertiliser N that volatilizes as NH_3 and NOx, kg N volatilised (kg of N applied).

$Frac_{ONV}$ denotes the fraction of applied organic N fertiliser materials (FON) that volatilizes as NH_3 and Nox, kg N volatilized (kg of N applied or deposited).

EF2 denotes country specific emission coefficient for volatilized N from fertilisers, kg N_2O-N/kg N.

N_2O (L) – N = [(FSN * $Frac_{SNL}$) + ((FON + $Frac_{ONL}$)] * EF3

where:

$Frac_{SNL}$ denotes the fraction of N lost through leaching of synthetic fertiliser N, (kg of N leached).

$Frac_{ONL}$ denotes the fraction of N lost through leaching of organic fertiliser N, (kg of N leached).

EF3 denotes country specific emission coefficient for leached N from fertilisers, kg N_2O-N/kg.

2.1.2.3 *Total N_2O emissions*

Total emissions of N_2O-N from rice cultivation were estimated using the following equation.

N_2O-N TOTAL = N_2O-N DIRECT + N_2O-N INDIRECT

Conversion of N_2O–N emissions to N_2O emissions was done using the following equation:

N_2O = N_2O–N *44/28

Total emission (state-wise) was converted into Gg CO_2eq by multiplying calculated N_2O emissions by 273 (which is the 100-yr GWP and 20-yr GWP as per Sixth Assessment Report of IPCC (IPCC 2021).

2.1.2.4 *Emission coefficients for N_2O*

India specific N_2O emission factors were used for calculating N_2O emissions (**Table 2.3**)

Table 2.3: N_2O Co-efficients

Parameter	Country-specific coefficient
N_2O emissions from N fertilisers	0.58 %
N_2O emissions from volatilized N from fertilisers	0.5 %
N_2O emissions from leached and run off N	0.5 %
Gas lost through volatilization from inorganic N fertiliser	15 %
Leaching loss of N from applied fertiliser	10 %

Source: MoEFCC 2021

2.1.3 | Non-CO_2 GHGs from rice residue burning

Rice residue is burnt in the fields in Punjab, Haryana, and western Uttar Pradesh producing carbon monoxide (CO), CH_4, N_2O, Nitrogen oxides (NOx), non-methane hydrocarbons (NMHCs), sulphur dioxide (SO_2) and many other gases. In this paper, non-CO_2 GHG emissions (CH_4 and N_2O) have been reported.

Non-CO_2 GHG emissions from crop residue burning were calculated using the equation given below.

$$E_{RB} = R_B * CF * EF * 10^{-9}$$

where:

E_{RB} = Emissions from rice residue burning (Gg per year).

R_B = Rice Residue burnt (dry matter in Kg).

CF = Combustion Factor (0.89 for rice, Source: MoEFCC 2021).

EF = Factor applied for CH_4 and N_2O (g/kg dry matter).

10^{-9} = to convert g into Gg.

The state-wise data on surplus rice residue has been taken from TIFAC-IARI Report (2018). It was assumed that the surplus residue in the state was burnt. The emission factors from residue burning (2.70 g CH_4/Kg) of dry matter and 0.07 g N_2O/Kg of dry matter was used in the present study (MoEFCC 2021).

2.1.4 | Carbon-dioxide emissions from energy use in rice cultivation

Ploughing, cultivation, sowing, irrigation, manufacturing, and application of inputs like fertilisers and pesticides, and harvesting require diesel and electricity, leading to CO_2 emissions. The energy use for rice cultivation is different in various parts of the country due to differences in climate, soil, method of cultivation, farm mechanization, electricity availability, and economic status of farmers. There is no documentation of state-wise energy use for rice cultivation. Different groups of researchers have reported energy use and related CO_2 emissions from rice cultivation in selected regions (**Table 2.4** and the same has been used in this study for calculating state-wise CO_2 emissions from energy use in rice cultivation.

Table 2.4: CO_2 emissions (Kg/ha) from energy use

Agro-climatic Region	Average Rain-Fall	States	CO_2 Kg/ha	Reference
Gangetic Plain Region				
Middle Gangetic Plains (MGP)	100-200 cm	Eastern U.P. and Bihar		Gupta et al. 2015
		Puddled Rice (MGP)	326	
		Aerobic Rice (MGP)	203	
Lower Gangetic Plains (LGP)	100-200 cm	West Bengal, Eastern Bihar		Pathak et al. 2005
		Puddled Rice (LGP)	197	
		Aerobic Rice (LGP)	198	
Eastern Himalayan Region (EHR)	200-400 cm	Assam		Considered to be similar as that of LGP reported by Pathak et al. 2005
		Puddled Rice (EHR)	197	
		Aerobic (EHR)	198	
Eastern Plateau and Hills (EPH)	80-150 cm	Jharkhand, Odisha, Chhattisgarh		Considered to be similar as that of LGP reported by Pathak et al. 2005
		Puddled Rice (EPH)	197	
		Aerobic Rice (EPH)	198	
Central Plateau and Hills (CPH)	50-100 cm	Madhya Pradesh, Rajasthan		Considered to be similar as that of Southern Plateau and Hills reported by Basavalingaih et al. 2020
		Puddled Rice (CPH)	207	
		Aerobic Rice (CPH)	86	
Southern Plateau and Hills (SPH)	50-100 cm	Maharashtra, Andhra-Pradesh, Karnataka, Tamil-Nadu		Basavalingaih et al. 2020
		Puddled Rice (SPH)	207	
		Aerobic Rice (SPH)	86	

Source: MoEFCC 2021

2.2 Methodological framework for estimating GHG emissions from livestock

2.2.1 | Methane emissions

Data on state-wise livestock population was taken from the 20th Livestock Census (Livestock Census 2019). CH_4 emissions from EF was calculated by multiplying the selected emissions factors with the associated animal population (IPCC equation 10.19):

Emissions = $EF_{(T)}.(N_{(T)}/10^6)$

where:

Emissions = CH_4 emissions from Enteric Fermentation, Gg CH_4 per year

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 per head per year (Refer Table 2.5)

$N_{(T)}$ = the number of head of livestock species/category T in the country

T = species/category of livestock

Emissions from all livestock categories were added to get the total CH_4 emissions from EF. CH_4 emissions from manure management was calculated by multiplying the selected emissions factors with the associated animal population (IPCC equation 10.22) given below:

$$CH_4 Manure = \sum_T (EF_{(T)} * N_{(T)})/10^6$$

where:

$CH_4 Manure$ = CH_4 emissions from Manure Management, Gg CH_4 per year

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 per head per year (Refer Table 2.5)

$N_{(T)}$ = the number of head of livestock species/category T in the country

T = species/category of livestock

Emissions from all livestock categories were added to get the total CH_4 emissions from manure management.

2.2.2 | Nitrous oxide emissions

N_2O emissions from manure management were calculated by multiplying the selected emissions factors with the associated animal population (MoEFCC 2012):

$$N_2O_{Animals} = \sum_T (EF_{(T)} * N_{(T)})/10^6$$

where:

N_2O animals = N_2O emissions from manure management, Gg CH_4 per year

$EF_{(T)}$ = emission factor for the defined livestock population, kg N_2O per head per year (Refer Table 2.5)

$N_{(T)}$ = the number of head of livestock species/category T in the country

T = species/category of livestock

Emissions from all livestock categories were aggregated to get total N_2O emissions from manure management.

Table 2.5: Methane and nitrous oxide emission coefficients for Indian livestock

Livestock Category	Methane Emission Coefficient (Kg CH_4/animal/year)				Nitrous Oxide Emission Coefficient (Kg N_2O/animal/yr)
	Enteric Fermentation		Manure Management		
	Country Specific Coefficient (MoEFCC 2004)	IPCC 1996 (Default Values)	Country Specific Coefficient (MoEFCC 2004)	IPCC 1996 (Default Values)	Country Specific Coefficient/IPCC default values (MoEFCC 2004)
Indigenous Dairy Cattle	28±5	46	3.50	5.5	0.0006
Cross-Breed Dairy Cattle	43±5	46	3.80	5.5	0.0006

Livestock Category	Methane Emission Coefficient (Kg CH_4/animal/year)				Nitrous Oxide Emission Coefficient (Kg N_2O/animal/yr)
	Enteric Fermentation		Manure Management		
Non-Dairy Cattle (Indigenous)		25		2.0	0.0004
Below 1 year	9±3		1.20		–
1–3 years	23±8		2.80		–
Above 3 years (adults)	32±6		2.90		–
Non-Dairy Cattle (Exotic)		25		2.0	0.0004
Below 1 year	11±3		1.10		–
1–3 years	26±5		2.30		–
Above 3 years (adults)	33±4		2.50		–
Dairy Buffalo	50±17	55	4.40	4.9	–
Non-Dairy Buffalo		55		4.9	–
Below 1 year	8±3		1.80		–
1–3 years	22±6		3.40		–
Above 3 years (adults)	44±11		4.0		–
Other Livestock					
Sheep	4±1	5	0.18	0.16	–
Goat	4±1	5	0.18	0.17	–
Horse and Pony	18	18	1.60	1.0	–
Mule, Donkey	–	10	0.96	1.0	–
Camel	–	46	1.96	1.0	–
Pig	–	1	4.37	1.0	0.0074
Poultry					0.0025

Source: Author's compilation

2.3 Methodological framework for estimating GHG emissions from agricultural soils

This methodology estimates N_2O emissions using human-induced net N additions to soils (e.g., synthetic, or organic fertilisers, deposited manure, crop residues). The emissions of N_2O that result from anthropogenic N inputs occur through a direct pathway (directly from the soils to which the N is added/released), and through two indirect pathways: (i) following volatilisation of NH_3 and NOx from managed soils and from fossil fuel combustion and biomass burning, and the subsequent re-deposition of these gases and their products NH_4+ and NO_3- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3-, from managed soils.

2.3.1 | Direct N_2O emissions

The following N sources are included for estimating direct N_2O emissions from agricultural soils:

- synthetic N fertilisers (FSN);
- organic N applied as fertiliser (e.g., animal manure, compost) (FON); urine and dung N deposited soils by grazing animals (FPRP); N in crop residues (above-ground and below-ground), including from N-fixing crops and from green manures (FCR);

The following N sources are not included for estimating direct N_2O emissions from agricultural soils:

- N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils (FSOM); (as land-use changes in India are not significant) and
- Drainage/management of organic soils (i.e., Histosols) (FOS) (as India does not have areas under organic soils with 12-18 percent of organic carbon content.

Data on state-wise annual consumption of synthetic N fertilisers, organic compost (urban and rural compost) and area under green manuring was gathered from the Fertiliser Statistics 2022-23.

The total annual direct emissions were calculated using the following equation (IPCC 2996):

N_2O direct –N = {(FSN + FON + FCR) * EF1} + FPRP*EF PRP

where:

N_2O direct-N denotes direct N_2O-N emissions from agricultural soils (Gg per year).

FSN denotes the annual amount of un-volatilized and un-leached synthetic fertiliser N (Kg) applied to soil.

FON denotes the annual amount of un-volatilized and un-leached organic N (from FYM) applied (Kg) to soil.

FCR denotes the annual amount of N in crop residues[9] (above ground and below ground), including N-fixing crops, and from green manures, returned to soil, Kg N.

FPRP = annual amount of urine and dung N deposited by grazing animals on agricultural soil, kg N per year.

EFL denotes country specific emission coefficient from N-fertilisers, kg N_2O-N/kg N.

EF PRP denotes emission factor for N_2O emissions from urine and dung N deposited on agricultural soils by grazing animals, kg N_2O–N (kg N input).

The calculations were done as per the tier 2 methodology of 2006 IPCC Guidelines for National GHG inventories. Emissions coefficient was used as given in Table 2.3 of section 2.1.2.4.

---

9 The IPCC default value for residue incorporation is 25 percent. In India, residues are used for fuel, feed, and other domestic purposes and in Punjab, Haryana and western Uttar Pradesh, the majority of rice straw is burnt. We have considered 5 percent of crop residues to be incorporated in the field (Bhatia et al. 2013).

2.3.2 | Indirect N_2O Emissions

15 percent nitrogen loss per kg of urea and other N-fertilisers from volatilization of NH_3 and NOx was considered, instead of IPCC fraction of 10 percent (Bhatia et al. 2013, MoEFCC 2021). 10 percent of the N applied to the soil was considered to be lost through leaching (Bhatia et al 2013., MoEFCC 2021).

The total annual indirect emissions were calculated by the following equation:

N_2O Indirect –N = N_2O (V)-N + N_2O (L) –N

where:

N_2O Indirect - N denotes Indirect N_2O-N emissions from agricultural soils (Gg per year).

N_2O (V) - N denotes the annual amount of N_2O–N produced from atmospheric deposition of N volatilized from agriculture fields, kg N_2O–N per year.

N_2O (L) – N denotes the annual amount of N_2O-N produced from leaching and runoff of applied fertiliser and animal manure N from agriculture fields, kg N_2O–N per year.

N_2O (V) – N = [(FSN * $Frac_{SNV}$) + (FON + $Frac_{ONV}$) + (FCR + $Frac_{CRV}$)] * EF2

where:

$Frac_{SNV}$ denotes the fraction of synthetic fertiliser N that volatilizes as NH_3 and NOx, kg N volatilised (kg of synthetic N applied).

$Frac_{ONV}$ denotes the fraction of applied organic N fertiliser materials (FON) that volatilizes as NH_3 and Nox, kg N volatilized (kg of organic N applied or deposited).

Frac CRV denotes the fraction of applied crop residues N (FCR) that volatilizes as NH_3 and NOx, kg N volatilized (kg of N applied or deposited).

EF2 denotes country specific emission coefficient for volatilized N from fertilisers, kg N_2O-N/kg N.

N_2O (L) – N = [(FSN * $Frac_{SNL}$) + (FON + $Frac_{ONL}$) + (FCR + $Frac_{CRL}$)] *EF3

where:

$Frac_{SNL}$ denotes the fraction of N lost through leaching of synthetic fertiliser N, (kg of N leached).

$Frac_{ONL}$ denotes the fraction of N lost through leaching of organic fertiliser N, (kg of N leached).

Frac CRL denotes the fraction of N lost through leaching of crop residues N, (kg of N leached).

EF3 denotes country specific emission coefficient for leached N from fertilisers, kg N_2O-N/kg

Emissions coefficient was used as given in **Table 2.3** of section 2.1.2.4.

2.3.3 | Total N_2O emissions

Total emissions of N_2O-N from agriculture soils were estimated using the following equation.

N_2O-N TOTAL = N_2O-N DIRECT + N_2O-N INDIRECT

Conversion of N_2O–N emissions to N_2O emissions was done using the following equation:

N_2O = N_2O–N * 44/28

Total emission (state-wise) was converted into Gg CO_2 eq by multiplying calculated N_2O emissions by 273 (which is the 100-yr GWP and 20-yr GWP as per Sixth Assessment Report of IPCC (IPCC 2021).

2.4 Methodological framework for estimating GHG emissions from electricity consumption in agriculture

State-wise electricity consumption for agriculture use was taken from Agriculture Statistics at a Glance (2024). CO_2 emissions from electricity use was calculated using the equation.

CO_2 = EC * EF

where,

EC denotes electricity consumption for agriculture use (in Kwh)

EF denotes the emission factor (carbon intensity of 0.82 kgCO_2/kWh was used by Central Electricity Authority, Ministry of Power, 2023).

3

GHG emission estimates from rice cultivation

The total harvested area of rice for the reference year 2022-23 was 49.53 mha (LUS 2024). Of the total rice area, 62 percent was irrigated, 9 percent was rain-fed upland, 3 percent was deep-water and the remaining 26 percent was rain-fed lowland. Refer Table 3.1.

Table 3.1: Area (000 ha) under different rice ecosystems in various states

State/Union Territories	Total Harvested area	Upland area	Irrigated area	Rain-fed and deep-water area				
			Continuous Flooding	Single drainage period	Multiple drainage period	Deep water	Regular/ Flood-prone	Drought prone
Assam	2308	577	249	233	233	283	519	637
Andhra Pradesh	2289	0	719	1044	487	70	0	0
Bihar	3091	272	664	906	393	242	151	393
Chhattisgarh	3759	531	417	531	417	0	0	1895
Gujarat	892	0	153	243	117	0	0	387
Jharkhand	1445	112	27	27	14	27	312	841
Haryana	1281	0	966	242	242	0	0	0
Karnataka	1398	199	307	460	214	0	0	0
Madhya Pradesh	2109	263	242	303	242	0	0	970

State/Union Territories	Total Harvested area	Upland area	Irrigated area	Rain-fed and deep-water area				
Maharashtra	1652	372	93	93	47	0	186	791
Odisha	3948	806	564	322	363	121	887	967
Punjab	2969	0	893	1283	614	0	0	0
Tamil Nadu	2217	20	612	877	388	20	61	61
Telangana	3655	0	716	1062	508	23	0	0
Uttar Pradesh	5703	170	1534	1079	2272	57	227	341
West Bengal	5586	558	893	1507	446	446	670	1060
Other States & Union Territories	1932	243	435	447	533	41	200	264

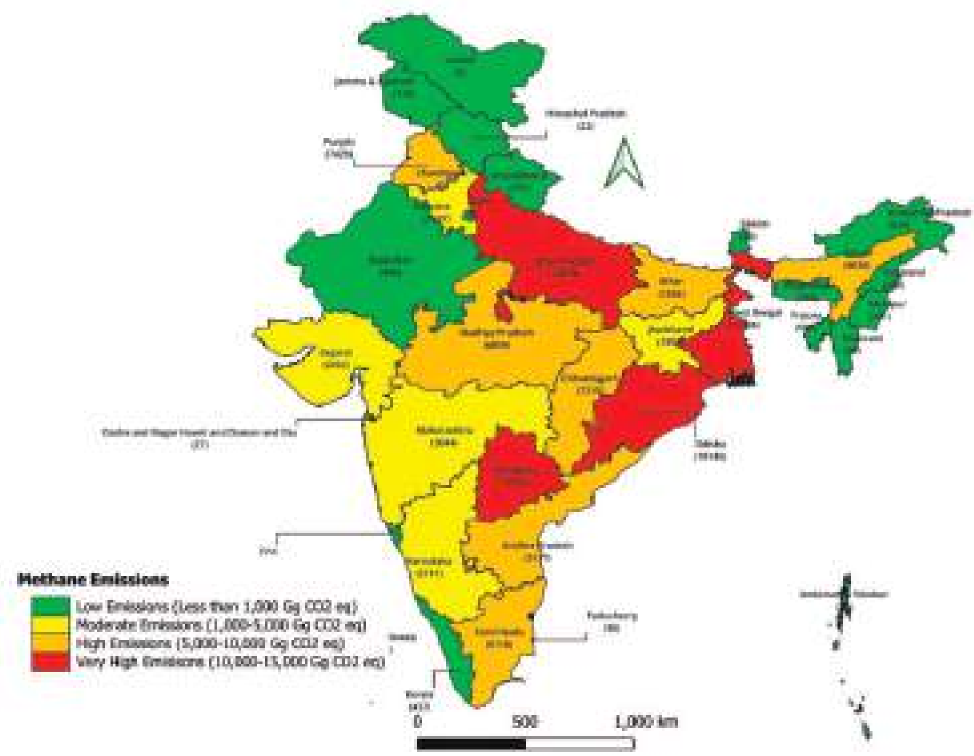
Source: Author's estimate based on (1997), Gupta et al. (2008) and IARI (Pathak et al. 2010; Bhatia et al. 2013)

