NET ZERO IN AGRICULTURE: ROLE OF TECHNOLOGIES

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LIST OF ACRONYMS

ADM	Archer Daniels Midland
AI	Artificial Intelligence
CCAC	Climate and Clean Air Coalition
CDP	Carbon Disclosure Project
CIWF	Compassion in World Farming
CLF	Crop- Livestock-Forestry Systems
CNB	Carbon Neutral Beef
CO_2	Carbon Dioxide
CO_2eq/kWh	Carbon Equivalent per Kilo Watt Hour
COP26	Conference of Parties 26
CSRD	Corporate Sustainability Reporting Directive
DFIs	Development Finance Institutions
EE	Energy Efficiency
ESG	Environment Social Governance
EWS	Early Warning System
F&V	Fruits and Vegetables
FIs	Financial Institutions
FLAG	Forest Land Agriculture Sector Guidelines
GAFSP	Global Agriculture and Food Security Program
GFANZ	Glasgow Financial Alliance for Net-zero
GHG	Green House Gases
GIS	Geographical Information Systems
$GtCO_2eq$	Giga Tons of Carbon Dioxide Equivalent
IDEA	Indian Digital Ecosystem for Agriculture
IDH	The Sustainable Trade Initiative
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISSB	International Sustainability Standards Board
LD	Louis Dreyfus
LMICs	Low- and Middle-Income Countries
MFIs	Micro Finance Institutions
MIS	Management Information System
ML	Machine Learning
MRV	Measurement, Reporting and Verification
MT	Metric Tonnes
N2O	Nitrogen Oxide
NBFCs	Non-Banking Financial Companies
NDCs	Nationally Determined Contributions
NDPE	No Deforestation No Peat and No Exploitation
PES	Payment of Ecosystem Services
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan
R&D	Research & Development
RAS	Recirculating Aquaculture Systems
RE	Renewable Energy
SBTi	Science Based Target Initiatives
SEA	Southeast Asia
SLCP	Short Lived Climate Pollutants
SMEs	Small and Medium Enterprises
SoLAR	Solar Irrigation for Agriculture Resilience
TCFD	Task Force on Climate related Financial Disclosures
UNFCCC	United National Framework Convention on Climate Change
USD	US Dollars

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To know more about our work in Net-Zero Transitions, please reach out to borthakur@idhtrade.org or ravi.gupta@intellecap.net

OVERVIEW OF THE IDH-INTELLECAP STUDY

With a growing focus on the use-of technology in the agriculture sector, there have also been several digital and non-digital innovations that are being used to optimize the use of resources and consequently the emissions associated with agriculture supply chains. This study seeks to evaluate the role of digital and non-digital technologies in supporting a net-zero transition in the agriculture sector.

Objective of the study -

a) Map Green House Gas (GHG) emissions across agricultural supply chains,

b) Evaluate the role of digital and non-digital technologies in supporting a transition to net-zero emissions in agriculture, and

c) Provide recommendations for scaling high-impact technologies.

Methodology undertaken -

This study relied on secondary sources for landscaping different technologies used in the agricultural sector and assessing their potential in mitigating GHG emissions. Following this the team conducted interviews with corporates, technology service providers, global philanthropic foundations and experts from the agriculture and food sectors to identify high-impact technology clusters. The objective of these interviews was to understand the demand and supply of these technologies and to validate the assessment frameworks used to shortlist the high-impact technology clusters. The team concluded this phase with a detailed literature review and conducted another round of primary interviews to gain an in-depth understanding of each shortlisted technology cluster.

*Who will benefit from this research**-*

If you represent…	and are responsible for…	This report will help you to…
Agri & food corporates	Implementing sustainability practices to help your organization reduce its GHG emissions.	• Understand key GHG emission hotspots across the value chain. • Identify key technology clusters that have the potential to mitigate GHG emissions from such hotspots. • Understand different technologies and their relevance to achieve net-zero emissions.
Development Finance Institutions or International Foundations	Designing programs/ pilots for climate action in agriculture and food systems.	• Understand the spread of GHG emissions across pre-production, production, processing, and consumption stages. • Learn about high-potential digital and non-digital technologies for climate action. • Identify design principles for piloting and scaling technologies for climate action along with other socio-economic benefits for the smallholder farmers.
Digital or non-digital technology service providers	Delivering products and services that can reduce GHG emissions across agriculture and food systems.	• Understand upstream and downstream emission hotspots across corporate supply chains. • Understand how to make solutions more practical and cost-effective to encourage adoption by smallholder farmers and other actors/ stakeholders in low and middle income (LMIC) countries.
Governments	Planning and developing policy related to climate action in agriculture and food sectors.	• Understand key challenges faced by farmers and corporates in the adoption of Agriculture technologies (Agtechs). • Understand challenges faced by service providers in scaling their solutions. • Assess policy measures that can be deployed to encourage the use of technologies that can support transitions to net-zero emissions.

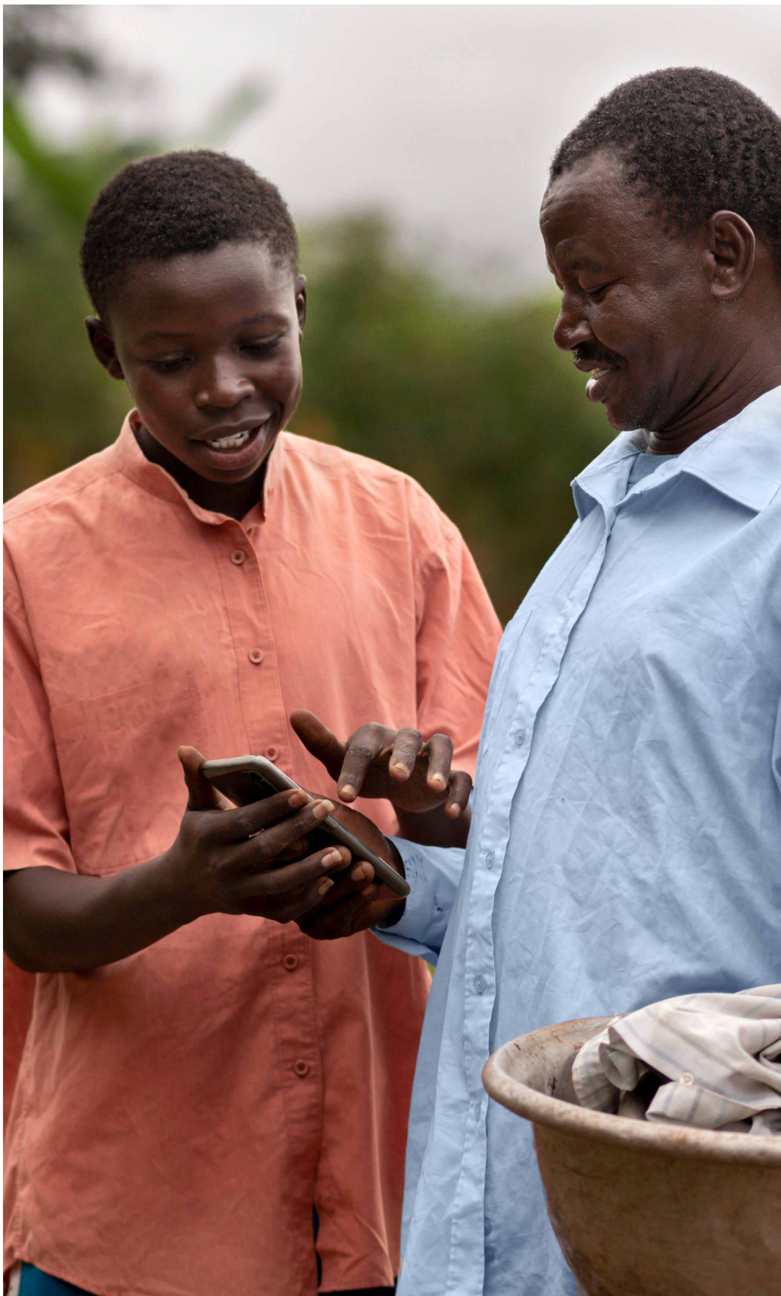
**Framework inspired from the "Farmer-Centric Data Governance: Towards a New Paradigm" Report.*

Key sections of the report-

1 Climate change and food systems in developing countries	**2 Understanding the transition to net-zero emissions in agriculture and food systems**	**3 Role of technologies in achieving net-zero emissions**	**4 Key technology clusters to facilitate net-zero transitions**
Highlights the need for and the importance of mitigating GHG emissions in agriculture and food systems	Maps key emission hotspots across agricultural value chains and highlights the current efforts being made by corporations to meet their net-zero commitments	Showcases the evolution of agricultural technologies and discusses the role of technologies in moving to net-zero emissions	Assesses high-impact technology clusters against multiple parameters
5 Co-benefits of net-zero technologies on climate resilience	**6 Challenges in scaling high-impact technology clusters**	**7 Recommendations for implementing net-zero technologies**	**8 Conclusion**
Represents climate resilience co-benefits of high-impact technology clusters	Discusses challenges that restrict the adoption of high-impact technology clusters	Provides stakeholder wise recommendations on the adoption of proposed technologies	Summarizes the key findings of this study
9 Annexure- Details the research methodology undertaken to identify high-impact technology clusters			

Limitations of the study-

The study attempts to undertake/ conduct a deep-dive into an evolving space at the intersection of climate, agriculture, and technology, where data is scanty. To overcome this challenge, the research team has relied on primary interviews and information from secondary sources to make certain assumptions while evaluating the different technology clusters. Consequently, while describing the efficacy of certain technologies, the report uses ranges rather than absolute numbers. Additionally, the efficacy of the identified technology clusters may vary across regions and crops: some technologies may have a higher mitigation impact in a specific value chain, while their impact may be limited in another. Given this, the study seeks to provide an overarching sense of the potential role of technologies and makes sectoral recommendations rather than case-specific recommendations. The research team is, however, confident that despite these limitations, the study will empower decision makers to leverage its insights to better design their technology-enabled strategies for combating climate change in agriculture.



EXECUTIVE SUMMARY

In support of evolving net-zero commitments, IDH and Intellecap conducted a study to evaluate the role of technologies in accelerating transitions to net-zero emissions in agriculture. This study seeks to complement existing and future climate action initiatives and provides recommendations to accelerate transitions to net-zero emissions by leveraging technologies. This summary highlights some of the report's key findings.

Current actions to combat climate change are insufficient and as a result global warming may exceed 1.5°C by the end of the century.

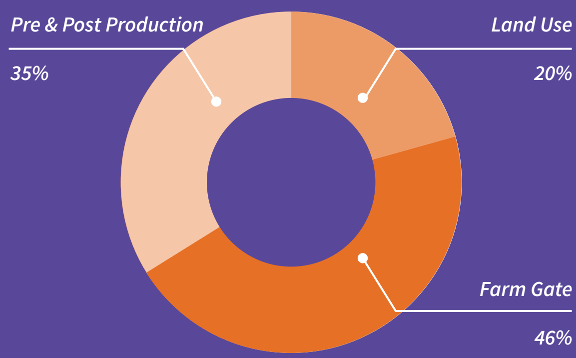
> In 2019, the net anthropogenic GHG emissions were 54% (21 GtCO2eq) higher than in 1990.
>
> - Source: IPCC, AR6 Report

Across 2011 to 2020, surface level temperatures rose by 1.1°C above pre-industrial levels as result of global warming and climate change caused by human induced GHG emissions.[1] Based on the current level of global efforts and commitments the world is projected to experience a catastrophic 2.8°C of global warming.[2] Exceeding this threshold will have severe and damaging consequences, with up to 132 million people pushed into extreme poverty by 2030, mainly in South Asia and Sub-Saharan Africa,[3] along with an increased frequency in climate-related disasters.