3.1 State-wise methane emission estimate

Total emission of CH_4 from rice cultivation in India was estimated to be 3,982.8 Gg, which is 108,333 Gg CO_2 eq (100-yr GWP) and 321,810 Gg CO_2 eq (20-yr GWP) for 2022-23. The highest emission was from irrigated continuously flooded rice (38 percent) followed by irrigated single drainage period (20 percent), rain-fed flood-prone (16 percent), rain-fed drought-prone (15 percent), deep-water (7 percent), and irrigated multiple drainage periods (4 percent) rice ecosystems. The state-wise CH_4 emission (at 100-yr) under different rice ecosystem for the year 2022-23 is given in **Annexure 1.**

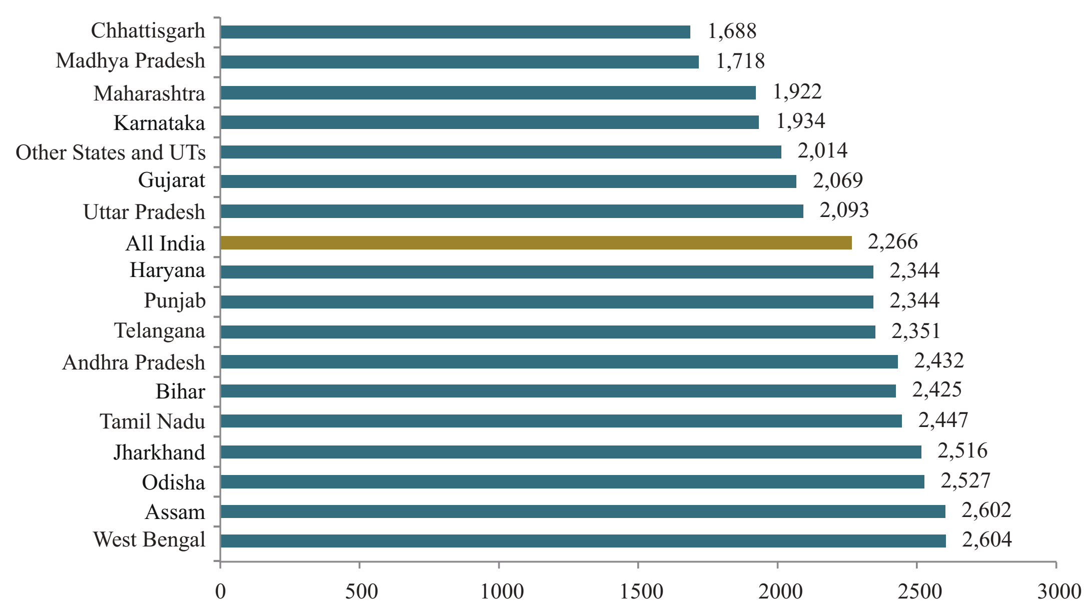
50 percent of the methane from rice cultivation came from five states: West Bengal (13,188 Gg CO_2 eq from 5.19 Mha), Telangana (11,562 Gg CO_2 eq from 4.96 Mha), Uttar Pradesh (10,839 Gg CO_2 eq from 6.04 Mha), Odisha 10,145 Gg CO_2 eq from 4.06 Mha) and Bihar (7,266 Gg CO_2 eq from 2.94 Mha) mainly due to high rice cultivation area (**Figure 3.1**). CH_4 emissions per hectare of rice ranged from 308-2604 kg CO_2 eq per hectare (ha) (at GWP 100-yr) and West Bengal, Assam, Orissa, Bihar, and Jharkhand, emitted higher amount of methane per ha of rice (**Figure 3.2**) due to larger rice ecosystems of deep water and rain-fed areas.

Figure 3.1 Hot-spots of methane emissions from rice cultivation in India



Source: Author's estimate based on MoEFCC 2021, IPCC Sixth Assessment Report 2021

Figure 3.2: State-wise methane emission (Kg CO_2 eq/ha) from rice cultivation

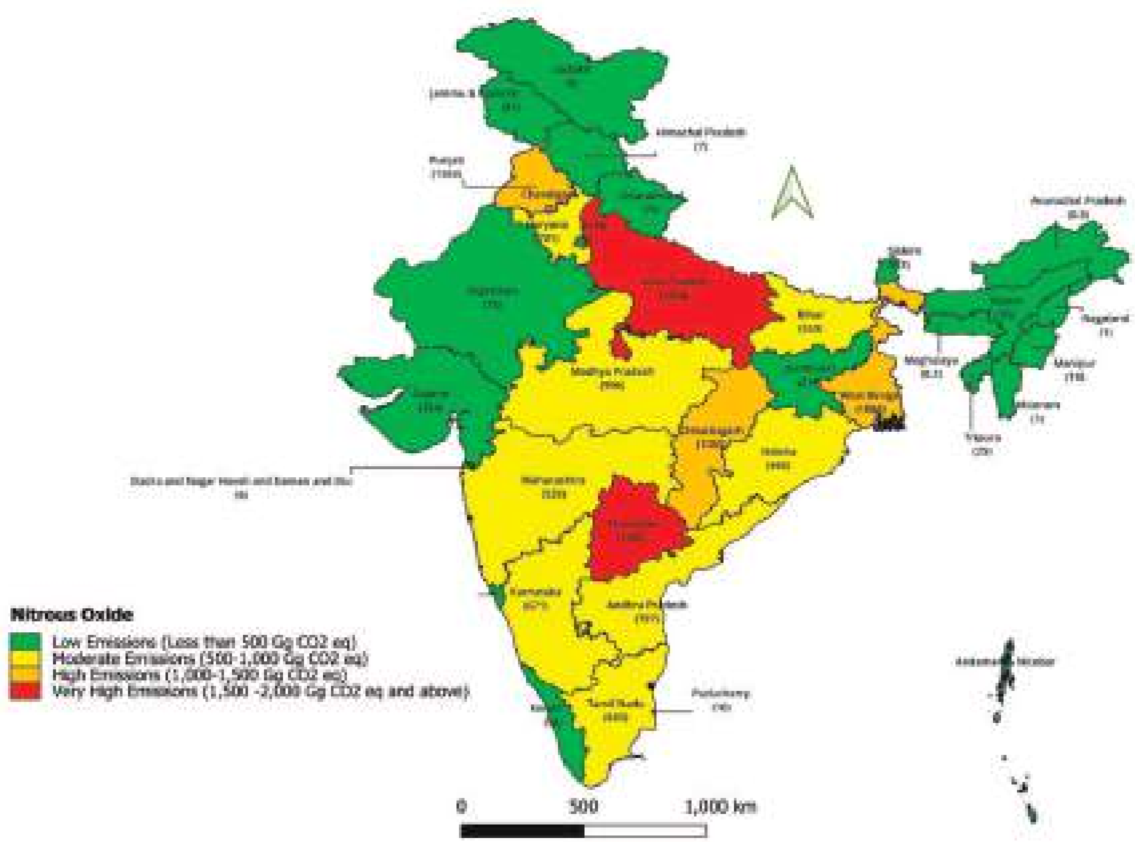


Source: Author's estimate based on MoEFCC 2021, IPCC Sixth Assessment Report 2021

3.2 State-wise nitrous oxide emission estimates

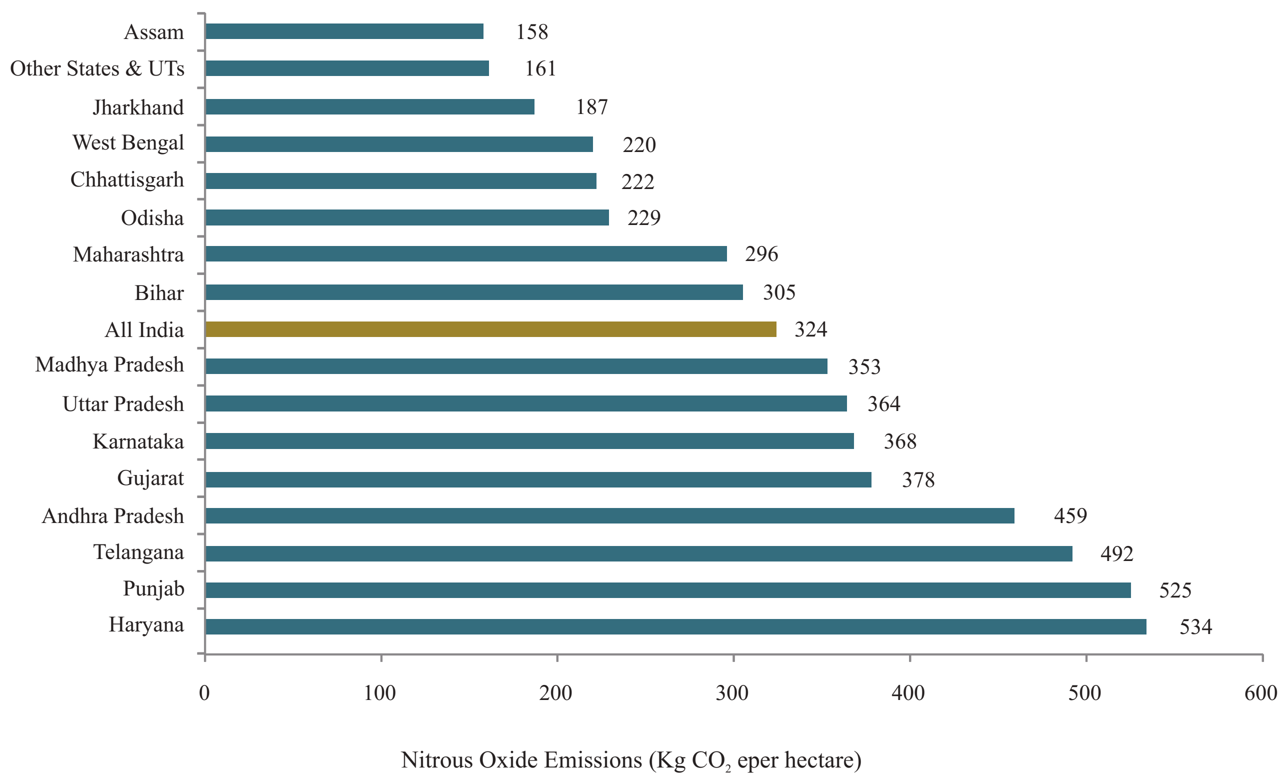
Total N_2O emission estimated for rice cultivation was 50.9 Gg, which is equivalent to 13,897 Gg CO_2 eq for the base year 2022-23. The direct emission of N_2O-N was estimated to be 10,702 Gg CO_2 eq, and the indirect N_2O-N emission was 2,713 Gg CO_2 eq from the re-deposition of volatilized and leached fertiliser. 427 Gg CO_2 eq was emitted from FYM N inputs to soil. There were significant differences in the extent of N use in various states. Telangana emitted the highest N_2O-N (2,005 Gg CO_2 eq) followed by Uttar Pradesh (1,904 Gg CO2 eq), Punjab (1363 Gg CO_2 eq), Chhattisgarh (1,085 Gg CO_2 eq) and West Bengal (1,084 Gg CO_2 eq) (**Figure 3.3**). However, on per-ha basis, Haryana (@ 534 Kg CO_2 eq/ha), Punjab (@ 525 Kg CO_2 eq/ha), Telangana (@ 492 Kg CO_2 eq/ha), Andhra Pradesh (@ 459 Kg CO_2 eq/ha), and Tamil Nadu (@ 388 Kg CO_2 eq/ha) emitted higher amount of N_2O (**Figure 3.4**) due to higher application of the synthetic fertilisers for higher targeted yields in rice.

Figure 3.3: Hot-spots of nitrous oxide emissions from rice cultivation in India



Source: Author's estimate based on Cost of Cultivation data (2021-22) and fertiliser Statistics (2022-23)

Figure 3.4: State-wise nitrous oxide emission (Kg CO_2 eq/ha) from rice cultivation in India

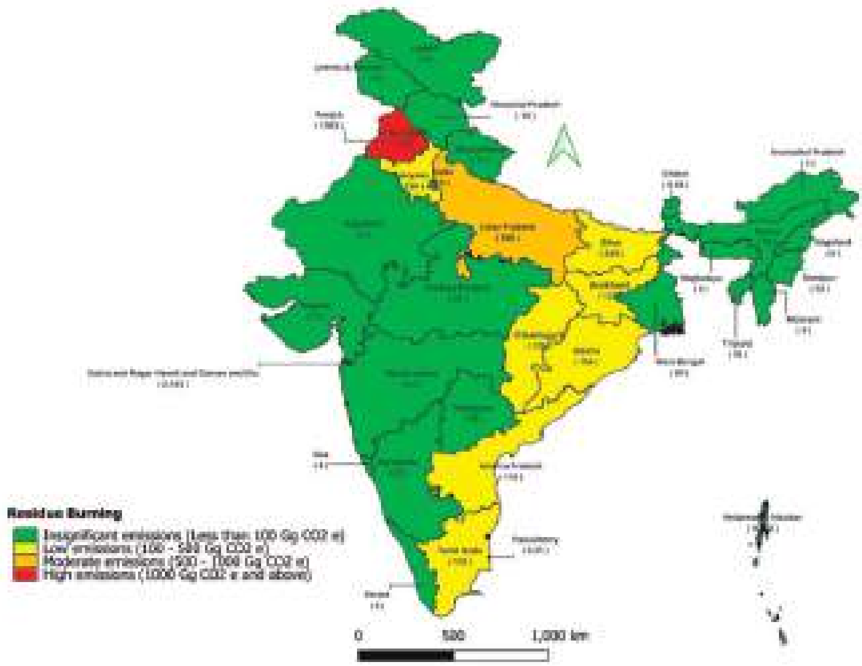


Source: Author's estimate based on Cost of Cultivation (2021-22), fertiliser Statistics (2022-23)

3.3 State-wise non-CO_2 GHG emissions from rice residue burning

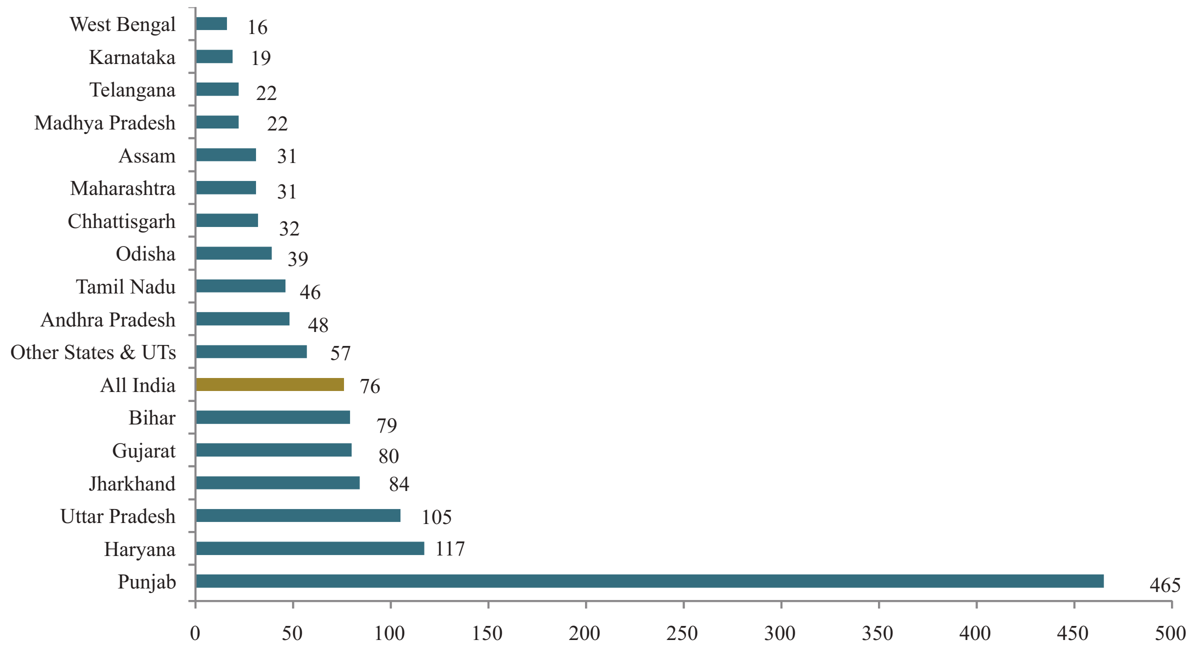
Surplus rice residue in the country was estimated to be 43 million tons (**Annexure 2**). Large-scale burning of rice residues in Punjab, Haryana, and western Uttar Pradesh causes GHG emission, poses a health hazard and leads to loss of nutrients. Based on the surplus rice residues estimates by TIFAC-IARI (2018), cumulative emissions from field burning of rice residues were 2,828 Gg CO_2 eq of CH_4, and 736 Gg CO_2 eq of N_2O (**Annexure 1**). We observed that Punjab emitted the highest methane (1,097 Gg CO_2 eq) and N_2O (286 Gg CO_2 eq) (**Figure 3.5**) total as well as per hectare basis (**Figure 3.6**).