Agriculture and food systems are a significant contributor to climate change; however, they also bear the brunt of its adverse effects. Smallholder farmers especially are disproportionally impacted.

Agriculture and food systems account for almost one-third of all global emissions, or around 16-18 GtCO2eq[4] every year, with emissions projected to increase to 30 GtCO2eq by 2050.[5] However, climate change continues to have a damaging impact on agriculture and food systems. For example, climate change reduces soil organic content, reducing the availability of water, and causing an increase in insect and pest infestation. This is, in turn, affecting crop yields and disproportionally impacting smallholder farmers.

Figure 1- GHG emissions from agriculture and food system (2020 data)



Source: FAOSTAT 2020

Governments and large corporations worldwide continue to make commitments towards net-zero emissions, with over 70 countries and 40% of Food and Agri companies in the Fortune Global 2000 rankings setting net-zero goals.

Governments across the world have recognized the importance of addressing climate change, and to this end, have submitted Nationally Determined Contributions (NDCs) in compliance with the Paris Agreement. More than 70 countries, accounting for 76% of global emissions, have committed to net-zero targets and introduced, or plan to intro-duce, regulations promoting the decarbonization of supply chains.[6] In addition to government efforts, large agri and food system corporates have a crucial role to play in agri and allied value chains as they procure significant amounts of farm produce from a large number of suppliers who directly deals with the smallholder farmers. As climate change is one of the significant risks impacting business continuity, some of these corporates have also declared their net-zero plans, with 40% of the Food and Agri companies in the Fortune Global 2000 rankings setting net-zero targets.[7] Out of the approximately 5000 companies engaged with the Science Based

1 IPCC AR6 Synthesis report
2 IPCC AR6 report
3 World Bank Report- Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030
4 FAOSTAT data
5 Synthesis report of the IPCC AR6
6 UN Climate Action Race to Zero
7 Zerotracker
8 SBTi data

Targets initiative (SBTi) as of March 2023, around 550 belong to the agri-food sector and are committed to setting science-based targets for decarbonization. Of these, 176 have committed to net-zero emissions.[8]

Digital and non-digital technologies play a key role in reducing emissions across major GHG emission hotspots in the agriculture and food system supply chain.

To meet their net-zero emissions targets throughout the agri-food supply chain, both public and private sector actors are actively searching for ways to minimize GHG emissions. The incorporation of digital and non-digital technologies has tremendous potential to drive this transformation by substituting high-emitting inputs with low carbon inputs, using renewable sources of energy, offering guidance on optimized farm inputs, enhancing post-harvest management, managing farm waste, promoting sustainable packaging, streamlining retail and end-use management, and more. The emerging role of agricultural technologies in climate action complements its existing role in enhancing production, reducing cultivation costs, improving sales, and reducing vulnerabilities for farmers and their communities. Given the need for sustainable food security alongside the transition to net-zero, the widespread use of technology is even more critical in today's world. Currently, there are three key areas where technology is being utilized to support net-zero transitions:

Mapping:	*In-setting:*	*Off-setting:*
measuring the amount of GHG emissions to identify key sources within a company's value chain	managing and reducing emissions within a company's value chain by adopting technologies/ practices to implement nature-based solutions, improve energy efficiency, etc.	meeting a company's decarbonization commitments by purchasing carbon credits generated outside its value chain.

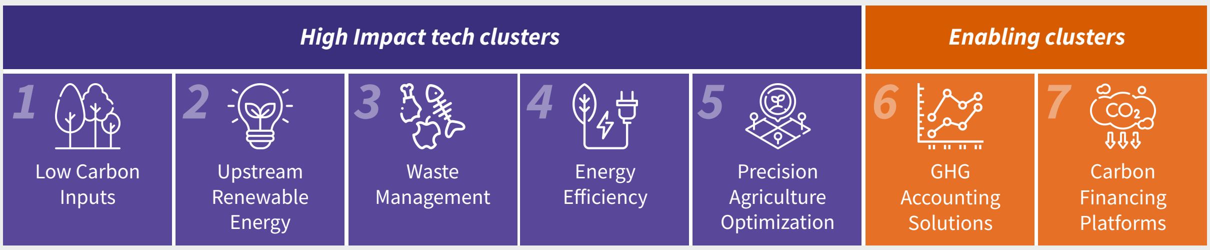
This study methodically assesses 13 technologies for their ability to decarbonize supply chains. It also assesses their feasibility for large-scale use by LMICs. From these, 5 high-impact technology clusters and 2 enabling clusters with the potential to mitigate 65–70% of the GHG emissions from agri-food supply chains were shortlisted for deep-dives.

Terms in this study:
Technology clusters refers to groups of digital and non-digital technologies that share similarities and have the potential to reduce GHG emissions across an agricultural supply chain. These clusters can facilitate the transition towards net-zero emissions in agriculture.

High-impact technology clusters are clusters shortlisted in this study based on an assessment of their potential to reduce GHG emissions and their feasibility of implementation in low and middle-income countries.

Enabling clusters do not directly impact GHG emissions within a supply chain but enable transitions to net-zero emissions by facilitating mapping, measurement, or trading of carbon credits.

Figure 2: Diagrammatic representation of the key recommended clusters



8 SBTi data

Key characteristics of the shortlisted technology clusters are highlighted below-

Description and Benefits	Illustrative Decarbonization Potential	Costs Involved
1 Low Carbon Inputs		
Technologies for replacing existing high GHG emitting farm/livestock inputs with low or zero carbon emission inputs. This cluster includes manufacturers of organic/bio-based fertilizers, controlled release fertilizers, biochar, low carbon pesticides, and feed additives. They reduce emissions by: • **Reducing the application of synthetic fertilizers** • **Preventing soil carbon loss** • **Preventing deforestation by reducing soy, rice, wheat, corn-based feeds** • **Reducing enteric fermentation** *Non-environmental benefits* can include a reduction in cultivation costs by 15 – 40%.	• Alternative fertilizers (Bio-fertilizers and low carbon fertilizers) mitigation potential of 40-50%[9] by reduction in use of chemical fertilizers. • Biochar-mitigation potential varies between 0.41 and 0.78 MT CO2eq per year, of which 79% could be attributed to increased soil carbon stock, and 21% to the co-production of bioenergy. [10] • Feed additives and alternate feeds-mitigation potential of 5-15% compared to regular feed. [11]	• **Technology costs**[12]**:** Less than USD 20/MTCO2eq Alternative fertilizer, controlled release fertilizer, Biochar, Low carbon pesticide USD 20-100/MT CO2eq - Alternative feed, Feed additives. • **Implementation/usage costs:** Capacity building for the farmers, and additional labor cost in some cases.[13]
2 Upstream Renewable Energy (RE)		
Technologies that replace fossil fuel-based energy in farm operations. These operations can include **irrigation, mechanization, ventilation and aeration for livestock, and aquaculture operations.** They reduce emissions by replacing fossil fuels. ***Non-environmental benefits*** **can include an increase of 40-50% in the users' income due to energy saving reduced use of fossil fuels and increased yield** (in areas without prior energy access).	• Irrigation- potential reduction of 95-98% in GHG emissions per unit of energy used for water pumping (CO2eq/kWh) as compared to pumps operated with grid electricity and/or diesel-pumps.[14] • Mechanization- fuel consumption savings of 35-40% per ton of crop produced and harvested[15] with mechanization based on renewable energy. • RE based ventilation technologies- can reduce the emission from on farm energy use which is approximately 15% of the total GHG emissions from aquaculture.[16]	• **Technology Cost:** USD 20-100/MT CO2eq. • **Implementation/usage costs:** Cost of supportive infrastructure like grids, batteries, as well as maintenance cost.
3 Waste management		
Technologies that reduce GHG emissions caused by inefficient farm and livestock waste management. This cluster includes microbe-based decomposition, bio-decomposers, nitrification, and urease inhibitors. They reduce emissions by avoiding crop burning, landfills, and other inefficient manure disposal processes. *Non-environmental benefits* can include additional **income from the sale of farm waste to waste processors and self-conversion of farm waste to useful end products.** It can also support the creation of livelihoods through rural waste management.	• Efficient farm waste management technologies- 5-15%[17] reduction in GHG emissions from farm waste. • Livestock manure management technologies-reducing GHG emissions by 18-20% (0.01- 0.26 GtCO2eq per year), with the range depending on the economic and sustainable capacity of the technology.	• **Technology Cost:** USD 20-100/MT CO2eq • **Implementation/usage costs:** Labour and ancillary costs for managing and maintaining waste management solutions, capacity building cost.

9 MDPI Article, 2017, Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics
10 Science Direct, 2022, Climate change mitigation potential of biochar from forestry residues under boreal condition
11 Research Gate 2021, Feed additives as a strategic approach to reduce enteric methane production in cattle: modes of action, effectiveness and safety
12 Technology cost- This is the cost of technology for reduction of one additional unit of CO2eq. This has been taken for all the identified technology clusters, based on inferences drawn from the IPCC AR6 Working Group III report.
13 IPCC AR6 Working Group III report.
14 FAO, 2021, The State of World's Land and Water Resources for Food and Agriculture
15 CEMA, 2022, The role of agricultural machinery in decarbonising agriculture
16 Nature, 2020, Quantifying greenhouse gas emissions from global aquaculture
17 Our World in Data website, retrieved in March 2023, Emissions by sector

Description and Benefits	Illustrative Decarbonization Potential	Costs Involved
4 Energy efficiency (EE)		
Technologies that optimize the use of fossil fuel-based energy for upstream and downstream operations. This cluster can include smart water controller, energy saving pump, small farm level coolbox for storing perishables, low energy dryers, and automated sorting. This cluster reduces emissions by reducing the use of fossil fuels and improving the efficiency of inputs across agricultural processes. *Non-environmental benefits* can include increased profit and income realization due to a reduction in energy use.	• Upstream EE technologies- 20-50% reduction in energy usage compared to non-EE solutions.[18] 10% improvement in water efficiency could reduce diesel consumption by 102 million liters, thus improving energy efficiency.[19] • Downstream EE technologies- 20-23% reduction in GHG emissions from storage, processing, and retail operations.[20]	• **Technology Cost:** USD 20-100 MT CO2eq.[21] • **Implementation/usage Costs:** Operational costs including maintenance and monitoring costs.
5 Precision agriculture optimization		
Technologies based on agri 4.0 technologies (such as remote sensing, Internet of Things, Machine Learning) that optimize the use of inputs and enable informed farm management decisions. This includes data-driven technologies for farm, livestock, and aquaculture management. This cluster reduces emissions by reducing the use of synthetic inputs such as fertilizers, feed, and agrochemicals. Through data-driven application of inputs, the cluster can also increase soil organic carbon and reduce enteric fermentation (in livestock). *Non environmental benefits* can include a **15-40%[22] increase in farm level incomes by reducing input usage and increasing productivity.**	• Precision agriculture technologies- 5-40% reduction in GHG emissions from the farm[23] depending upon the number of parameters analysed.	• **Technology Cost:** USD 20-100 MT CO2eq for around 80% of the technologies. • **Implementation/usage costs:** Operational costs include energy, communications, and costs associated with capacity building for farmers, agri-entrepreneurs, and suppliers. Additionally, there could be a need to invest in digital assets.