Figure 3.5: Hot-spots of non-CO_2 GHG emission from burning of rice residues in India



Source: Author's estimate using TIFAC-IARI Joint Report (2018)

Figure 3.6: State-wise non-CO_2 GHG emission (Kg CO_2 eq/ha) from burning of rice residues in India

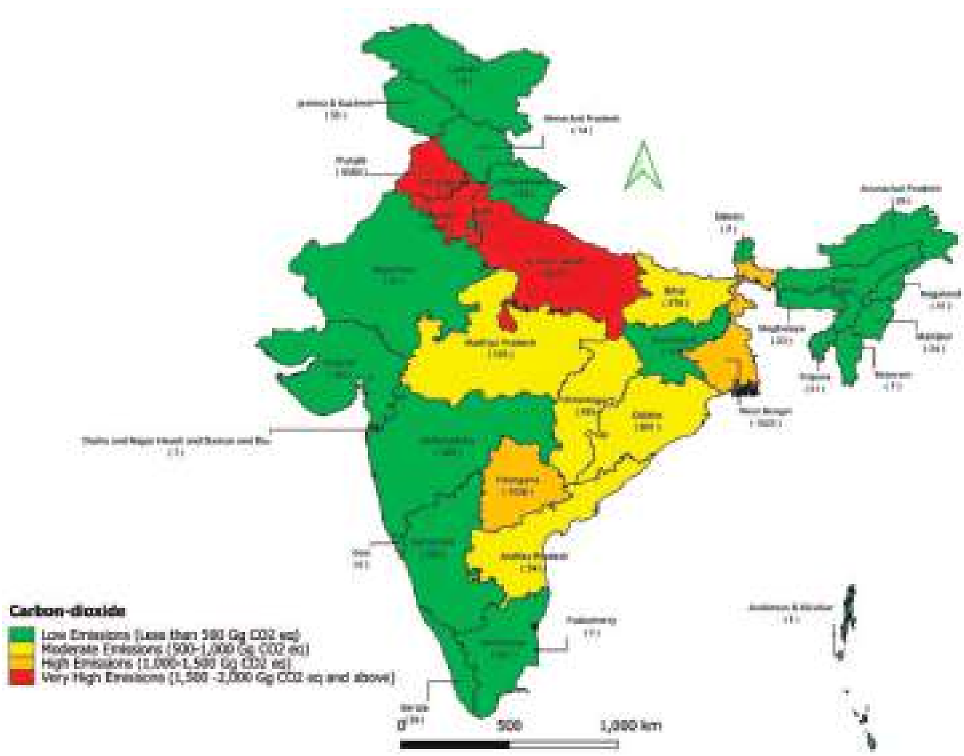


Source: Author's estimate based on TIFAC-IARI Joint Report (2018)

3.4 State-wise carbon dioxide emission estimates from energy sources used for rice cultivation

Total CO_2 emissions estimated was 18,272 Gg CO_2 eq for the base year 2022-23. The state-wise CO_2 emission for 2022-23 is given in **Figure 3.7**. Due to high dependence on electricity operated pumps for ground-water extraction, Punjab and Haryana were the highest emitters.

Figure 3.7: Hot-spots of carbon-dioxide emission from energy sources used for rice cultivation in India

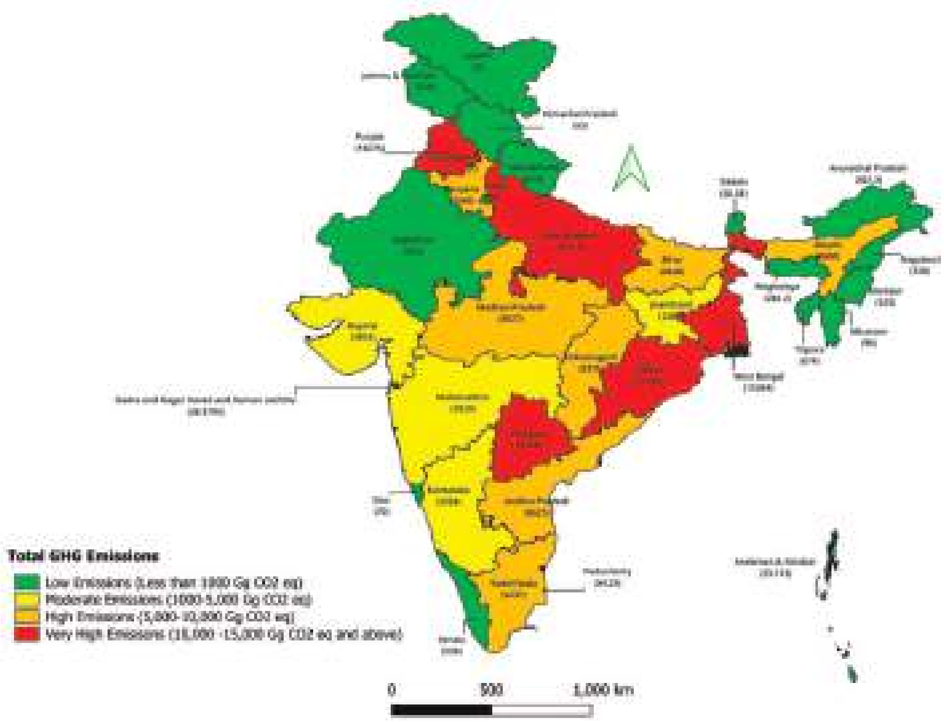


Source: Author's estimate based on Pathak et al. (2005), Gupta et al. (2015) and Basavalingaih et al. 2020

3.5 Total green-house emission from rice cultivation

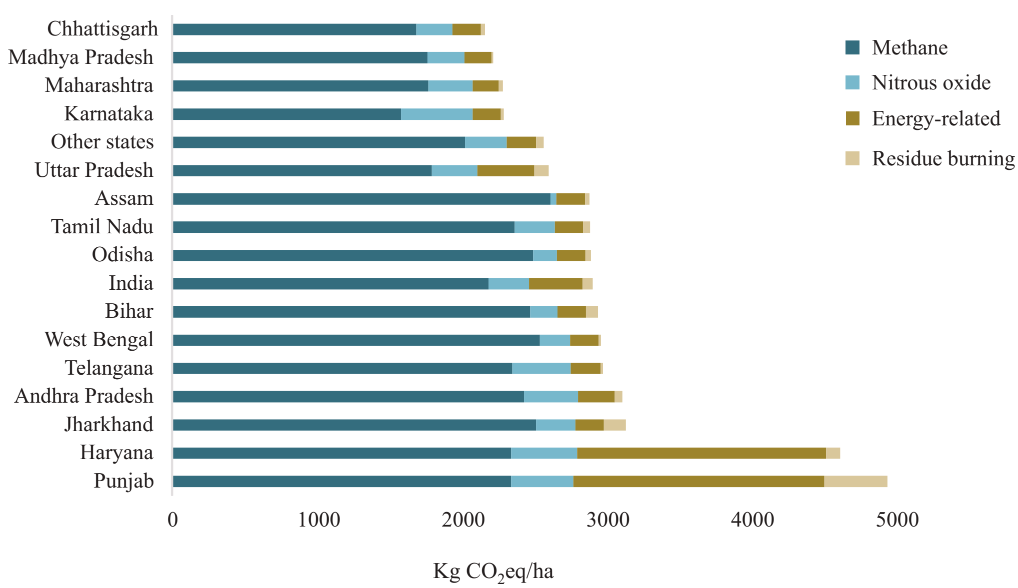
The total GHG emission from Indian rice cultivation for 2022-23 was estimated to be 144,031 Gg CO_2 eq at 100-yr GWP. Uttar Pradesh, followed by West Bengal emitted the highest GHG from rice cultivation (**Figure 3.8**) due to high rice cultivation area. But, Punjab (5,040 Kg CO_2 eq/ha and Haryana (4,715 Kg CO_2 eq/ha (**Figure 3.9**) emitted highest on per hectare basis owing to higher fertiliser & energy usage and residue burning.

Figure 3.8: Hot-spots of total GHG emissions from rice cultivation in India



Source: Author's estimate

Figure 3.9: Source-wise GHG emissions from rice cultivation (Kg CO_2 eq per hectare) in different states of India



Source: Author's Estimate

Box 3.1

Comparison of our rice cultivation GHG estimates with National GHG Inventory

Our estimates are approximately double than the national GHG inventory estimates of 73,437 Gg CO_2 eq from rice cultivation (MoEFCC 2023):

(I) India's GHG emission from rice cultivation is based on 2019 base year data, for which rice cultivation area was 43.19 mha. Our estimates are based on 2022-23 base year data where the rice cultivation area was 49.53 mha.

(ii) National inventory uses GWP 21 (as per IPCC Second Assessment Report 1996) for CH_4 emission calculations and we have used the latest GWP 27.2 (as per IPCC Sixth Assessment Report 2021). If we use GWP 27.2 for the same rice cultivation data of national inventory then on carbon equivalent terms, methane emission values of national inventory would become 95,118 Gg CO_2 eq. This figure is comparable to our methane estimate of 108,332 Gg CO_2eq.

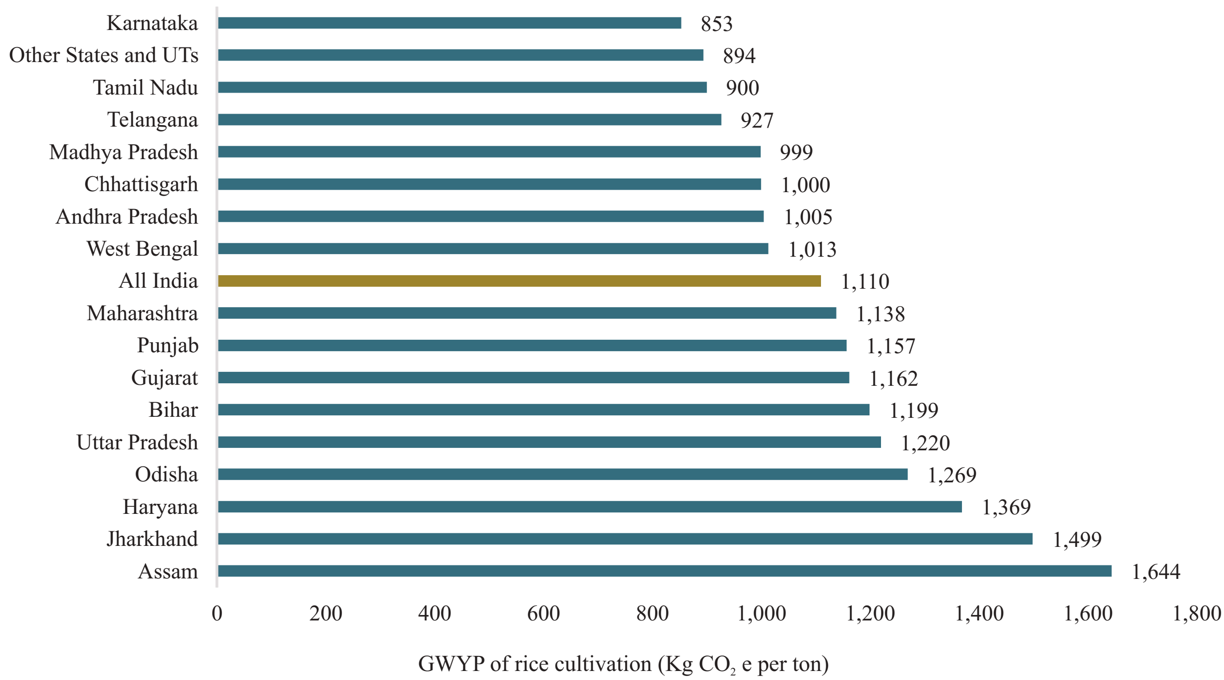
(iii) National GHG inventory for rice cultivation is based on CH_4 emissions. GHG released by rice cultivation have four major sources: first, CH_4 emissions from irrigated rice production; second, N_2O emissions from nitrogenous fertilisers use; third, CH_4 and N_2O from the burning of residue and fourth the release of CO_2 from energy sources to pump groundwater for irrigation and for other mechanical operations. This study focuses on the total emissions from rice cultivation, so we estimated all four sources of GHG emissions.

This is the first study that has estimated state-wise GHG emissions from all sources of rice cultivation. This understanding provides a basis for conservation and GHG mitigation for low-carbon rice production.

Global Warming Yield Potential (GWYP)

GHG emission intensity per tonne of rice production was highest in Assam (1,644 Kg CO_2 eq/t), Jharkhand (1,499 Kg CO_2 eq/t) and Haryana (1,369 Kg CO_2 eq/t) (**Figure 3.10**). Increased rice production of Punjab is the result of adoption of high-yielding rice varieties and better crop management practices. The application of N fertiliser and irrigation increased the GHGs in Punjab but the increase in yield was greater and an overall GWYP of Punjab is comparatively low compared to states such as Assam and Jharkhand where the yield was low.

Figure 3.10: State-wise global warming yield potential of rice cultivation (Per Tonne)



Source: Author's estimates based on Agriculture Statistics 2022-23

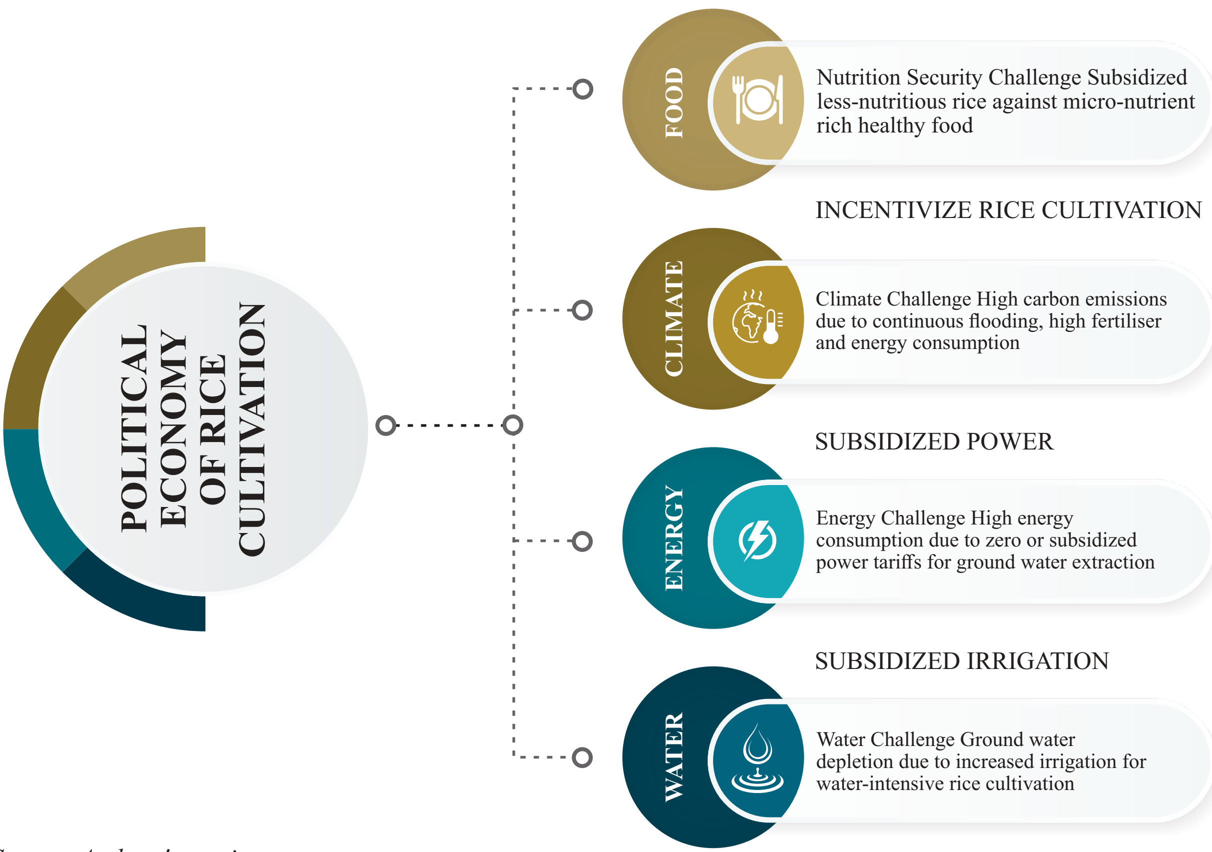
3.6 Mitigating GHG emissions from rice cultivation

Rice produced under continuous flooding is the most carbon-intensive plant-derived carbohydrates (Pathak et. al. 2014), producing GHG emission of 3500-3700 Kg CO_2 eq/ha. This is 3-4 times of rice produced under intermittent flooding (900-1050 Kg CO_2 eq/ha), 8-10 times of wheat (340-450 Kg CO_2 eq/ha) and maize (320-365 Kg CO_2 eq/ha), 12-15 times of millets (230-250 Kg CO_2 eq/ha) and oilseeds (220-275 Kg CO_2 eq/ha), 15-20 times of pulses (180-240 Kg CO_2 eq/ha), and 6-8 times of vegetables (440-475 Kg CO_2 eq/ha) (although this is still small compared to animal products) (Pathak et al. 2014).

The overall emission trend from rice cultivation is greatly influenced by rice cultivation area, water management regimes, fertiliser use and energy use. Whilst GHG emissions from rice are reported to be constant in last two decades as the rice cultivation area is also same through out (44-45 million hectares). As per India's National GHG Inventory for 2019, CH_4 from rice cultivation contributes 13.8 percent of India's anthropogenic CH_4 emissions, 17.4 percent of the country's agriculture sector GHG emissions, and 2.3 percent of the country's total GHG emissions (MoEFCC 2023). In reality however, climate impacts of the Indian rice cultivation sector go beyond what appears under rice cultivation category in the GHG inventory reports (**Box 3.1**) and requires interventions for reducing its carbon footprint.

With respect to rice and wheat, domestically, government intervention is large. First it supports increasing the production of these staples by announcing MSPs, procuring these for the central pool, and then distributing these through public distribution system (PDS). During KMS 2022-23, 84.6 million metric tonnes (MMT) of paddy was procured at MSP value of ₹1,744 billion. Also, it encourages production through heavy input subsidies like fertilisers (₹2513 billion in 2022-23), and highly subsidised power by states (e.g. free power in Punjab and ₹0.10/kwh in Haryana). These policies resulting from the political economy of the day, have led to a very complex but interconnected situation of food security-water-energy-and environment (**Figure 3.11**). This is particularly so in major rice producing Indian states.

Figure 3.11: Political economy of rice cultivation



Source: Authors' creation

Rice is in one segment where India registers trade surplus by way of being a net exporter and thus showcases an area of our inherent strength. While China is the leading rice producing nation globally, India occupies the second position; however, as regards export of rice, India tops the chart as the major exporting nation. In Financial Year (FY) 2021-22 total rice production was 129.5 MMT which had significantly increased upto 135.8 MMT tonnes in FY 2022- 23 and has scaled to 137.8 MMT in FY 2023-24. The rice exports were also substantial. In 2021-22, India exported 21.22 MMT of rice (export value $9.37 billion), which increased to 22.35 MMT (export value $11.15 billion) in 2022-23 and declined to 16.35

MMT (export value $10.41 billion) in 2023-24 (due to India's policy of export ban on non-basmati rice since July, 2023). Rice export showcase country's strength which may be amply fostered and augmented further with time. Recent global trade polices such as Carbon Border Adjustment Mechanism (CBAM) is designed for both (a) preventing carbon leakage and (b) further reducing consumption emissions. Currently, agrifood products are out of scope but in future the sector will be required to meet more ambitious mitigation targets than has been the case to date. By producing rice with low carbon footprint, India will have additional advantage for exports. It needs a holistic approach to address this complex problem where we can retain our food security while saving our precious groundwater and reducing the carbon footprint of rice cultivation.