The research team also identified two enabling clusters, that do not lead to GHG reductions directly but enable transitions to net-zero emissions. Brief features of these enabling clusters are-

Description	Technologies	Benefits
6 Enabling Cluster: GHG Accounting Cluster		
Technologies that use remote sensing, AI, IoT sensors to map, monitor and measure the GHG emissions across the supply chain.	• Remote sensing based geospatial monitoring of biomass and soil carbon. • Data driven technologies for tracking climate risks/ tracking deforestation. • Emission accounting software- Supply chain mapping for getting access to the estimates of supplier's GHG emissions.	• **Environmental benefits:** Enables f monitoring emissions, identifying hotspots and hence, facilitates planning for decarbonisation. • **Socio-economic benefits:** Provides transparent and reliable data, which can be leveraged for the payment of ecosystem services or result based financing that can lead to additional income for producers and communities.

18 Based on primary interactions with technology providers
19 OECD study
20 IPCC, 2018, Chapter 8, Agriculture
21 IPCC AR6 Working Group III report.
22 Based on primary interactions with technology providers
23 Nature, 2012, Carbon emissions from forest conversion by Kalimantan oil palm plantations

Description	Technologies	Benefits
7 Enabling Cluster : Carbon financing platform		
Technologies that use remote sensing, AI, drones for measurement, reporting and verification of carbon credits generated by implementing nature-based solutions and help in selling/ offsetting carbon credits.	• Designing and implementing nature-based projects for carbon offsetting. • Designing and implementing carbon projects to reduce GHG emissions caused by land use change.	• **Environmental benefits:** Incentivizes producers and program owners to adopt sustainable agricultural practices such as agroforestry, which result in carbon sequestration. • **Socio-economic benefits:** Agriculture programs can generate revenue by selling carbon creditson carbon financing platforms. This can often offset the costs of transitioning to sustainable agricultural practices. Several models also ensure that 60-80% of the economic benefits are transferred back to producers.

Several barriers limit the adoption of these technology clusters, especially by smallholder farmers and related ecosystem actors from low- and middle-income countries; these barriers can be analyzed using the 3C framework of Cost, Complexity, and Capability.[24]

The nature of smallholder farming in low-and middle-income countries poses several challenges to scaling the shortlisted technology clusters. For example, smallholder farmers often face challenges in adopting technologies such as on-farm renewable energy efficient technologies due to the high initial costs involved. In many cases, innovative financing models are needed to make these technologies financially feasible. Similarly, several of the technology clusters such as those associated with GHG accounting and carbon financing platforms are difficult to scale due to the complex implementation requirements involved. These can include tasks such as digitizing farm records or performing ground-truthing exercises to calibrate geospatial imagery. Adoption of technologies that are data-driven and rely on digital assets, such as precision agriculture, has been limited due to challenges related to capabilities of smallholder farmers particularly regarding digital literacy.

The study recommends several ways in which stakeholders from the agricultural sector can take action to scale the adoption of these shortlisted technology clusters, both at the individual and collective level.

The study maps actions for 5 key stakeholder categories: **a) Corporates, b) Technology Service Providers, c) Governments, d) Financiers and Funders, and e) Industry Associations and Coalitions.**

Corporates, for instance, can build awareness amongst suppliers of the importance of GHG accounting and ways to approach it. They can further incentivize farmers and their collectives to adopt technologies that support sustainable cultivation practices through payments for ecosystem services, sustainability differentials, and carbon finance. To encourage adoption by last mile markets, technology providers can bundle GHG reducing technologies with other services such as financing and building market linkages.

Governments can promote data sharing and build digital infrastructure as well as provide subsidies and low-cost loans for adopting the shortlisted technologies. While offering finance to corporations and suppliers, financing institutions and investors can link lending and investing terms to ESG scores, to incentivize sustainability. Further, Development Finance Institutions and Donors can work with the private sector to design and offer financing mechanisms that de-risk investments into these shortlisted clusters. Such mechanisms can include impact bonds, long-term patient capital, and concessional debt. Industry associations and coalitions play a key role in scaling up these technologies. They can create awareness amongst members about available technologies by developing a platform which lists the climate smart technologies and develop an index that ranks and segments these technologies for use in different contexts and value chains with which corporates can relate based on their needs. For many of the emerging technologies, coalitions can play a key role in encouraging pre-competitive collaboration to test and validate the impact and business models associated with the identified technology clusters.

24 Framework adapted from ODI's working paper on Disruptive technologies in agricultural value chains: Insights from East Africa

1

CLIMATE CHANGE AND FOOD SYSTEMS IN LOW AND MIDDLE-INCOME COUNTRIES (LMICs)

The current increase in GHG emissions is having a negative socio-economic impact, highlighting the urgent need for climate action from both state and non-state actors.

The latest IPCC report estimates that at the current rate of GHG emissions, global warming is likely to reach 1.5°C between 2030 and 2052.[25] Human-induced GHG levels have been on the rise since industrialization. Over the last few decades, emissions have increased at an alarming pace. For instance, global net anthropogenic GHG emissions in 2019 were 54% (21 GtCO_2eq) higher than in 1990.[26] This increase is harming the environment in multiple ways: sea levels are rising, storms are getting stronger, ice caps are melting, and the incidence of floods and droughts have increased. GHG emissions are expected to reach 58 GtCO_2eq in 2023,[27] which is 23 GtCO_2eq higher than what is required to maintain the target of 1.5°C warming or lower, as committed to under the Paris Agreement. Closing this gap requires a reduction in GHG emissions by 45% annually.[28]

Climate change directly affects the private sector. Moreover, the private sector can play a key role in climate action and there has been a noticeable increase in commitments and climate action among businesses. As a result, meeting climate change adaptation and mitigation targets is now the responsibility of both governments and non-state actors. This approach continues to gain momentum as non-state actors, such as corporations, financial institutions, cities, education, and healthcare institutions, make commitments to reduce GHG emissions, in addition to the Nationally Determined Contributions (NDCs) submitted by country governments. The United Nations Climate Change Race to Zero Campaign[29], has recorded over 8,000 pledges by global companies to go “net-zero”. Some of these companies have also come out with science-based near-term targets for 2030 and long-term targets for 2040 to 2050.

25 IPCC, special report March 2023
26 IPCC, AR6 Report, Page 12
27 World Emission Clock
28 UN Emission GAP report 2022
29 UNCCC Race to Zero

1.1 THE IMPACT OF CLIMATE CHANGE IN AGRICULTURE AND FOOD SYSTEMS

WHEAT
Every 1° C increase above mean temperature of 23°C decreases wheat yield by 10%.

COFFEE
50% of the coffee cultivation area may no longer be suitable for its cultivation by 2050.

COCOA
A rise of just 2.1°C could leave 89.5% of land used to cultivate cocoa, unsuitable by 2050.

LIVESTOCK
Rising temperatures can cause increased instability in feed supply, increased heat stress, changes to fertility and disease susceptibility.

Agriculture and food systems are a key contributor to GHG emissions and climate change; at the same time, rising temperatures and erratic weather patterns adversely impact the sector.

Agriculture and food systems account for one third of the global GHG emissions per year, highlighting the need for targeted efforts to reduce emissions activities to limit global warming to 1.5°C or lower. In 2020, the sector's GHG emissions were 16 $GtCO_2eq$.[30] The agricultural sector is the largest emitter of methane (45%) and nitrous oxide (80%)[31] which are 81 and 273[32] times more harmful, respectively, than carbon dioxide over a 20-year period. In the absence of mitigation measures and improvement of technical efficiency, emissions from the sector may rise by 30% by 2050.[33]

Moreover, the sector is vulnerable to climate change since crops and livestock are highly sensitive to temperature changes, water availability, extreme weather, and other factors. The impact of increased temperature varies across crops[34] and livestock as depicted below:

Among sectoral stakeholders, smallholder farmers are specifically vulnerable to climate change; reduced yield from crops, livestock, and aquaculture directly impacts their livelihoods.

Smallholder farms (less than 2-hectares of land) account for 84% of the 608 million farms worldwide. However, they manage only 12% of the world's cropland and produce roughly about 35% of the global agricultural output.[35] The income of smallholder farmers from crop and livestock production is very low and ranges from USD 0.8 to USD 4.0 across LMICs.[36] Due to their low income, smallholder farmers do not have the capital to invest in climate resilience and adaptation measures. The increasing negative impact of climate change further reduces their income, making them more vulnerable to climate change related disasters.

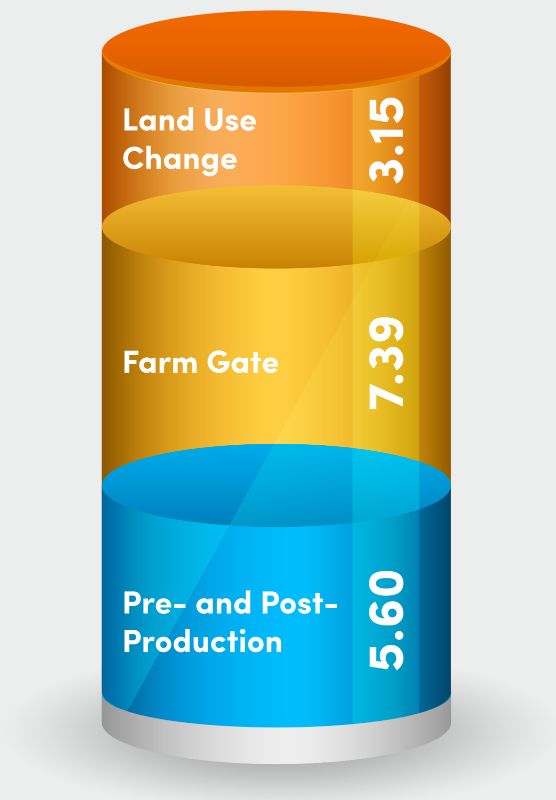
30 FAOSTAT, 2020
31 FAOSTAT: Enteric Fermentation (2016)
32 IPCC, AR6 Working Group I report, Chapter-7
33 FAO report-Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks Wheat- Hede AR, Skkovm B, Reynolds MP, et al. Evaluating genetic diversity for heat tolerance traits in Mexican wheat landraces. Genet Res Crop Evol. 2001;46:37–45, Coffee- Fairtrade and
34 Climate Institute estimate, Cocoa- Climate & Chocolate, Livestock- Impact of Climate change on livestock food supply chain
35 FAO research study
36 FAO Report- The economic lives of smallholder Farmers

1.2 SOURCES OF GHG EMISSIONS FROM AGRICULTURE AND FOOD SYSTEMS

Agricultural activities at the farm-gate have the highest share of emissions across all value chains.