The immediate solutions, benefits, and trade-offs to reduce emissions in rice cultivation are given in **Table 3.2**. Shifting towards less GHG intensive products like maize and legumes inevitably implies a reduction in the production of rice with a greater GHG footprint. Considering the food security targets of the country, it does not automatically impose a reduction in overall production as the country is maintaining stocks more than the buffer stock (Gulati & Singh 2022). Reducing 1.5 Mha rice production area in Punjab and Haryana, where per ha GHG emissions from rice cultivation was highest (approximately 5 t/ha), can lead to an absolute reduction in rice emissions in the country. Both these states are facing ecological disaster with declining ground water table due to rice cultivation, which requires minimum 20-25 irrigation as compared to 4-5 irrigation in other kharif crops. By shifting to other crops in 1.5 Mha rice production area in Punjab and Haryana, approximately 3.75 MMT CO_2 eq can be reduced (considering 2.5 t/ha of GHG emissions can be reduced if farmers shift from rice to other crops in these states; Singh et al. 2024). Simultaneously, we need to take measures to improve productivity of paddy in the water abundant but energy deprived eastern region to compensate for any loss in total paddy production.

Table 3.2: Co-benefits, trade-offs and challenges related to adoption of mitigation measures in rice cultivation

GHG Mitigation Measures	Co-benefits	Trade-offs	Challenges for Adoption
Reducing methane emissions from rice cultivation (through Direct Seeded Rice (DSR), Alternate Wetting and Drying (AWD) promotion of laser levelling of fields, micro-irrigation	Increased resilience, water saving, decrease in fuel and energy consumption for irrigation.	Water management can only be done in irrigated systems and requires knowledge on the specifics of the respective technique and cannot be done in terraced fields. DSR lead to higher pest infestation and may lead to high pesticide application.	Subsidized power, low or zero-tariff electricity and subsidized irrigation have encouraged farmers to pump more water than required leading to continuous flooding in rice fields.
Crop diversification (by reducing GHG intensive rice cultivation areas and cultivating maize, legumes, and oilseeds)	Reduced fertiliser, water and energy use, improved air quality and climate resilience.	Perceived food security threat in case of unforeseen extremities like drought, yield uncertainties due to impact of climate changes, natural calamity (e.g., Covid) etc., when country needs food grains like rice.	The well-existing market, assured MSP and region-centric procurement for rice discourages farmers in the favoured region for crop diversification.

GHG Mitigation Measures	Co-benefits	Trade-offs	Challenges for Adoption
Improving nitrogen fertiliser management and production	Pollution abatement, health benefits and improved soil health.	Potentially reduced yields if application is reduced below optimal application, availability of specific inputs may be a problem in certain areas. Changing fertiliser management practices will require additional labour (e.g., split application) or technical knowledge on how and when to apply the fertiliser.	Subsidies have lowered the relative price of urea compared to other fertilisers, leading to skewed over-application of urea.
Reduce stubble burning through machinery by in situ management of residues, application of bioformulations to decompose residues, biochar from rice residues	Reduced farm fires, improved air quality and climate resilience, improved soil carbon sequestration.	Advanced technologies requires knowledge on the specifics of the respective technique and require additional labour.	Limited time window for wheat sowing and comfort of burning residues as per the sowing requirement encourage farmers to continue burning.
Sequestrating carbon in agricultural systems (through conservation or no tillage, agro-forestry)	Soil conservation, improvement of soil quality and fertility that will improve yield.	Practices like increased use of perennials can displace primary crops, potentially causing indirect land use change.	There are no cost-effective ways of accurately measuring soil carbon stocks and changes in stocks over time. Benefits-sharing mechanisms from mitigation measures will be required.

Source: Author's Compilation

Bayer's DSR Initiative

Bayer launched DirectAcres program (for adoption of DSR by farmers) as a pilot in 2021 on 100 hectares across Punjab & Haryana. The program has the potential to reduce water requirements by up to 40 percent or between 5 and 6.5 million litres of water per hectare of rice cultivated. The absence of stagnant water is expected to lower GHG, reducing emissions by up to 45 percent and methane emissions between 30-98 percent depending on the water management practices and geographies. Farmers participating in Bayer's DirectAcres program have the option to participate in the Bayer Carbon Initiative and earn additional revenues by generating carbon credits.

In 2022, the program was scaled to 800 hectares and Bayer plans to expand the program to cover 10,000 hectares and by 2030 to facilitate 2 million farmers succeed over 1 million hectares.

Source: Bayer's DSR initiative – delivering on water conservation and reducing methane emissions

4

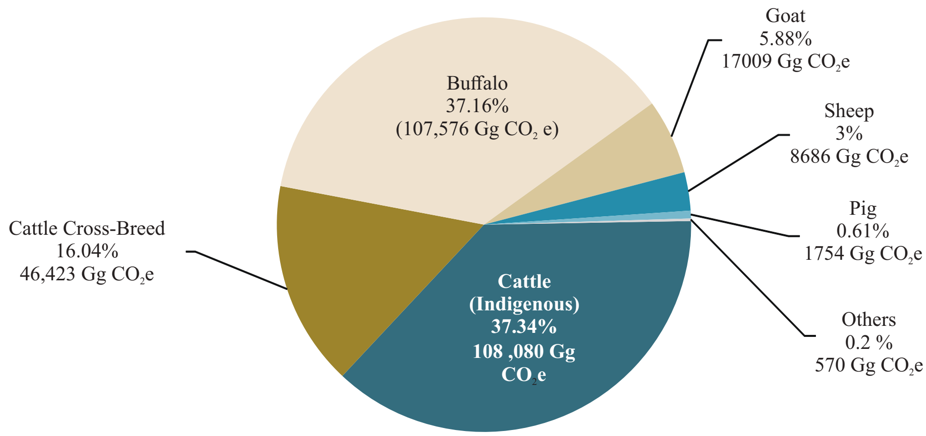
GHG emission estimates from livestock

Livestock rearing has been an integral part of the Indian agricultural system. The contribution of livestock to the total GVA (at constant prices) in agriculture and allied sectors increased from 24.32 percent in 2014-15 to 30.38 percent in 2022-23. In 2022-23, the livestock sector contributed 4.66 percent of the total GVA, significantly boosting the per capita availability of milk, eggs, and meat. The total livestock population in the country is 536.76 million (Livestock Census 2019), comprising 13 percent of the world's total livestock population. Among the categories, cattle dominate with 193.46 million (36.04 percent), followed by 148.88 million goats (27.74 percent), 109.85 million buffaloes (20.47 percent), 74.26 million sheep (13.83 percent), 9.06 million pigs (1.69 percent) and 1.25 million other livestock (0.23 percent) that include horse, pony, mule, donkey, mithun, yak and camel. Uttar Pradesh, Rajasthan, and Madhya Pradesh are the top three livestock rearing states with 68.01, 56.8, and 40.6 million total livestock, respectively. The total poultry population in the country is 851.81 million. Tamil Nadu, Andhra Pradesh and Telangana have 120.81, 107.9, and 80 million total poultry populations, respectively.

4.1 State-wise methane emissions from enteric fermentation

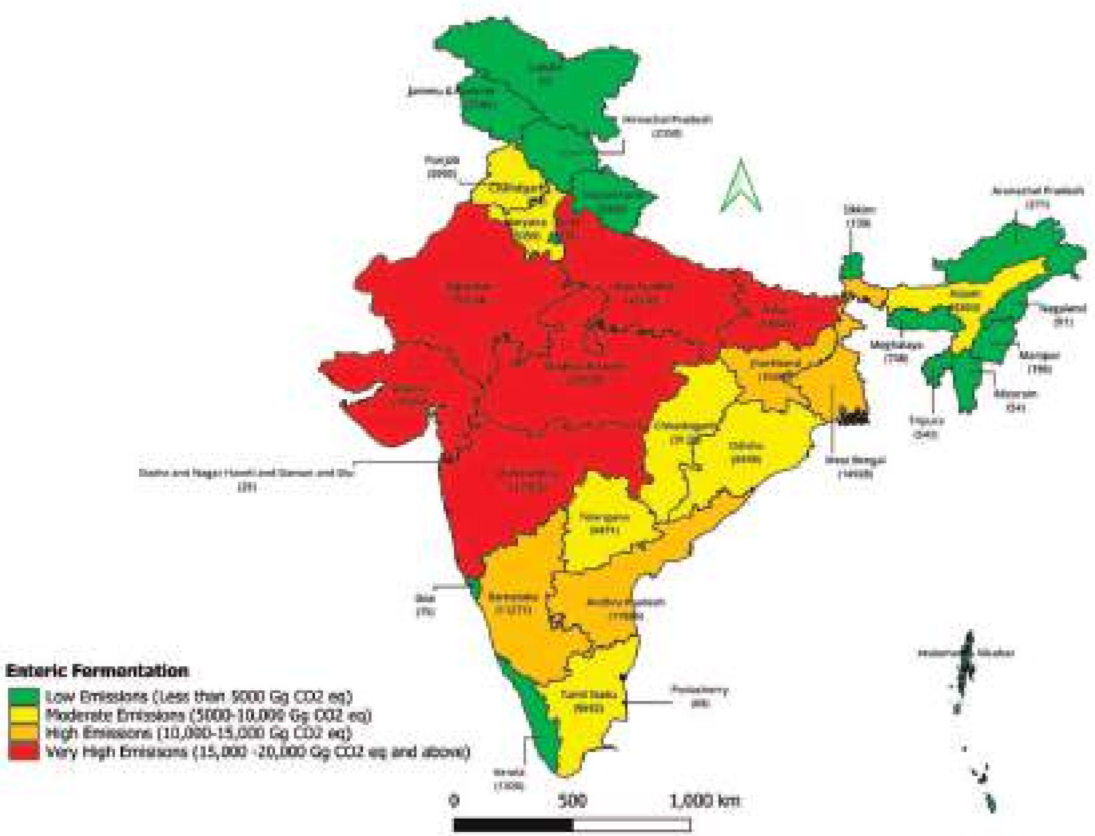
The CH_4 emission from EF was estimated at 9,660.67 Gg equivalent to 262,770 Gg CO_2 eq per year using the country specific methane emission coefficients based on IPCC methodology. Bovines contribute a bulk of the methane emission from enteric fermentation i.e., indigenous cattle (37 percent), cross-bred cattle (16 percent) and buffalo (37 percent) followed by small ruminants like sheep (3 percent) and goat (6 percent), and a negligible emission of 0.5 percent from other categories. Among cattle, the emission coefficients for indigenous dairy and non-dairy animal are lower than exotic animals but the emissions from indigenous dairy and non-dairy cattle (24,355 Gg CO_2 eq and 72,930 Gg CO_2 eq) is higher than exotic dairy and non-dairy cattle (23,755 Gg CO_2 eq and 18,952 Gg CO_2 eq) due to their higher population (**Figure 4.1**).

Figure 4.1: Methane emission estimates from enteric fermentation of Indian livestock



Source: Authors' Estimates using 20th Livestock Census and IPCC Tier 2 Methodology

Figure 4.2: State-wise methane emission estimates from enteric fermentation in India

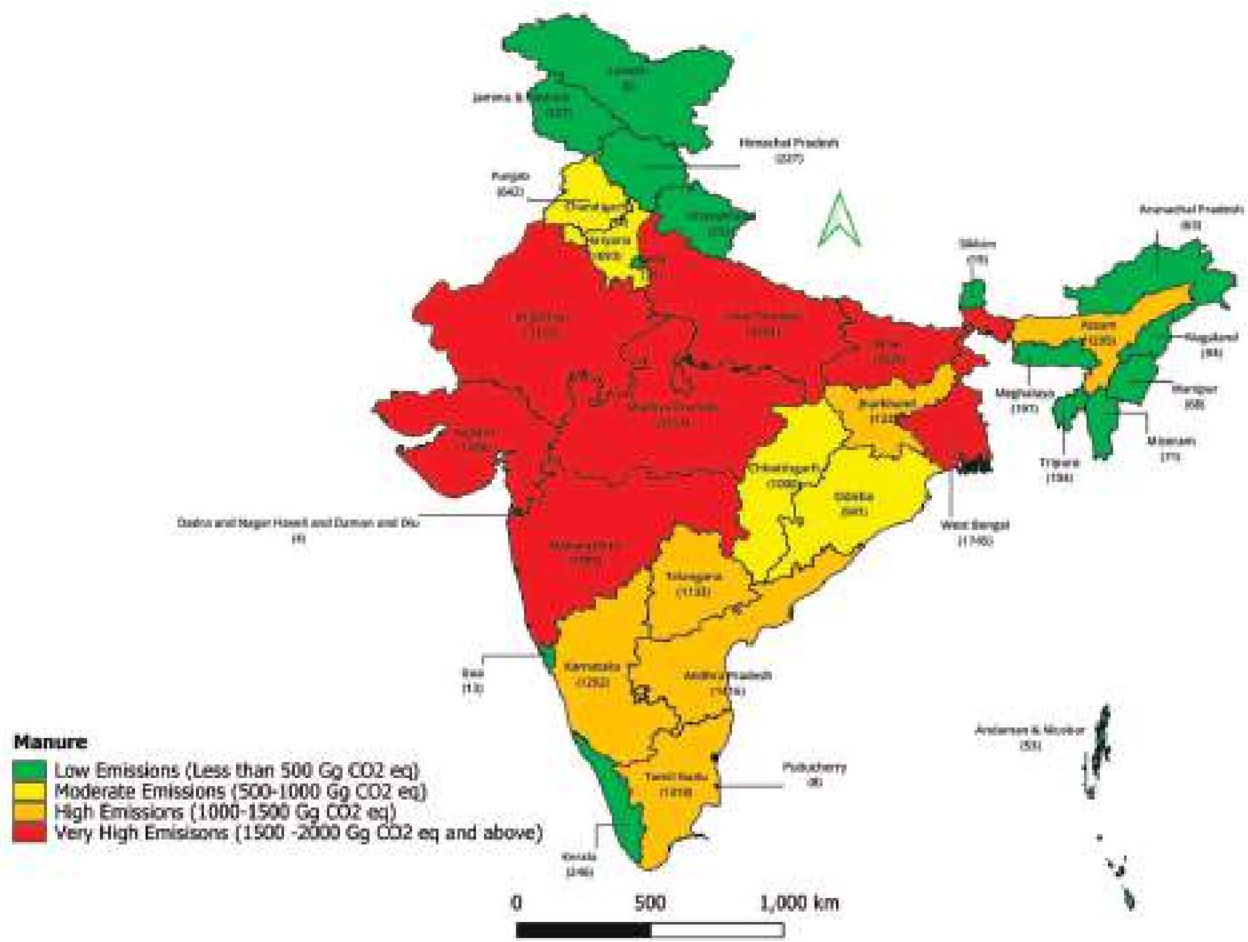


Source: Author's estimates based on 20th Livestock Census

4.2 State-wise emission estimates from manure management

The CH_4 emission from manure management accounts for a very small emission of 981.83 Gg that is equivalent to 26,706 Gg CO_2 eq or 9.2 percent of the total livestock-based CH_4 emissions. The total N_2O emission from Indian livestock and poultry was estimated at 10.15 Gg/year equivalent to 2,772.44 Gg CO_2 eq/year for 2019. Amongst categories, poultry contributes maximum N_2O emissions of 2,704.15 Gg CO_2 eq or ~97 percent, while indigenous cattle and buffalo have 1 percent share each. Amongst states, highest emission of 386 Gg CO_2 eq/year was estimated from Tamil Nadu followed by 345 Gg CO_2 eq/year from Andhra Pradesh. The state-wise estimates due to manure management are presented in **Figure 4.3**.

Figure 4.3: State-wise emission estimates from manure management



Source: Author's estimates based on 20th Livestock Census

4.3 State-wise total GHG emissions from livestock and poultry

The total GHG emission from Indian livestock was estimated at 292,248 Gg CO_2 eq that included 90 percent from enteric fermentation and 10 percent from manure management. Indian livestock is a major source of CH_4 emission from the agriculture sector compared to N_2O emissions. Although, the total methane emission is much higher, the per head emission is 53.93 kg CH_4/animal/year. The estimated category/age-group methane, nitrous oxide, and total GHG emissions in terms of CO_2 equivalent along with category/sub-category population of Indian livestock for 2019 are presented in **Table 4.1**. The details of **Table 4.1** are presented in **Annexure 4**.