At the sectoral level, GHG emissions are categorized across land use change, farm-gate, and pre and post-production to reflect the entire supply chain. These hotspots are summarised below:

Figure 3- Global agri and food system based GHG emissions in GtCO2eq



2.95	18%	Deforestation
0.20	1%	Fires in organic soil and tropical forest
2.85	18%	Enteric Fermentation
1.34	8%	Manure#
0.92	6%	Drained Organic Soils
0.63	4%	Synthetic Fertilizers
0.69	4%	Rice Cultivation
0.44	3%	Crop Residues*
0.53	3%	On-farm Energy Use
1.26	8%	Food System Waste Disposal
1.25	8%	Food Household Consumption
0.89	6%	Food Retail
0.50	3%	Pre and Post-Electricity Use
0.47	3%	Food Processing
0.54	3%	Food Transport
0.30	2%	Food Packaging
0.39	2%	Fertilizers Manufacturing

(Including livestock manure, manure left on pastures & applied to soils)
* (Including savanna fires)

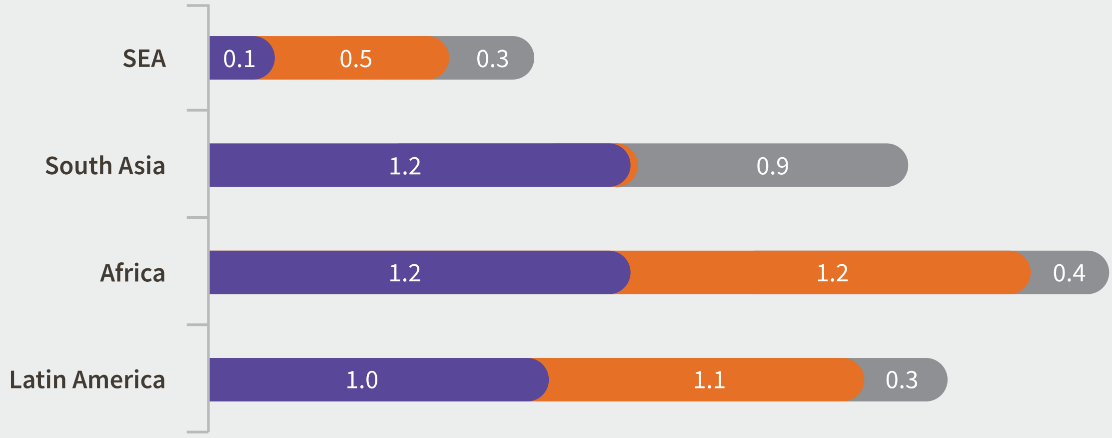
Source: FAOSTAT 2020 data

Deforestation due to changes in land use, enteric fermentation[37] from livestock, soil degradation due to the uneven use of chemical inputs and water, and poor farm waste management are key GHG emission concentration points.

37 Enteric fermentation- fermentation that takes place in the digestive systems of ruminants.

1.3 GEOGRAPHICAL DIFFERENCES IN GHG EMISSIONS AMONG LMIC REGIONS

Figure 4: LMIC region wise GHG emission data across three stages of the agri supply chain (Total ~8.2 GtCO2eq)



Source: FAOSTAT data, 2020

LMICs account for approximately half of all global agricultural emissions.

Given the high dependence on, and the range of agriculture practiced in developing economies, agricultural GHG emissions from LMICs were about 8.2 GtCO2eq[38] in 2020. This is more than half of the total global GHG emissions from agriculture and food systems. GHG emissions from LMIC regions account for 85% of total global GHG emissions from agriculture. Land use change and farm gate activities are major contributors to GHG emissions from LMICs. Among LMIC regions, Africa and Latin America are the major contributors to the GHG emissions.

Key sources of GHG emissions vary depending on the crop and livestock composition of different regions.

Net forest conversion is a major source of GHG emissions in Africa and Latin America due to the high production of plantation-based crops like cocoa and coffee. Similarly, enteric fermentation contributes significantly to GHG emissions in South Asia and Latin America due to their large livestock population. Apart from net forest conversion and enteric fermentation, other activities account for less than 10% each of overall agricultural GHG emissions from LMICs.

The below table lists out the key GHG emission activities, GHG emissions as a percentage of total, and region-wise GHG emissions across key activities. Activity-wise, GHG emissions contributing more than 30% are highlighted to indicate the key regions.

38 FAOSTAT data

Table 1 Emissions by LMIC regions in 2020

Activity	GHG emissions as % of sum of all activities	Africa	SEA	South Asia	Latin America
Net Forest conversion	38%	43%	15%	0%	42%
Enteric Fermentation	28%	27%	5%	31%	37%
Manure left on Pasture	8%	43%	5%	19%	34%
Drained organic soils	8%	14%	77%	7%	3%
Rice Cultivation	7%	10%	48%	38%	4%
Synthetic Fertilizers	3%	9%	17%	51%	22%
Manure Management	2%	19%	25%	38%	19%
Crop Residues	2%	16%	17%	37%	30%
Fires in humid tropical forests	2%	70%	10%	1%	19%
On-farm energy use	2%	21%	15%	17%	46%
Manure applied to Soils	1%	14%	21%	35%	31%
Burning - Crop residues	0.3%	26%	17%	33%	24%
Overall contribution by the LMIC		**34%**	**11%**	**25%**	**30%**

Source: Intellecap analysis based on FAOSTAT 2020

Some of important observations related to GHG emissions from LMICs are:

a. ***Overall, net forest conversion (38%) is a major source of GHG emissions, with Africa (43%) and Latin America (42%) being the largest contributors.*** The conversion of forest land to both subsistence and commercial agriculture is by far the most common cause of deforestation in Africa and other tropical regions.[39] Beef and soy production are the two of the most significant global drivers of deforestation; they also account for more than two-thirds of the recorded habitat loss in Brazil's Amazon and Cerrado regions, as well as Argentina and Paraguay's Gran Chaco region. Demand for soy is closely connected to demand for beef and other animal proteins.

b. ***Enteric fermentation (28%) is the second largest source of GHG emissions.*** Latin America (37%), South Asia (31%), and Africa (27%), have significant emissions due to enteric fermentation. Some of key factors that affect enteric fermentation include the species and age of the animal, feeding strategies, dietary composition, and environmental stress.

c. ***Manure left on pastureland (8%) along with drained organic soil (8%) and rice cultivation (7%) are the third and fourth major sources of emissions.*** Drainage of organic soils releases large quantities of carbon dioxide (CO_2) and nitrous dioxide (N_2O) into the atmosphere. Removal of water leads to faster oxidation and decomposition of the underlying matter resulting in the release of these gases. Agriculture, particularly the cultivation of permanent crops, is a major cause of the drainage of organic soils around the world. This is corroborated by the fact that of the 8% GHG emissions from drained organic soil, 77% originates from Southeast Asia, a major producer of palm oil.[40] Rice cultivation, which is practiced on a large scale in Asia, is also a significant source of methane emissions due to the decomposition of organic matter under highly anaerobic conditions.