Table 4.1: Total GHG emissions from livestock sector

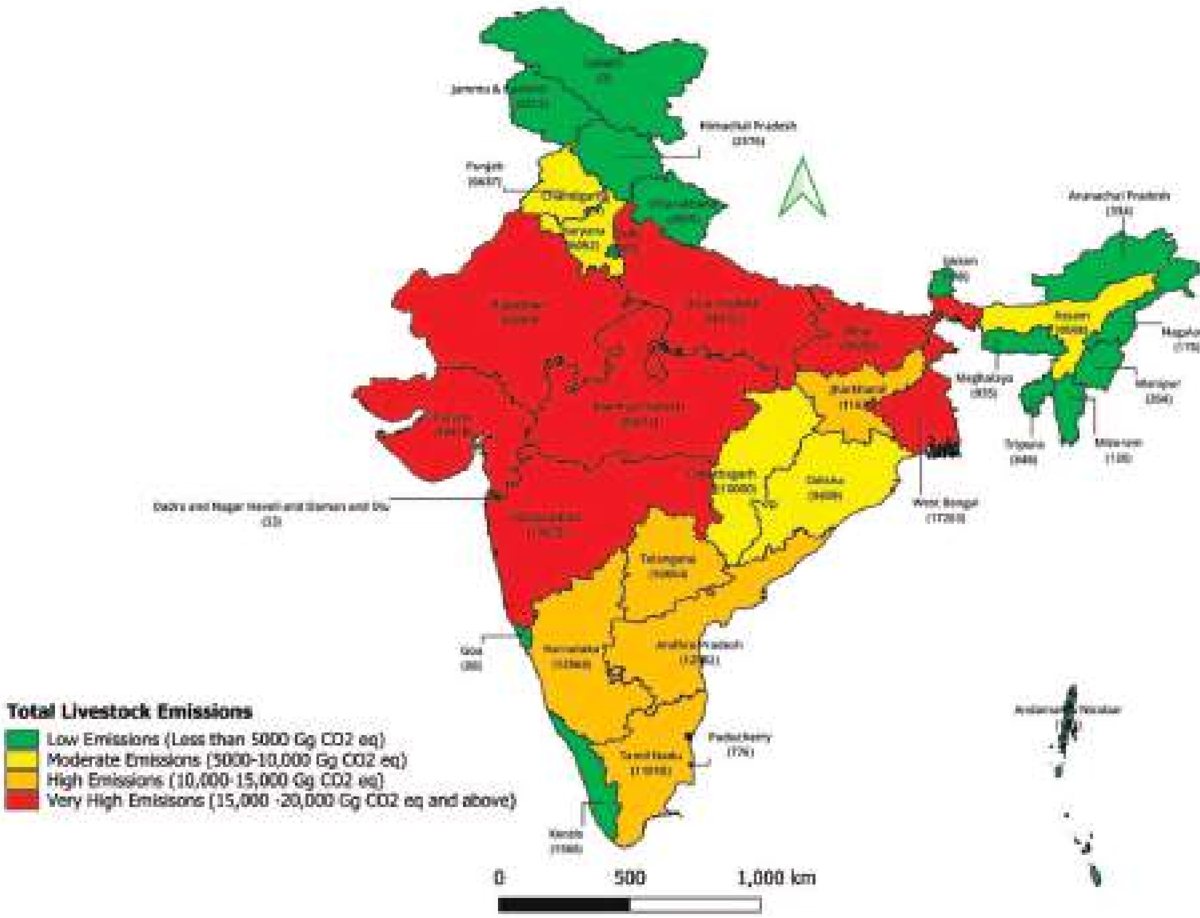
Livestock Category	Population (Million)	GHG Emissions			
Dairy Cattle		Methane Emission		Nitrous oxide from manure management (Gg CO_2 eq/year)	Total GHG Emissions (Gg CO_2 eq/year)
		Enteric Fermentation (Gg CO_2 eq/year)	Manure Management (Gg CO_2 eq/year)		
Cross-Breed	20.31	23,755	2,099	6	25,860
Non-Dairy Cattle (Indigenous)					
Below 1 year	24.28	5,945	793	5	6,743
1–3 years	31.57	19,755	2,404	5	22,164
Above 3 years (adults)	54.26	47,230	4,280	9	51,519
Non-Dairy Cattle (Exotic)					
Below 1 year	11.49	3,437	344	2	3,783
1–3 years	10.71	7,577	670	2	8,249
Above 3 years (adults)	8.84	7,939	601	1	8,541
Dairy Buffalo	38.16	51,899	4,567	3	56,469
Non-Dairy Buffalo					
Below 1 year	24.48	5,327	562	5	5,894

Livestock Category	Population (Million)	GHG Emissions			
Dairy Cattle		**Methane Emission**		**Nitrous oxide from manure management (Gg CO_2 eq/year)**	**Total GHG Emissions (Gg CO_2 eq/year)**
		Enteric Fermentation (Gg CO_2 eq/year)	**Manure Management (Gg CO_2 eq/year)**		
1–3 years	26.71	15,981	2,470	7	18,458
Above 3 years (adults)	20.50	24,540	2,231	3	26,774
Other Livestock					
Sheep	74.26	8,079	606	0	8,685
Goat	148.88	16,198	810	0	17,008
Horse and Pony	0.34	168	15	0	183
Mule, Donkey	0.21	55	5	0	60
Camel	0.12	315	1	0	316
Pig	10.95	297	1,192	12	1,501
Poultry	851.81	0	0	2,704	2,704
Total	536.76 livestock +851.81 poultry	262,770	26,706	2,772	292,248

Source: Author's estimates based on 20th Livestock Census

Uttar Pradesh, Rajasthan, Madhya Pradesh, and Bihar are the leading states with 15.88 percent, 11.38 percent, 8.97 percent, and 6.94 percent GHG emissions, respectively from livestock (**Figure 4.4**).

Figure 4.4: Total GHG emission estimates (methane and nitrous oxide) from livestock in India



Source: Author's estimate based on 20th Livestock Census

4.4 Mitigating GHG emissions from livestock

As per India's National GHG Inventory for 2019, CH_4 from EF (2,23,251 Gg CO_2 eq) contributes 54.5 percent of India's anthropogenic CH_4 emissions, 53.03 percent of the country's agriculture sector GHG emissions, and 7.1 percent of the total GHG emissions (MoEFCC 2023). Our estimates (262,770 Gg CO_2 eq), though close to this estimate, are higher as National inventory uses GWP 21 (as per IPCC Second Assessment Report 1996) for CH_4 emission calculations and we have used the latest GWP 27.2 (as per IPCC Sixth Assessment Report 2021). Considering its highest share in agriculture emissions, technological interventions to reduce CH_4 emissions from EF would substantially reduce country's CH_4 emissions. Immediate solutions to reduce emissions from livestock fall into four categories: feed and nutrition, measures at animal level, manure management, and grassland management. Their co-benefits and trade-offs are given in **Table 4.2**.

Table 4.2: Co-benefits, trade-offs and challenges related to adoption of mitigation measures in livestock

GHG mitigation measures	Co-benefits	Trade-offs	Challenges for adoption
Feed and Nutrition			
Altering the feed composition (Ration Balancing) by switching to roughage with a high digestibility or increased number of concentrates or adding different additives e.g., nitrates, ionophores, fats, plant- or fungal-derived bioactive compounds	Increased feed efficiency and productivity can improve farm profitability	Upscaling such approaches may conflict with food security if crops are used to feed animals instead of humans directly.	Precision feeding requires investment in new technologies, capital, knowledge and different management practice. Access to information and up-skilling of farm managers may be limited.
Measures at Animal Level			
Animal genetics and breeding to improve resource efficiency (reducing input/output ratio) and to select animals with lower GHG emissions per unit of feed intake	Efficient and robust animals.	Having higher genetically bred animals does not result in higher productivity since adequate feeding and management strategies are needed to realise the full genetic potential of the animal.	Evaluation of genetic merit can be difficult as actual production depends on the animal, animal nutrition and management practices.
Rumen modification through inhibitors, vaccines and transferring the microbiome of low-methane producing ruminants	Potentially very wide applicability, ranging from extensive grazing to highly intensive farm systems.	Animal health and food safety concerns or prohibitive costs.	Rumen substitute microbial mixture could be regarded as a "probiotic," hence face restrictions in some markets or consumer segments.
Manure Management			
Capturing the biogas (through anaerobic digesters)	Can improve productivity, food security and livelihoods. It also has many hygienic benefits and will improve the overall living environment of the farm/household.	High upfront installation cost of the biogas plant, market for fuel/electricity generated through biogas plant is required.	National Biogas and Manure Management Programme (NBMMP) scheme offers financial incentive to the households having adequate cattle ownership and exclude households with inadequate cattle.

GHG mitigation measures	Co-benefits	Trade-offs	Challenges for adoption
Grassland Management			
Carbon sequestration in grasslands through adjusting stocking densities to avoid overgrazing, balance between grazing and rest periods; Sowing of improved grass varieties.	Soil conservation, improvement of soil quality and fertility that will improve the yield.	Practices like increased use of perennials can displace primary crops potentially causing indirect land use change.	Carbon sequestration remains difficult to monitor and verify, is highly variable across small spatial scales, and is subject to reversibility/ impermanence due to short-term effects of flooding, droughts and wind erosion, and changes in management practice.

Source: Author's Compilation

Rumin8 Initiative

Methane is a short-lived climate pollutant with lifetime of 12.5 years in the atmosphere, and contributes significantly to near-term global warming. Its global warming potential, if emits from non-fossil, is 80.8 or 27.2 for 20- or 100-y time horizons, respectively. Thus, sharp reduction in methane emissions can deliver a net cooling effect within a relatively short period. Acknowledging this, Global Methane Pledge (reducing 30 percent global methane from 2020 levels by 2030) was launched at COP 26 in November 2021 to catalyse action to reduce methane emissions. The Global Methane Pledge is a voluntary commitment with 159 signatories' countries. After China and Russia, India is the third topmost emitter of methane but kept itself away from this pledge.

Rumin8's (Australian start-up) patented technology uses a pharmaceutical process to synthesize and stabilize the target compound Tribromomethane (TBM), originally found in seaweed. As per the cattle trials (undertaken by independent universities of Australia, the United States and Brazil) – lasting between 75-130 days and involving 92 head of cattle – recorded reductions of methane intensity of up to 86 percent.

Source: rumin8.com

5

GHG emissions from agricultural soils

Nitrogen (N) is vital for all life forms and is a critical component for increasing food production to feed the growing human population. Crops utilize nitrogen from the soil that is carried away from the field after harvest, so the fields are replenished through the application of synthetic or organic (such as manure) nitrogen fertiliser. The quantity of crops produced per unit of applied fertiliser has continuously decreased to very low values and fertiliser use efficiency following blanket fertiliser application is generally observed below 35 percent. fertiliser consumption in India is increasing (though still less than world's average). India is the second largest consumer of fertilisers in the world after China, with about 29.8 MMT of total N, P_2O_5 and K_2O used by the agricultural sector in 2022-23 (fertiliser Statistics 2022). Out of this, 20.2 MMT was N consumption. Hugely subsidized urea (often 85 to 90 percent of cost) has led to skewed consumption of N as compared to P_2O_5 and K_2O, with corresponding increase in N_2O emissions. In 2022-23, the N_2O emissions from synthetic fertilisers were estimated to be 53,571 Gg CO_2 eq (**Annexure 5**). Other sources of N_2O emissions from agricultural soils of India's GCA of 219 Mha are green manuring, production of legumes, forages, crop residue incorporation, mineralisation of soils and urine/dung from grazing livestock.

The total emission from agriculture soils was estimated to be 67,552 Gg CO_2 eq[10]. These are lower as compared to National GHG inventory's[11] agriculture soils emission estimates, which are (88,412 Gg CO_2 eq). The difference in estimation is mainly due to the two reasons: (i) N_2O emissions related to rice cultivation are included in the rice emission estimates (Section 3.1.2). If we include these emissions, then our total N_2O estimates from agriculture soils are 81,449 Gg CO_2 eq; (ii) National inventory uses GWP 310 (as per IPCC Second Assessment Report 1996) for N_2O emission calculations and we have used the latest GWP 273 (as per IPCC Sixth Assessment Report 2021).

5.1 State-wise nitrous oxide emissions from agriculture soils

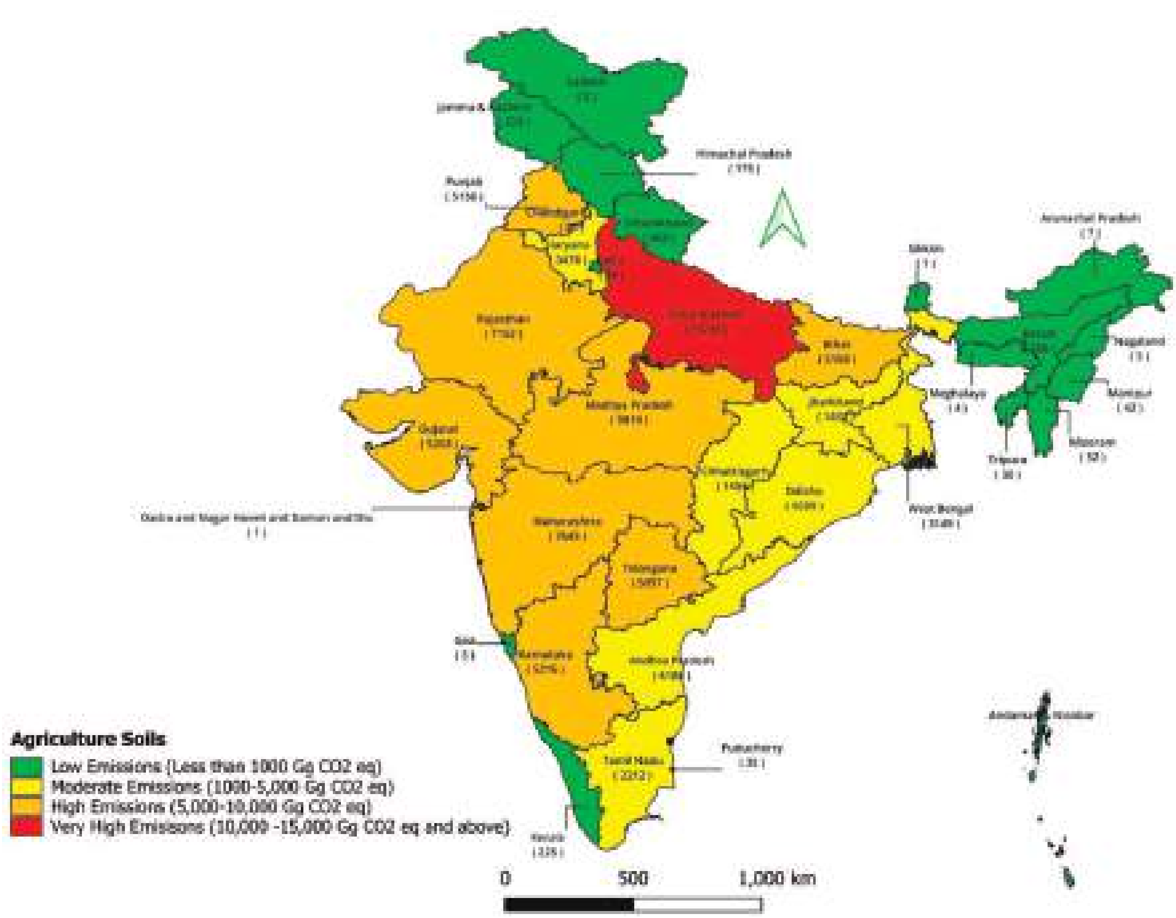
Uttar Pradesh emitted the highest N_2O emissions (13,218 Gg CO_2 eq) followed by Madhya Pradesh

[10] Excludes emissions related to rice cultivation as rice related emissions are included under rice cultivation estimates (section 3)

[11] National GHG emission inventory accounts only CH_4 emissions in rice cultivation and all N_2O emissions from fertilisers and manure application (including rice) is included under agriculture soils

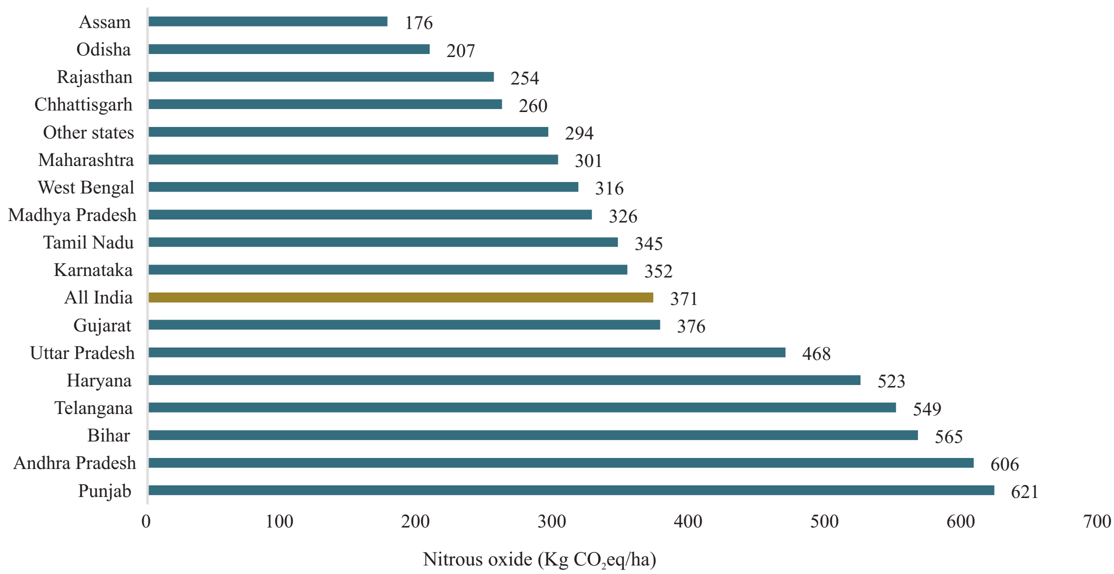
(9,819 Gg CO_2 eq) and Maharashtra (7,645 Gg CO_2 eq) due to larger area under cultivation (**Figure 5.1**) and total higher fertiliser application. On per-hectare basis, Punjab (621 Kg CO_2 eq/ha), Andhra Pradesh (606 Kg/CO_2 eq/ha) and Bihar (565 Kg CO_2 eq/ha) are the highest emitters due to high consumption of N-fertilisers (**Figure 5.2**). In this regard, it is worth mentioning that even though consumption of fertiliser in Bihar is one of the highest (average 225.2 kg/ha for 2022-23) as per the data from fertiliser association of India (FAI), the cost of cultivation data provided by Ministry of Agriculture shows huge difference (average 141.5 kg/ha for wheat, paddy and maize). N_2O estimations from fields would be required for the data accuracy.

Figure 5.1: Hot-spots of nitrous oxide emissions from agricultural soils in India



Source: Author's estimate based on fertiliser Statistics 2022-23, 20th Livestock Census, Agriculture Statistics at a glance 2023, LUS 2024

Figure 5.2: State-wise nitrous oxide emission estimates from agricultural soils



Source: Author's estimate based on fertiliser Statistics 2022-23, 20th Livestock Census & Agriculture Statistics at a glance 2023, LUS 2024

5.2 Mitigating GHG emissions from agricultural soils

As per India's National GHG Inventory for 2019, N_2O from agriculture soils (88,412 Gg CO_2 eq) contributes 62.04 percent of India's anthropogenic N_2O emissions, 21 percent of the country's agriculture sector GHG emissions, and 2.82 percent of the country's total GHG emissions (MoEFCC 2023). It is predominantly from the application of fertilisers. However, these figures do not include the emissions produced by the manufacture and transportation of fertiliser products. N fertiliser production has a notable carbon footprint resulting from the fact that all synthetic N fertilisers are derived from ammonia (NH_3) synthesized from nitrogen and hydrogen, the latter being typically obtained from hydrocarbons via the so-called steam reforming process, with associated emission of CO_2 and methane (CH_4). The UNFCCC accounting system includes these emissions in the industrial sector rather than the agricultural sector (Singh 2024). Share of urea in total N production in India is currently around 80 percent. During 2021-22, 34.1 MMT of urea was consumed in the country. Out of which, 25 MMT of urea was produced indigenously and 9.1 MMT was imported. Urea production involves two steps: (i) the production of ammonia, predominantly from natural gas using Haber-Bosch process and then (ii) ammonia's reaction with carbon dioxide (CO_2) to produce urea using the Bosch–Meiser process. Natural gas used as feedstock and as a thermal energy source is the primary source of emissions in fertiliser plants. In the case of production, energy efficient technologies and renewable energy should be encouraged through financial incentives, such as carbon credits. Green ammonia can have a transformative impact on the fertiliser industry, but has cost-related challenges.

India's drive to achieve food security has been greatly aided by the fertiliser sector. However, more than half of the applied fertiliser remains un-utilized and get lost from the soil-water system through leaching (predominantly as nitrate (NO_{3-} ions), volatilization (as ammonia (NH_3) gas), denitrification (N_2 gas), N_2O emissions, surface run off and erosion (Prasad 2009). Besides climatic impact, the inefficient application of N-fertilisers has significant environmental implications. The leached NO_{3-} ions contaminates the groundwater resources affecting human health, leads to water pollution and eutrophication affecting aquatic ecosystem and aquatic biodiversity. It also contributes to acidification, and mineral depletion of the soil. Use of synthetic N-fertilisers can suppress production of certain soil enzymes involved in nutrient cycles and its excessive application can also cause soil and land degradation (NEP 2006). Efficient management of N-fertilisers is thus required but it has challenges.

From April 2010, the government moved from product pricing regime toward selective implementation of Nutrient Based Subsidy (NBS) regime for P and K fertilisers. NBS is now applicable on 22 fertiliser products; however, urea was left out of the NBS policy and continues to remains so. This resulted in price increase of P and K fertilisers by 2-3 times whereas urea prices continued to be at very low level due to heavy subsidy. There was serious distortion in urea vis-a-vis P and K prices. The price of Di-ammonium phosphate (DAP) increased from ₹ 9,350 per ton in 2009-10 (pre-NBS) to ₹ 26,440 per ton in 2015 (post-NBS). Similarly, the price of muriate of potash (MOP) increased from ₹ 4,455 per ton to ₹17,892 per ton during the corresponding period. However, the price of urea remained constant at ₹ 5,360 per ton. This has led to the unbalanced use of nutrients. The ratio of NPK usage has increased to 9.9:3.3:1 in 2012-13 and 8.4:2.8:1 in 2013-14. However, in 2016-17, the ratio is still biased towards nitrogen and is 11.8:4.6:1.

Sound fertiliser management practices need to be followed to improve fertiliser use efficiency and minimal fertiliser loss (thus, less N_2O emissions) to the environment. State awareness for PM-PRANAM (PM Programme for Restoration, Awareness, Nourishment and Amelioration of Mother Earth) needs to be taken up on priority. Under this scheme, 50 percent of the fertiliser subsidy saved by a State/UT by way of reduction in chemical fertilisers consumption (Urea, DAP, NPK, MOP) compared to previous 3 years' average consumption, will be provided to State/UT as Grant for the benefit of people in the state, including farmers. The scheme as on date has no takers. The subsidies on fertilisers, which are currently skewed towards urea, should be rationalized in order to have parity in nutrient pricing to promote balanced fertiliser use. There is also a need to develop crop rotations involving legumes to gain the benefits of biological nitrogen fixation. Legume rotation after cereals also has additional benefit of greater nitrogen use efficiency for cereals than that for cereals following cereals or fallow (NAAS 2005). The immediate solutions, benefits and trade-offs to reduce emissions from agricultural soils are given in **Table 5.1**.

Table 5.1: Co-benefits, trade-offs and challenges related to adoption of mitigation measures in agricultural soils

GHG Mitigation Measures	Co-benefits	Trade-offs	Challenges for Adoption
Improving nitrogen fertiliser management through 4Rs (apply the right fertiliser, at the right rate, using the right method, and at the right time)	Pollution abatement, health benefits, improved soil health	Potentially reduced yields if application is reduced below optimal application, availability of specific inputs may be a problem in certain areas.	Subsidies have lowered the relative price of urea with respect to other fertilisers, leading to skewed over-application of urea.
Increasing fertiliser efficiency through split application	Pollution abatement, health benefits and improved soil health.	Changing fertiliser management practices require additional labour (e.g., split application) or technical knowledge to apply the fertiliser.	Extra fuel costs from additional trip.

GHG Mitigation Measures	Co-benefits	Trade-offs	Challenges for Adoption
Slow-release fertiliser products e.g., polymer coated urea	Slow-release products fertilizes crops continuously in the growing season and improves fertiliser efficiency.	Rate of release may be slow (depending upon soil conditions) so that the nutrients are not released when the plants need them.	Less water solubility and the extra cost.
Precision agriculture or soil-specific farming	Allows farmers to optimize placement via the Global Positioning System (GPS) and other forms of technology that use spatial and temporal data about field, leading to productivity gains and reduced pollution.	Requires expert advice before actual implementation.	Requires a significant investment in technology, this management system is prohibitively expensive for most farms smaller than 500 acres and India has meagre and fragmented land-holdings.
Applying fertiliser in irrigation water via subsurface drip irrigation (SDI) systems	Deliver nitrogen more precisely and in proximity to plant roots, increasing plant uptake and limiting excess nitrogen in the soil; SDI is also less likely to fill soil pore space with water, avoiding the anaerobic conditions that are conducive to nitrous oxide.	May not be warranted in areas with uncertain water and energy availability, SDI systems have a shorter design life than alternative irrigation systems.	Higher initial investment cost.
Nitrification inhibitors	Delay the conversion of ammonium to nitrate and reduce N_2O emissions by allowing plants to absorb a larger share of nitrogen.	Nitrification inhibitors are antimicrobial pesticides that kill or inhibit the soil microbes involved in nitrification and impact beneficial soil micro-communities.	Effectiveness of nitrification inhibitors varies due to soil, climate, geography, and other factors and it may not have consistent performance.
Nano fertilisers	Nanoparticles possess unique properties due to their small size (1-100 nm) and large surface area, which give them the edge over other existing bulky fertiliser products. Nano fertilisers have high efficiency (85-90 percent).	The same property of small size and large surface area imparts toxicity to nanoparticles as they can easily diffuse and disperse through biological barriers.	There have been reservations world-wide from the risk assessment point of view that are required to be critically examined for the safety of humans, animals and environment.

Source: Author's Compilation

6

GHG emissions from electricity consumption in agriculture

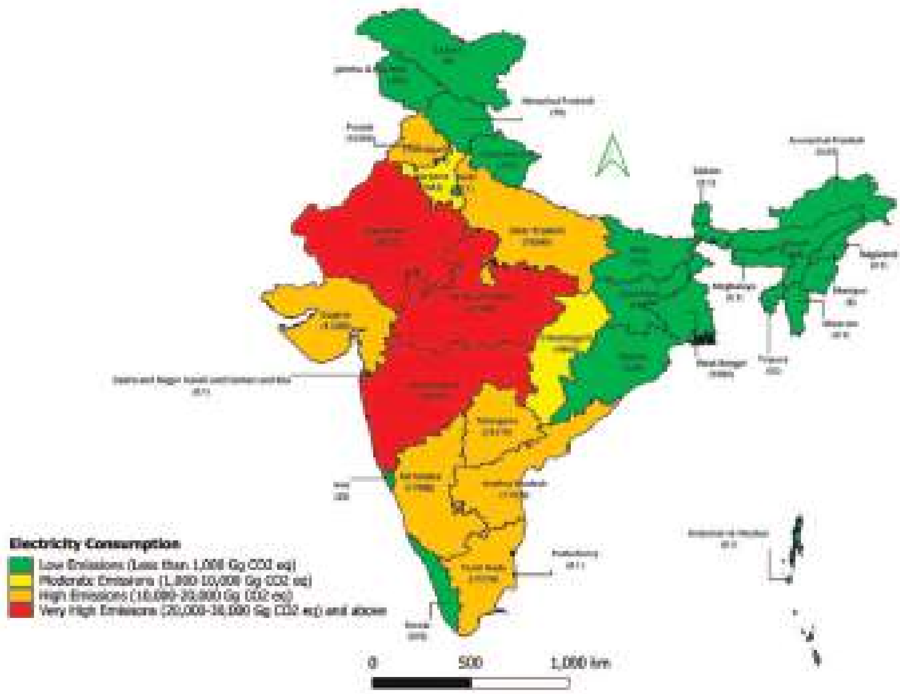
India uses 78 percent of its water resources (sourced from surface water through canals and tanks and groundwater) for irrigation. More than 63 percent of irrigated area in India is dependent on groundwater (Central Ground Water Report 2021). Subsidized power and irrigation have led to growth in electricity and its consumption in agriculture, particularly for energizing irrigation pump sets. The number of electric pump sets has seen a remarkable increase and its share in the total tube-wells has increased from 36 percent (1986-87) to 67 percent (2013-14), which is reflected by a corresponding increase in the energy consumption from 17,817 GWh in 1982-83 to 240,800 GWh in 2022-23. This translates to 178,963 Gg CO_2 eq Mt CO_2[12] eq emissions related to electricity consumption in agriculture.

6.1 State-wise emissions from electricity consumption

Maharashtra (29,727 Gg CO_2 eq) and Rajasthan (23,630 CO_2 eq) have the highest share (**Figure 6.1**) but per hectare emissions from electricity consumption was the highest in Telangana (1,958 Kg CO_2 eq/ha) (**Figure 6.2**).

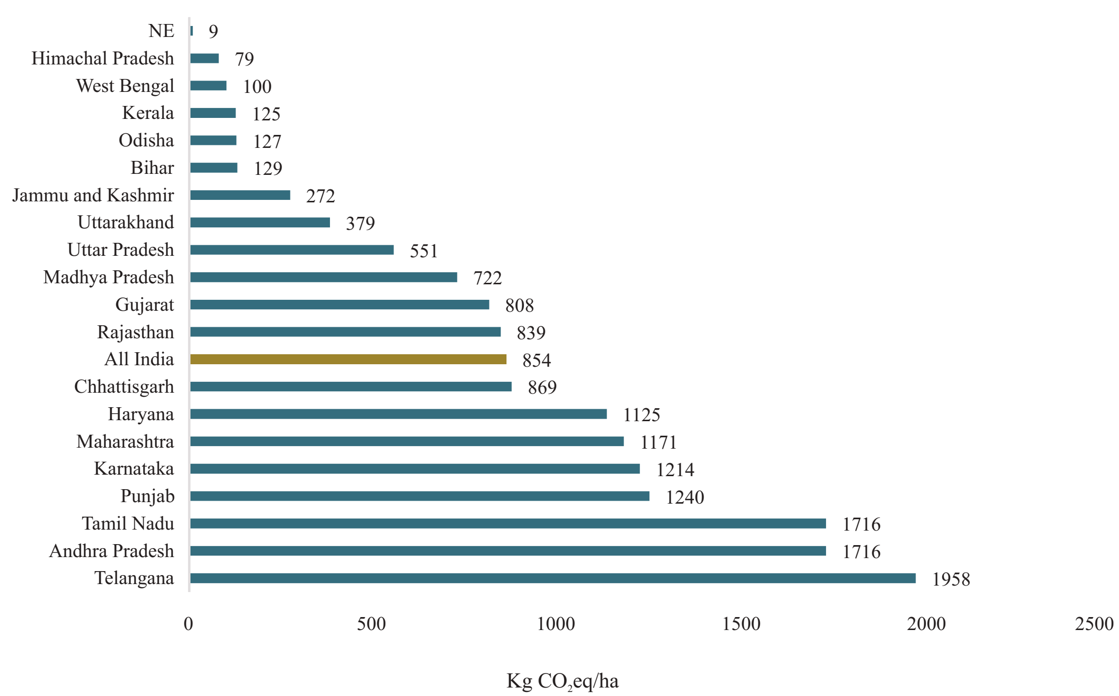
[12] This does not include emissions from rice cultivation, which are included in emissions related to rice cultivation in section 3.

Figure 6.1: Hot-spots of carbon dioxide emissions from electricity consumption in Indian agriculture



Source: Authors Calculations based on agriculture statistics at a glance, CEA

Figure 6.2: State-wise GHG emissions (Kg CO_2 eq/ha) from electricity consumption in agriculture



Source: Authors Calculations based on agriculture statistics at a glance, CEA

6.2 Mitigating GHG Emissions from electricity consumption in agriculture

The agriculture sector primarily focuses on the production of food and non-food products of economic value. It also encompasses or is closely linked with pre- and post-production processes, including fertiliser production, post-harvest processing, and food transport. Broadly defined, the sector aims to provide food for the population or for export. Therefore, any measure that reduces energy consumption while delivering food services could be considered a potential mitigation option.

Energy is mainly used for groundwater pumping and farm machinery like threshers and tractors. The agriculture sector accounts for 17.2 percent of the power used in the country (2022-23, CERC 2023). Due to price subsidies, electricity and fuel use can be inefficient, making mitigation options an opportunity to improve efficiency and reduce GHGs from this sector. Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme with an overall aim to improve irrigation access and farmers' income through solar-powered irrigation can also help in mitigating GHG emissions by (i) setting up 10 GW of decentralised solar or other renewable energy plants on agricultural lands through installation of small solar power plants of capacity up to 2 MW (Component A); (ii) installation of 2 million stand-alone solar pumps for off-grid areas (Component B) and (iii) solarising 1.5 million existing grid-connected irrigation pumps (Component C). Potential mitigation options for agricultural energy use are described in **Table 6.1**.

Table 6.1: Co-benefits, trade-offs and challenges related to adoption of mitigation measures for agriculture energy use

GHG Mitigation Measures	Co-benefits	Trade-offs	Challenges for Adoption
Improving efficiency of pumps.	Reduced energy cost, lower maintenance needs, high productivity gains due to optimized fluid flow measurement.	Higher initial purchase cost, potential complexity in system integration.	Free or subsidised power poses a major barrier as the farmer has little incentive to pay more to install an energy efficient pump.
Switch to lower-carbon energy sources such as wind- and photovoltaic-powered pumps, enhanced solar drying, and use of biofuels instead of fossil fuels in various applications where heat is required.	Energy efficiency, reduced reliance on fossil fuels, contributing to sustainable future.	Higher initial purchase cost, potential complexity in system integration.	Free or subsidised power poses a major barrier as the farmer has little incentive to pay more to switch to lower-carbon energy option.

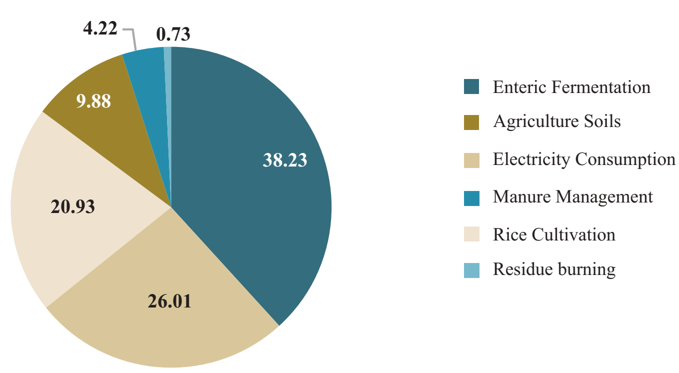
GHG Mitigation Measures	Co-benefits	Trade-offs	Challenges for Adoption
Reduce input of chemical fertilisers. Reduced demand for chemical fertiliser lowers energy use in the chemical industry.	Pollution abatement, health benefits and improved soil health.	Potentially reduced yields if application is reduced below optimal application,	Subsidies have lowered the price of fertilisers leading to inefficient use of fertilisers
Agrivoltaics for pairing solar energy technology with agriculture	Creating energy while providing space for crops, grazing, and ecosystem services.	Lesser crop yields, agricultural land may be taken out of food production if farmers install large-scale solar operations for getting more profit by selling surplus electricity to the grid.	Apart from high installation cost of solar panels, balancing agricultural land use with solar panel placement.

7

Recommendations and way forward: aligning policies for a low carbon agriculture

In 2022-23, total CH_4 and N_2O emissions from production of crops (include emissions related to rice cultivation, agriculture soils and residue burning) and livestock (include emissions related to EF and manure management) were estimated to be 490 Mt CO_2 eq. After including the emissions related to electricity consumption in agriculture, the total agriculture emissions amounted to 688 Mt CO_2 eq. Of this, emissions from EF comprised 263 Mt CO_2 eq (38.23 percent), followed by 178.9 Mt CO_2 eq (26.01 percent) from electricity consumption in agriculture, 144 Mt CO_2 eq (20.93 percent) from rice cultivation, 67.5 Mt CO_2 eq (9.8 percent) from agriculture soil, 29.4 Mt CO_2 eq (4.22 percent) from manure management and 5 Mt CO_2 eq[13] (0.7 percent from residue burning).

Figure 7.1: Major sources of agriculture emissions in India (% share)



Source: Author's Calculations

[13] During the study the emissions related to rice residues was estimated in section 3. Emissions related to burning of other crops was taken from MoEFCC 2023.

Policy recommendation: aligning policies for a low carbon agriculture

7.1 Shift from price input subsidy to income subsidy on per hectare

fertiliser and power subsidies have led to inefficient use of fertilisers (particularly urea), water and electricity with negative environmental consequences and higher GHG emissions. These subsidies are skewed towards rice cultivation, which receives the highest subsidy (₹ 38,973 per hectare in Punjab during 2023-24) amongst its kharif crop counterparts (Singh et al. 2024), even though this crop is GHG intensive. These incentives need to be "crop neutral" and "input neutral" (Singh & Gulati 2024). By shifting from price subsidy to income subsidy to farmers on per hectare basis either through direct cash transfer or coupons with varying input options (including low-carbon products), farmers can purchase the inputs as per their requirement (including micronutrient fertilisers) and choice (that include bio-inputs, vermicompost, etc).

7.2 Premium support price for low-carbon crops

GoI procures foodgrains (wheat and rice) at MSP for buffer stock requirements for PDS and other welfare schemes. Every year the CACP recommends the MSP of various crops to the GoI. At present, CACP is not accounting carbon cost while recommending MSP for various commodities. In rice, cultivation practices like DSR, AWD, SRI are reported to save up to 2-2.5 t CO_2 eq/ha (Sapkota et al. 2019). To encourage farmers to shift to low-carbon footprint rice cultivation practices and low-carbon crops such as legumes, and oilseeds, premium support price (which can be linked to the carbon price and can be recommended by CACP) should be offered to farmers. Since farmers respond to price signals through MSP, this measure will not only address food security objectives but will also encourage farmers to grow low-carbon crops.

7.3 Performance-Linked Incentives (PLI) for industries that produce low-carbon or climate resilient products or commodities for agriculture use

Technological interventions to reduce GHG emissions from agriculture sector would reduce the country's total emissions. Through PLI scheme, the government is supporting manufacturing of PV solar panels. The scheme should be extended to the manufacturers of agriculture-related products that has the potential to reduce emissions. For example, the feed additives for livestock for reducing emissions (e.g. Rumen8), biofertiliser products, nanoproducts, climate resilient seed varieties, etc.

7.4 Agriculture sector offers India the opportunity to lead carbon market for carbon farming credits

The country's agriculture contributes to 490 Mt CO_2 eq of CH_4 and N_2O emissions from agriculture sector and have significant scope for trading carbon under carbon trading system, where one carbon credit unit is equivalent to one tonne of carbon dioxide emissions. Carbon credits can allow farmers to earn an income for every unit of GHG reduction or sequester from the atmosphere. Indian agriculture has the potential to mitigate 85.5 $MtCO_2$ eq per year, 80 percent of which is delivered by cost-effective options (Sapkota et al. 2019). By mitigating the emissions, farmers can earn 3-5 credits per hectare. The value of one carbon credit depends upon the carbon market price. Farmers are generally paid $15 to $20 per ton of carbon saved/sequestered under agriculture companies' programs. Companies such as fertiliser producers, mining, oil companies, etc. who have higher carbon footprints and have opted for carbon neutrality goals, can offset their emissions by purchasing carbon credits from farmers. National and international companies can pitch in to offset their emissions from Indian croplands and livestock sector and can contribute to the global mission of net zero.

7.5 Complement adaptation with mitigation in agriculture

While innovation played a significant role in the increased gains of productivity of the second half of the 20th century, continuing to focus on productivity alone may lead to natural resource depletion and increased GHG emissions. A shift is needed in approach from increased productivity to sustainably increased productivity. Adaptation can reduce sensitivity and resilience against climate change while mitigation can reduce the rate and extent of the climate change. Therefore, response options to protect agriculture from effects of climate change should include both adaptation and mitigation. Together, they can reduce climate change risks. This will rely on the emergence of new technologies, climate resilient varieties and the adoption of innovative farming practices that encourages economic efficiency and climate performance. This will be possible through investment in agricultural innovation systems that include investments in technological improvements and in education, training and organizational improvements.

7.6 Enabling private investments towards climate financing

One of the key ways to address the rising environmental crisis is through climate financing, a fund meant to address the challenges of climate change through mitigation and climate action. Estimates put the cost of adaptation in a BAU scenario for India, to be ₹56.68 trillion till 2030, assuming 2023-24 as the base year of analysis. Climate induced damages could lead to an incremental cost of ₹15.5 trillion by 2030, and the requirements for building adaptation capital stock could be as high as ₹72 trillion after accounting for the country's developmental needs and climate-induced pressures (MoEFCC 2023). At COP15 (Copenhagen 2009), the developed countries had collectively committed to mobilising $100 billion per year by 2020, and at COP 21 (Paris 2015), it was re-emphasized and extended to 2025. During COP 29 (Bali 2024), climate finance agreement proposed triple finance to developing countries, from the previous goal of $ 100 billion annually, to $ 300 billion annually by 2035. This deal was rejected by India. There is a huge gap between the requirement and the allocation of climate funds. In this climate change crisis, the country should enable private sector to invest in building the infrastructure and innovations for mitigation and adaptation for agriculture sector. Of the total country's agriculture R&D expenditure, private sector R&D expenditure in agriculture sector is a mere 11 percent (Year 2020-21, DST 2023), whereas the overall R&D expenditure by private sector in the country comprise the share of 40 percent. Financial incentives (or reducing risks/costs) for private sector investment in agriculture can be encouraged through public finance instruments such as blended finance, credit enhancement, and other targeted risk reduction or revenue-boosting measures, undertaking public-private partnerships for green agricultural research with focus on climate mitigation and adaptation.

7.7 Solarisation of agriculture

Given the sector accounts for 17.2 percent of all the power used in the country, energy security for farmers needs to be secured through solar energy, which will ease financial stress on DISCOMS and reduce emissions. The PK-KUSUM scheme is an effort in this direction that includes deploying 10 GW of solar capacity through installation of small solar power plants of capacity up to 2 MW, installing 2 million standalone solar powered agriculture pumps, and solarizing agricultural feeders for 1.5 million grid connected pumps. Diesel and electric pumps for ground water extraction emit 45.3–62.3 Mt CO_2 per year (Rajan et al. 2020). These emissions can be mitigated by replacing them with solar pumps, though it will over-exploit ground water.

It is possible to counter climate change shocks and turn crisis into opportunity. The first step is to cope successfully with climate change, by adapting and building climate resilience in agriculture using climate resilient varieties and practices. India needs to mitigate GHG emissions from agriculture sector. That means cutting down GHGs, ensuring low-carbon agriculture growth, and using new techniques and policies to “build back better.” The key: don't replicate the GHG-intensive practices and crops, but instead build toward improved low-carbon agricultural practices and crops without compromising crop yields and farmer's income. Roughly 130-150 Mt CO_2 eq (85 Mt CO_2 eq from mitigating CH_4 and N_2O and 45-60 Mt CO_2 by replacing solar pumps) can be mitigated from the agriculture sector. The GoI and state governments could align existing natural farming, regenerative farming, organic farming and agriculture solarisation schemes to encourage farmers to participate in carbon credit programmes along with the associated organizations. To ensure quality credits from agriculture, government should fix minimum floor price of $ 20 per credit. Agriculture sector does not have emission reduction targets so the smart move is to begin by offering other sectors and domestic entities to offset their emissions indirectly by purchasing carbon credits from farmers.

8

References

- Agriculture Statistics at a Glance (2024). Directorate of Economics & Statistics (DES), Ministry of Agriculture & Farmers Welfare, Government of India.
- APEDA Agricultural and Processed Food Products Export Development Authority. https://apeda.gov.in/apedawebsite/.
- Basavalingaiah K., Ramesha Y.M., Paramesh V., Rajanna V.A., Jat S.L., Misra S.D., Gaddi A.K., Girisha S.C., Yogesh, G.S., Raveesha S., Roopa T.K., Shashidhar K.S., Kumar B., El-Ansary D.O., and Elansary H.O. (2020). Energy budgeting, data envelopment analysis and greenhouse gas emission from rice production system: A case study from puddled transplanted rice and direct-seeded rice system of Karnataka, India. Sustainability 2020, 12, 6439; doi:10.3390/su12166439.
- Bhatia A., Jain N., and Pathak H. (2013). Methane and nitrous oxide emissions from Indian rice paddies, agricultural soils and crop residue burning. Greenhouse Gases Science & Technology. 1-16 (2013); DOI: 10.1002/ghg.
- Central Electricity Authority (2023). CO_2 baseline database for the Indian power sector, Central Electricity Authority (CEA), Ministry of Power.https://www.cea.mic.in/wp-content/uploads/baseline/2024/User_Guide_Version_19.0.pdf.
- Central Ground Water Board (2021). National compilation on dynamic ground water resources of India, 2020. Central Ground Water Board, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India.
- Conrad R. (1989). Control of methane production in terrestrial ecosystems. In: Andreae, M.O. and Schimel, D.S., Eds., Exchange of trace gases between terrestrial ecosystems and the atmosphere, Wiley, Chichester, 39-58.
- Cost of Cultivation (2021-22). https://eands.dacnet.nic.in/Cost_of_Cultivation.htm.
- DST (2023). Updated R&D Statistics at a Glance, 2022-23 Government of India, Ministry of Science & Technology, Department of Science and Technology, New Delhi, India.
- Fertiliser Statistics 2022-23. 68th Edition, The Fertiliser Association of India (FAI), New Delhi.
- Gulati A. and Singh R. (2022). Fix rice farming to avoid a bumper emissions harvest. Financial Express. 14th February 2022.

- Gupta P.K., Gupta V., Sharma C., Das S.N., Purkait N., Adhya T.K., Pathak, H., Ramesh R., Baruah K.K., Venkatratnam L., Singh G. and Iyer C.S.P. (2008). Development of methane emission factors for Indian paddy fields and estimation of national methane budget. doi: 10.1016/j.chemosphere. 2008.09.042.
- Gupta D.K., Bhatia A., Kumar A., Chakrabarti B., Jain N. and Pathak H. (2015). Global Warming Potential of Rice (Oryza sativa)- wheat (Triticum aestivum) cropping systems of the Indo-Gangetic Plains. Indian Journal of Agricultural Sciences 85 (6): 807-16, June 2015/Article.
- Granli T. and Bockman O.C. (1994). Nitrogen Oxide from agriculture. Norwegian Journal of Agriculture Science, 12, 7-127.
- International Monetary Fund (IMF) https://www.imf.org/en/Countries.
- IPCC (1996). https://www.ipcc.ch/report/revised-1996-ipcc-guidelines-for-national-greenhouse-gas-inventories/.
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (Eds), IGES, Hayama, Japan. Available at: http://www.ipccnggip.iges.or.jp/public/2006gl/index.htm.
- IPCC (2013). Climate Change 2013 Technical Summary, The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC. Available at https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_TS_FINAL.pdf.
- IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds). Published: IPCC, Switzerland.
- IPCC (2021). Sixth Assessment Report of IPCC. https://www.ipcc.ch/assessment-report/ar6/.
- IPCC (2022). IPCC Working Group II report, Climate Change 2022: Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/assessment-report/ar6/.
- IPCC Special Report on Climate Change and Land (2022) https://www.ipcc.ch/srccl/chapter/chapter-5/.
- IPCC (2023). Climate Change 2023. Synthesis Report for Sixth Assessment. https://www.ipcc.ch/report/sixth-assessment-report-cycle/.
- IRRI (1997). Huke R.E. and Huke E.H. Rice Area by Type of Culture: South, South-East and East Asia a revised and updated database. International Rice Research Institute (IRRI).
- Land Use Statistics at a Glance (2024). Land Use Statistics (LUS) at a glance 2022-23, Directorate of Economics and Statistics, Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India.
- Livestock Census (2019). 20th Livestock Census - 2019. All India Report, Ministry of Fisheries, Animal Husbandry & Dairying, Animal Husbandry Statistics Division.
- Ministry of Statistics and Programme Implementation (MoSPI), GoI: https://mospi.gov.in/data.
- "MoEFFCC (2004). India's Initial National Communications to the United Nations Framework Convention on Climate Change, Government of India.

- MoEFCC (2012). India Second National communication to the United Nations Framework Convention on Climate Change.
- MoEFCC (2018). India's Second Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.
- MoEFCC (2021). India's Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.
- MoEFCC (2022). India's long-term low-carbon development strategy. Ministry of Environment, Forest and Climate Change, Government of India.
- MoEFCC. (2023). India's Third National communication and Initial Adaptation Communication. Submitted to The United Nations Framework Convention on Climate Change (UNFCCC).
- MoES (2020). Assessment of Climate Change over the Indian Region. https://doi.org/10.1007/978-981-15-4327-2.
- National Academy of Agriculture Sciences (2005). Policy options for efficient nitrogen use. Policy Paper No. 33, National Academy of Agriculture Sciences (NAAS), New Delhi, pp 12.
- National Environmental Policy (2006). National Environmental Policy (NEP) 2006, Ministry of Environment and Forest, Government of India.
- Pathak H., Li C., and Wassmann R. (2005). Greenhouse gas emissions from Indian rice fields: Calibration and upscaling using the DNDC model. Biogeosciences 2: 113-123.
- Pathak H., Bhatia A., Jain N., and Aggarwal P.K. (2010). Greenhouse gas emission and mitigation in Indian Agriculture - A Review, In ING Bulletins on Regional Assessment of Reactive Nitrogen, Bulletin No. 19, (Ed. Bijay Singh), New Delhi, pp i-iv & 1-34.
- Pathak H., Bhatia A., and Jain N. (2014). Greenhouse gas emission from Indian agriculture: Trends, Mitigation and Policy Needs. Indian Agricultural Research Institute, New Delhi - 110012, p39.
- Prasad R. (2009). Efficient fertiliser use: The key to food security and better environment. Journal of Tropical Agriculture 47 (1-2).
- Rajan A., Ghosh K., and Shah A. (2020). Carbon footprint of India's ground-water irrigation. Carbon Management 11 (3): 265-280.
- Sapkota T.B., Vetter S.H., Jat M.L., Sirohi S., Shirsath P. B., Singh R., Jat H.S., Smith P., Hillier J., and Stirling C.M. (2019). Cost-effective opportunities for climate change mitigation in Indian agriculture. Science of the Total Environment 655 (2019) 1342-1354.
- Singh R. and Gulati A. (2023a). Climate Smart Agriculture for weather vagaries. In: Agri-Food Trends and Analytics Bulletin Issue 1, Volume 3 Climate Proofing Agriculture.
- Singh R. and Gulati A. (2023b). India's long-term carbon strategy and agriculture. In: Agri-Food Trends and Analytics Bulletin Issue 3, Volume 2 Building Back Better ToG20ether.
- Singh R. (2024a). Carbon footprint of nitrogen fertiliser production and agriculture use in India. Indian Journal of Fertilisers 10 (12): 1254-1258, Fertiliser Association of India.

- Singh R. and Gulati A. (2024b). Agriculture subsidies and agrobiodiversity. In: Agri-Food Trends and Analytics Bulletin Issue 4, Volume 3 Re-aligning agrifood policies for protecting soil, water, air and biodiversity.
- Singh, R., Thangaraj, P., Juneja, R., and Gulati, A. (2024c). Saving Punjab and Haryana from Ecological Disaster: Re-aligning agri-food policies (Policy Brief No. 21). Indian Council for Research on International Economic Relations (ICRIER), New Delhi, India.
- Takai, Y. (1970) The mechanism of methane fermentation in flooded paddy soil. Soil Science and Plant Nutrition, 16 (6). 238-244 doi:10.1080/00380768.1970.10433371.
- The Energy Policy Institute at the University of Chicago (EPIC). 2023. Air Quality Life Index. 2023. Retrieved from: https://aqli.epic.uchicago.edu/reports/.
- TIFAC and IARI Joint Report (2018). Estimation of surplus crop residues in India for biofuel production. Technology Information, Forecasting & Assessment Council (TIFAC) An autonomous body of Department of Science and Technology, Government of India.
- Union Budget 2024-25. Ministry of Finance, Government of India. https://www.indiabudget.gov.in/.
- United Nations Climate Change. https://www.unfccc.in/BR4.
- United Nations Environment Programme (2020). Emissions Gap Report 2020. United Nations Environment Programme (UNEP) Nairobi. https://www.unep.org/emissions-gap-report-2020.

1 Annexure

State-wise methane emissions/year (Gg CO_2 eq) under different rice ecosystems

State/Union Territories	Total Methane (Gg CO_2 eq)	Irrigated area	Rain-fed and deep-water area				
		Continuous Flooding (Gg CO_2 eq)	Single drainage period (Gg CO_2 eq)	Multiple drainage period (Gg CO_2 eq)	Deep water (Gg CO_2 eq)	Regular/ Flood-prone (Gg CO_2 eq)	Drought prone (Gg CO_2 eq)
Andhra Pradesh	5177	2908	1720	219	330	0	0
Arunachal Pradesh	532	0	93	0	0	439	0
Assam	6036	1027	418	0	1288	2266	1035
Bihar	7266	4397	1212	273	455	455	474
Chhattisgarh	7315	2101	1090	233	0	0	3891
Goa	57	0	21	0	0	0	36
Gujarat	2432	1544	528	70	0	0	289
Haryana	3597	2164	1268	165	0	0	0
Himachal Pradesh	22	0	0	22	0	0	0
Jammu & Kashmir	113	0	0	113	0	0	0
Jharkhand	1993	70	14	4	82	941	882
Karnataka	2141	1074	583	265	0	0	0

State/Union Territories	Total Methane (Gg CO_2 eq)	Irrigated area	Rain-fed and deep-water area				
		Continuous Flooding (Gg CO_2 eq)	Single drainage period (Gg CO_2 eq)	Multiple drainage period (Gg CO_2 eq)	Deep water (Gg CO_2 eq)	Regular/ Flood-prone (Gg CO_2 eq)	Drought prone (Gg CO_2 eq)
Kerala	437	209	133	16	0	79	0
Madhya Pradesh	6859	3426	1535	362	0	0	1536
Maharashtra	3044	454	432	67	0	888	1209
Manipur	421	107	67	9	10	115	114
Meghalaya	258	133	101	11	0	6	8
Mizoram	84	39	21	3	2	11	9
Nagaland	480	167	106	13	0	98	95
Odisha	10145	3044	584	219	420	4200	1678
Punjab	7429	4470	2618	341	0	0	0
Rajasthan	440	217	134	89	0	0	0
Sikkim	36	31	0	0	0	5	0
Tamil Nadu	5110	2854	1705	211	112	112	116
Telangana	11652	6770	4093	534	256	0	0
Tripura	588	90	53	7	153	188	114
Uttar Pradesh	10839	6651	2710	1478	0	0	0
Uttarakhand	541	264	81	44	26	90	36
West Bengal	13188	3201	2422	279	1072	5095	1118
Union Territories	96	0	31	3	0	31	31
Total	10832	47416	23777	5050	4205	15019	12865

Source: Author's estimate based on MOEFCC 2021, IPCC Sixth Assessment Report 2021

2 Annexure

State-wise nitrous oxide emissions/year from rice cultivation

State/Union Territories	Direct Nitrous Oxide Emissions from fertilisers (Gg CO_2 eq)	Indirect Nitrous Oxide Emissions from fertilisers (Gg CO_2 eq)	Nitrous Oxide Emissions from FYM (Gg CO_2 eq)	Total Nitrous Oxide Emissions (Gg CO_2 eq)	
		Nitrous Oxide emissions from Volatilization loss	**Nitrous Oxide Emissions from Leaching Loss**		
Andhra Pradesh	605	92	61	38	797
Arunachal Pradesh	44	7	4	0	55
Assam	74	11	7	2	95
Bihar	426	65	43	19	553
Chhattisgarh	859	131	87	8	1085
Goa	2	0.3	0.2	0.05	3
Gujarat	216	33	22	17	288
Haryana	556	85	56	4	701
Himachal Pradesh	9	1	1	1	12
Jammu & Kashmir	58	9	6	6	287
Jharkhand	168	25	17	4	214
Karnataka	515	78	52	25	671
Kerala	28	4	3	1	36
Madhya Pradesh	792	120	80	3	996

State/Union Territories	Direct Nitrous Oxide Emissions from fertilisers (Gg CO_2 eq)	Indirect Nitrous Oxide Emissions from fertilisers (Gg CO_2 eq)	Nitrous Oxide Emissions from FYM (Gg CO_2 eq)	Total Nitrous Oxide Emissions (Gg CO_2 eq)	
		Nitrous Oxide emissions from Volatilization loss	**Nitrous Oxide Emissions from Leaching Loss**		
Maharashtra	411	63	42	10	526
Manipur	6	1	1	0.02	8
Meghalaya	3	1	1	0	4
Mizoram	1	0.1	0.05	0	1
Nagaland	7	1	1	0	9
Odisha	452	69	46	98	665
Punjab	1067	163	108	23	1363
Rajasthan	53	8	5	2	69
Sikkim	0	0	0	0.3	0
Tamil Nadu	454	69	46	34	603
Telangana	1582	240	160	21	2005
Tripura	7	1	1	7	16
Uttar Pradesh	1514	240	154	6	1904
Uttarakhand	56	9	5	5	75
West Bengal	790	120	80	93	1084
Union Territories	23	4	2	0.2	29
Total	10702	1628	1085	427	13842

Source: Author's estimates based on Agriculture Census (2021), Cost of Cultivation (2019-20), fertiliser Statistics (2021-22)

3 Annexure

State-wise surplus rice residue availability/year and GHG emissions

State/Union Territories	Dry biomass Generation* ('000 t)	Surplus Biomass* ('000 t)	Methane Emissions** (Gg CO_2 eq)	Nitrous Oxide Emissions** (Gg CO_2 eq)
Andhra Pradesh	16926	1340	88	23
Arunachal Pradesh	357	35	2	1
Assam	8135	902	59	15
Bihar	14583	2954	193	50
Chhattisgarh	14759	1461	95	25
Goa	248	64	4	1
Gujarat	2892	859	56	15
Haryana	7773	1827	119	31
Himachal Pradesh	262	156	10	3
Jammu & Kashmir	711	71	5	1
Jharkhand	7489	1483	97	25
Karnataka	6513	323	21	5
Kerala	782	77	5	1
Madhya Pradesh	5777	571	37	10
Maharashtra	6200	614	40	10
Manipur	995	637	42	10
Meghalaya	202	60	4	1
Mizoram	120	60	4	1

State/Union Territories	Dry biomass Generation* ('000 t)	Surplus Biomass* ('000 t)	Methane Emissions** (Gg CO_2 eq)	Nitrous Oxide Emissions** (Gg CO_2 eq)
Nagaland	858	85	6	1
Odisha	13675	1875	123	32
Punjab	23068	16787	1097	286
Rajasthan	586	0	0	0
Sikkim	42	4	0	0
Tamil Nadu	12599	1247	81	21
Telangana	11430	905	59	15
Tripura	1889	156	10	3
Uttar Pradesh	27701	7238	473	123
Uttarakhand	1137	169	11	3
West Bengal	21923	1086	71	18
Union Territories	76	3	0	0
Total	209758	43262	2828	736

*Source: *TIFAC IARI Joint Report 2018 **Author's estimates*

4 Annexure

Table 4.1: State-wise total methane emissions/year from enteric fermentation from cattle

State/Union Territories	Dairy Cattle Indigenous (Gg CO_2 eq)	Dairy Cattle Cross-Breed (Gg CO_2 eq)	Non-Dairy Cattle (Indigenous)			Non-dairy Cattle (Cross-Breed)		
			Below 1 yr (Gg CO_2 eq)	1-3 yr (Gg CO_2 eq)	> 3 yr (Gg CO_2 eq)	Below 1 yr (Gg CO_2 eq)	1-3 yr (Gg CO_2 eq)	>3yr (Gg CO_2 eq)
Andhra Pradesh	375	1,010	82	305	891	152	133	376
Arunachal Pradesh	35	3	11	61	124	0.28	1	2
Assam	1,676	260	478	1,622	2,953	54	334	159
Bihar	2,469	1,748	692	1,751	2,116	321	587	631
Chhattisgarh	920	89	225	1,288	4,813	13	44	76
Goa	5	14	1	5	13	1	4	5
Gujarat	1,207	1,638	227	795	2,126	197	556	504
Haryana	171	443	38	141	301	58	150	175
Himachal Pradesh	132	580	18	65	355	54	127	191
Jammu & Kashmir	258	732	50	121	311	97	229	153
Jharkhand	1,397	252	373	1,475	4,247	44	102	107
Karnataka	734	2,135	151	557	1,817	247	458	546
Kerala	19	629	4	17	12	86	219	113

State/Union Territories	Dairy Cattle Indigenous ($Gg\ CO_2$ eq)	Dairy Cattle Cross-Breed ($Gg\ CO_2$ eq)	Non-Dairy Cattle (Indigenous)			Non-dairy Cattle (Cross-Breed)		
			Below 1 yr ($Gg\ CO_2$ eq)	1-3 yr ($Gg\ CO_2$ eq)	> 3 yr ($Gg\ CO_2$ eq)	Below 1 yr ($Gg\ CO_2$ eq)	1-3 yr ($Gg\ CO_2$ eq)	>3yr ($Gg\ CO_2$ eq)
Madhya Pradesh	2,753	700	654	2,050	6,522	122	256	294
Maharashtra	1,310	2,475	245	954	4,474	248	569	772
Manipur	29	7	9	38	61	1	3	2
Meghalaya	97	23	28	142	351	1	4	4
Mizoram	3	8	1	4	10	1	3	6
Nagaland	6	5	2	12	23	1	3	6
Odisha	1,095	604	289	1,062	3,487	111	232	328
Punjab	100	1,207	15	48	136	116	263	282
Rajasthan	2,537	1,052	5,694	1,543	3,038	157	342	373
Sikkim	6	46	1	5	9	7	17	27
Tamil Nadu	388	3,553	94	282	393	559	1,142	1,244
Telangana	529	270	122	450	1,485	41	83	112
Tripura	113	44	33	104	137	10	25	20
Uttar Pradesh	2,999	2,651	686	1,855	2,279	443	953	924
Uttarakhand	260	289	50	133	451	38	81	80
West Bengal	2,717	1,220	791	2,847	3,772	247	634	564
Union Territories	13	67	3	20	26	9	26	24
Total	24,355	23,755	5,945	19,755	47,230	3,437	7,577	7,939

Source: Authors' calculations based on 20th Livestock Census Data

Table 4.2: State-wise total methane emissions/year from enteric fermentation from buffalo

State/Union Territories	Dairy Buffalo (Gg CO_2 eq)	Non-Dairy Buffalo (Gg CO_2 eq)		
		Below 1 yr	1-3 yr	More than 3 yr
Andhra Pradesh	2,920	305	905	1,388
Arunachal Pradesh	1	0.13	1	4
Assam	117	15	65	187
Bihar	3,255	424	1,138	1,766
Chhattisgarh	246	25	132	787
Goa	11	1	4	10
Gujarat	5,200	458	1,574	2,375
Haryana	2,108	204	767	719
Himachal Pradesh	377	26	91	115
Jammu & Kashmir	389	33	71	160
Jharkhand	367	43	173	709
Karnataka	1,599	149	355	671
Kerala	7	1	50	11
Madhya Pradesh	4,739	518	1,380	2,555
Maharashtra	3,255	235	627	1,295
Manipur	6	1	7	18
Meghalaya	2	0.2	1	13
Mizoram	0.2	0.03	0.35	1
Nagaland	2	0.32	3	9
Odisha	114	12	58	266
Punjab	2,302	166	564	738
Rajasthan	6,461	714	1,973	2,829
Sikkim	0.3	0.04	0.2	0.3
Tamil Nadu	260	24	74	110
Telangana	1,980	217	560	1,001
Tripura	2	0.3	1	2
Uttar Pradesh	15,394	1,696	5,201	6,235
Uttarakhand	511	35	114	169
West Bengal	193	14	70	368
Union Territories	122	7	21	28
Total	51,899	5,327	15,980	24,539

Source: Authors' calculations based on 20th Livestock Census Data

Table 4.3: State-wise total methane emissions/year from enteric fermentation from other livestock

	Sheep (Gg CO_2 eq)	Goat (Gg CO_2 eq)	Horse & Pony (Gg CO_2eq)	Mule (Gg CO_2 eq)	Donkey (Gg CO_2 eq)	Pig (Gg CO_2 eq)
Andhra Pradesh	1,918	601	1	0.06	1	3
Arunachal Pradesh	1	17	1	0	0	8
Assam	36	469	6	0.19	0.2	70
Bihar	23	1,395	16	0.40	3	10
Chhattisgarh	20	436	0.33	0	0	15
Goa	0	1	0	0	0	1
Gujarat	194	530	11	0	3	0.02
Haryana	31	36	5	1	0.2	5
Himachal Pradesh	86	121	4	6	1	0.08
Jammu & Kashmir	353	188	31	5	3	0.03
Jharkhand	70	992	1	0.01	0.1	36
Karnataka	1,202	671	3	0.01	2	11
Kerala	0.16	148	0.27	0	0.02	6
Madhya Pradesh	35	1,204	6	1	2	5
Maharashtra	292	1,154	9	0.18	5	5
Manipur	1	4	1	0	0	7
Meghalaya	2	43	0.13	0	0	27
Mizoram	0.05	2	0.07	0	0	15
Nagaland	0.04	3	0.03	0	0	17
Odisha	139	696	0.07	0	0	4
Punjab	9	38	7	0.44	0.1	3
Rajasthan	860	2,267	16	0.36	6	4
Sikkim	0.22	10	0.05	0	0	1
Tamil Nadu	490	1,076	3	0.08	0.3	2
Telangana	2,074	537	2	0.02	0.5	5
Tripura	1	39	0	0	0	8
Uttar Pradesh	107	158	37	2	4	12
Uttarakhand	31	149	4	7	0.16	0.7
West Bengal	104	1,771	1	0	0.02	16
Union Territories	0	24	1	0	0	13
Total	8,080	16,198	168	23	34	298

Source: Authors' calculations based on 20th Livestock Census Data

Table 4.4: State-wise total methane emissions/year from manure management from cattle

State/Union Territories	Dairy Cattle Indigenous (($Gg\ CO_2$ eq))	Dairy Cattle Cross-Breed ($Gg\ CO_2$ eq)	Non-Dairy Cattle (Indigenous)			Non-dairy Cattle (Cross-Breed)		
			Below 1 yr ($Gg\ CO_2$ eq)	1-3 yr (Gg ($Gg\ CO_2$ eq)	> 3 yr (Gg ($Gg\ CO_2$ eq)	Below 1 yr ($Gg\ CO_2$ eq)	1-3 yr ($Gg\ CO_2$ eq)	>3yr ($Gg\ CO_2$ eq)
Andhra Pradesh	47	89	11	37	81	15	30	28
Arunachal Pradesh	4	0.22	1	7	11	0.02	0.11	0.13
Assam	210	23	64	197	268	5	12	12
Bihar	309	154	92	213	192	32	52	48
Chhattisgarh	115	8	30	157	436	1	4	6
Goa	1	1	0.14	1	1	0.14	0.33	0.4
Gujarat	151	145	30	97	193	20	49	38
Haryana	21	39	5	17	27	6	13	13
Himachal Pradesh	16	51	2	8	32	5	11	14
Jammu & Kashmir	32	65	7	15	28	10	20	12
Jharkhand	175	22	50	180	384	4	9	8
Karnataka	92	188	20	68	164	25	41	41
Kerala	2	56	1	2	1	9	19	9
Madhya Pradesh	344	62	87	250	591	12	23	22
Maharashtra	163	219	32	116	405	25	50	58
Manipur	4	1	1	5	6	0.14	0.2	0.2
Meghalaya	12	2	4	17	32	0.11	0.4	0.3
Mizoram	0.3	1	0.08	0.48	1	0.1	0.3	0.5
Nagaland	1	0.4	0.24	1	2	0.08	0.2	0.5
Odisha	137	53	39	129	316	11	21	25
Punjab	12	107	2	6	12	12	23	21

State/Union Territories	Dairy Cattle Indigenous (($Gg\ CO_2$ eq))	Dairy Cattle Cross-Breed ($Gg\ CO_2$ eq)	Non-Dairy Cattle (Indigenous)			Non-dairy Cattle (Cross-Breed)		
			Below 1 yr ($Gg\ CO_2$ eq)	1-3 yr (Gg ($Gg\ CO_2$ eq)	> 3 yr (Gg ($Gg\ CO_2$ eq)	Below 1 yr ($Gg\ CO_2$ eq)	1-3 yr ($Gg\ CO_2$ eq)	>3yr ($Gg\ CO_2$ eq)
Rajasthan	317	93	760	188	275	16	30	28
Sikkim	1	4	0.19	1	1	1	2	2
Tamil Nadu	49	314	12	34	36	56	101	94
Telangana	66	24	16	54	135	4	7	9
Tripura	14	4	4	12	12	1	2	1
Uttar Pradesh	375	234	91	226	252	44	84	70
Uttarakhand	32	26	7	16	41	4	7	6
West Bengal	340	108	106	346	341	25	56	43
Union Territories	1	5	0	2	2	0	2	2
Total	3,044	2,099	793	2,405	4,280	344	670	601

Source: Authors' calculations based on 20th Livestock Census Data

Table 4.5: State-wise total methane emissions from manure management from buffalo

State/Union Territories	Dairy Buffalo ($Gg\ CO_2$ eq)	Non-Dairy Buffalo ($Gg\ CO_2$ eq)		
		Below 1 yr	1-3 yr	More than 3 yr
Andhra Pradesh	257	25	140	126
Arunachal Pradesh	0.1	0.04	0.14	0.3
Assam	10	9	10	17
Bihar	286	53	176	160
Chhattisgarh	22	2	20	72
Goa	1	0.2	1	1
Gujarat	458	32	243	216
Haryana	185	9	119	65
Himachal Pradesh	33	9	14	11
Jammu & Kashmir	34	16	11	15
Jharkhand	32	7	27	64
Karnataka	137	40	55	61
Kerala	1	14	8	1
Madhya Pradesh	417	20	213	232
Maharashtra	287	41	97	118
Manipur	1	0.2	1	2
Meghalaya	0.1	0.2	0.2	1
Mizoram	0.01	0.2	0.05	0.1
Nagaland	0.1	0.1	0.5	1
Odisha	10	18	9	24
Punjab	203	19	87	67
Rajasthan	569	26	305	257
Sikkim	0.03	1	0.03	0.02
Tamil Nadu	23	91	11	10
Telangana	174	7	87	91
Tripura	0.2	2	0.2	0.2
Uttar Pradesh	1,355	72	804	567
Uttarakhand	45	6	18	15
West Bengal	17	40	11	33
Union Territories	10	2	3	2
Total	4,567	562	2,470	2,230

Source: Authors' calculations based on 20th Livestock Census

Table 4.6: State-wise total methane emissions from manure management from other livestock

	Sheep (Gg CO_2 eq)	Goat (Gg CO_2 eq)	Horse & Pony (Gg CO_2 eq)	Mule (Gg CO_2 eq)	Donkey (Gg CO_2 eq)	Pig (Gg CO_2 eq)
Andhra Pradesh	144	30	0.08	0	0.11	31
Arunachal Pradesh	0.05	1	0.1	0	0	11
Assam	3	23	1	0.02	0.02	278
Bihar	2	70	1	0.03	0.27	40
Chhattisgarh	1	22	0.02	0	0	58
Goa	0	0.05	0	0	0	4
Gujarat	15	26	1	0	0.27	0.07
Haryana	2	2	0.4	0.06	0.02	19
Himachal Pradesh	6	6	0.4	0.49	0.11	0.35
Jammu & Kashmir	26	9	3	0.41	0.23	0.16
Jharkhand	5	50	0.05	0	0	145
Karnataka	90	33	0.3	0	0.22	43
Kerala	0.01	7	0.02	0	0	22
Madhya Pradesh	3	60	1	0.06	0.20	19
Maharashtra	22	58	1	0.01	0.43	19
Manipur	0.04	0.2	0.04	0	0	29
Meghalaya	0.1	2	0.01	0	0	107
Mizoram	0	0.08	0	0	0	60
Nagaland	0	0.2	0	0	0	67
Odisha	10	35	0	0	0	15
Punjab	1	2	1	0.04	0.01	11
Rajasthan	64	113	1	0.03	0.57	17
Sikkim	0.01	0.5	0	0	0	4
Tamil Nadu	37	54	0.2	0	0.03	9
Telangana	156	27	0.1	0	0.04	20
Tripura	0.04	2	0	0	0	34
Uttar Pradesh	8	8	3	0.22	0.39	49
Uttarakhand	2	7	0.3	0.64	0.01	3
West Bengal	8	89	0.06	0	0	62
Union Territories	0	0	0	0	0	53
Total	606	810	15	2.06	3.03	1,191

Source: Authors' calculations based on 20th Livestock Census Data

Table 4.7: State-wise total nitrous oxide emissions from livestock and poultry

State/Union Territories	Livestock (Gg CO_2 eq)	Poultry (Gg CO_2 eq)
Andhra Pradesh	1	218
Arunachal Pradesh	0.23	3
Assam	3	94
Bihar	3	33
Chhattisgarh	2	38
Goa	0.03	1
Gujarat	2	44
Haryana	1	94
Himachal Pradesh	0.3	3
Jammu & Kashmir	0.4	15
Jharkhand	2.3	50
Karnataka	2	120
Kerala	0.3	60
Madhya Pradesh	4	34
Maharashtra	3	150
Manipur	0.2	12
Meghalaya	1	11
Mizoram	0.38	4
Nagaland	0.42	6
Odisha	1	55
Punjab	1	36
Rajasthan	6	30
Sikkim	0.04	1
Tamil Nadu	1	244
Telangana	1	162
Tripura	0.3	8
Uttar Pradesh	6	25
Uttarakhand	0.3	10
West Bengal	3	156
Union Territories	0	3
Total	43	1,721

Source: Authors' calculations based on 20th Livestock Census Data

5 Annexure

State-wise nitrous oxide emissions from fertiliser consumptions

	Synthetic fertilisers (Gg CO_2 eq)
Andhra Pradesh	2841
Arunachal Pradesh	0
Assam	472
Bihar	3148
Chhattisgarh	1231
Goa	5
Gujarat	3556
Haryana	2772
Himachal Pradesh	103
Jammu & Kashmir	218
Jharkhand	367
Karnataka	3290
Kerala	196
Madhya Pradesh	4819
Maharashtra	4234
Manipur	28
Meghalaya	0
Mizoram	3
Nagaland	1
Odisha	927
Punjab	3955
Rajasthan	3500
Sikkim	0
Tamil Nadu	1730

	Synthetic fertilisers (Gg CO_2 eq)
Telangana	3159
Tripura	19
Uttar Pradesh	10372
Uttarakhand	279
West Bengal	2257
Union Territories	29
Total	53571

Source: Author's calculations based on fertiliser Statistics 2022-23

NOTES

INDIAN COUNCIL FOR RESEARCH ON INTERNATIONAL ECONOMIC RELATIONS

Core-6A, 4th Floor, India Habitat Center, Lodhi Road, New Delhi – 110003

O: +91 11 43112400 / 24645218 **F:** +91 11 24620180

Website: www.icrier.org | **Email:** info@icrier.res.in

ISBN 978-81-954132-9-4