39 UN-Saving Africa's Forest
40 Earth System Science Data

2

UNDERSTANDING THE TRANSITION TO NET-ZERO EMISSIONS IN AGRICULTURE AND FOOD SYSTEM SUPPLY CHAINS

Net-zero refers to a state in which the greenhouse gases entering the atmosphere are balanced by removal from the atmosphere.[41] It means bringing down greenhouse gas emissions as close to zero as possible, with remaining emissions being re-absorbed from the atmosphere.

To minimize the frequency of climate-related catastrophes, ensure sustainable livelihoods and food security, and respond to growing international commitments and public demands, numerous governments have committed to achieving net-zero emissions and are actively taking steps towards this goal.

If global warming surpasses the threshold of 1.5°C, the consequences are predicted to be dire. For example, if the temperature rises by 2°C by the end of the century, nearly 37% of the world's population will endure extreme heatwaves every five years, and roughly 61 million people living in cities will be vulnerable to severe droughts.[42] Such climatic volatility is also expected to push millions of people into poverty and put global food security at risk. To address this threat, 196 countries signed the Paris Agreement during COP21 in 2015.[43] This legally binding international treaty aims to limit the rise of the global average temperature to well below 2°C above pre-industrial levels and to strive towards keeping limiting the increase to 1.5°C. In order to meet their obligations under the Paris Agreement, reduce the impact of frequent climate disasters, and protect their citizens' livelihoods, countries are announcing their net-zero targets and submitting Nationally Determined Contributions (NDCs). These NDCs outline plans to decrease emissions and adapt to the impact of climate change.

Apart from aligning with national net-zero commitments, corporates have committed to net-zero targets to manage supply chain, reputational and climate related finance risks.

Currently the materiality matrix[44] of most of global corporates identifies climate change and sustainable sourcing as issues that are important to stakeholders and that have a significant impact on business operations. Mitigating risks associated with climate change requires corporations to reduce their carbon

footprint, prompting them to commit to transitioning to net-zero. These risks are-

- ***Reputational risk-*** Consumers are increasingly aware and demand responsible sourcing and fair-trade practices for the products they purchase. This drives corporations to reduce their carbon footprint and improve sustainability across their supply chain.
- ***Climate related financial risk-*** Most global corporations are assessed against Environmental, Social and Corporate governance (ESG) parameters by financial institutions, investors, and shareholders. There are various frameworks for sustainability reporting, for example International Sustainability Standards Board (ISSB), Corporate Sustainability Reporting Directive (CSRD), Task Force on Climate Disclosure (TCFD) etc. These frameworks focus on the effects of climate change on corporates and the resulting financial risk. Better TCFD and ESG scores attract investors and make the finance available at competitive rates as investors relate climate risks with financial risks.
- ***Supply chain and procurement risks-*** Rising global temperatures lead to extreme weather events that can reduce crop production and affect procurement prices. This, in turn, can lead to uncompetitive product prices. It is therefore important for corporations to mitigate procurement risks arising from climate change to ensure adequate product quality and quantity.

41 Netzeroclimate.com
42 A Degree of Concern: Why Global Temperatures Matter – Climate Change: Vital Signs of the Planet (nasa.gov)
43 UNFCCC- Paris agreement
44 Materiality Matrix- the process used by businesses to identify issues which are most material for the corporate and have a high impact on the business and its stakeholders.

2.1 MAPPING EMISSIONS ACROSS SUPPLY CHAINS

To achieve their net-zero targets, corporates must have a detailed understanding of emissions across their supply chain and identify actions they can take to reduce emissions.

GHG emissions vary based on the type of crops and the degree of processing involved. It is insufficient to rely on the sectoral level estimates of GHG emissions mentioned in Chapter 1 while devising a decarbonization plan. It is necessary to meticulously map GHG emission hotspots across both upstream and downstream activities, as well as classify these hotspots according to the three different scopes of GHG emissions as per global standards.

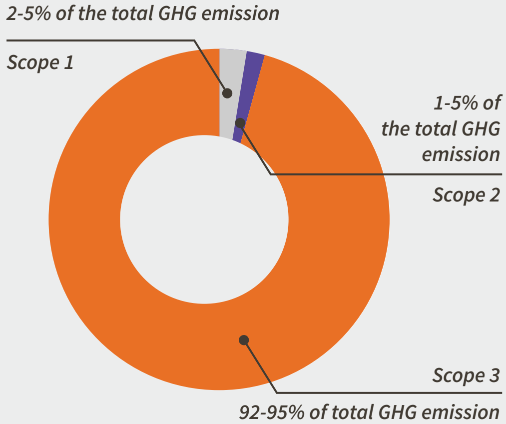
Upstream and downstream activities across the supply chain & Scope 1,2 and 3 emissions

↑ Upstream Activities	↓ Downstream Activities
Activities undertaken during the procurement of raw materials - from farm-gates to processing centers.	Activities undertaken during the manufacture of products - from processing plants to consumers.

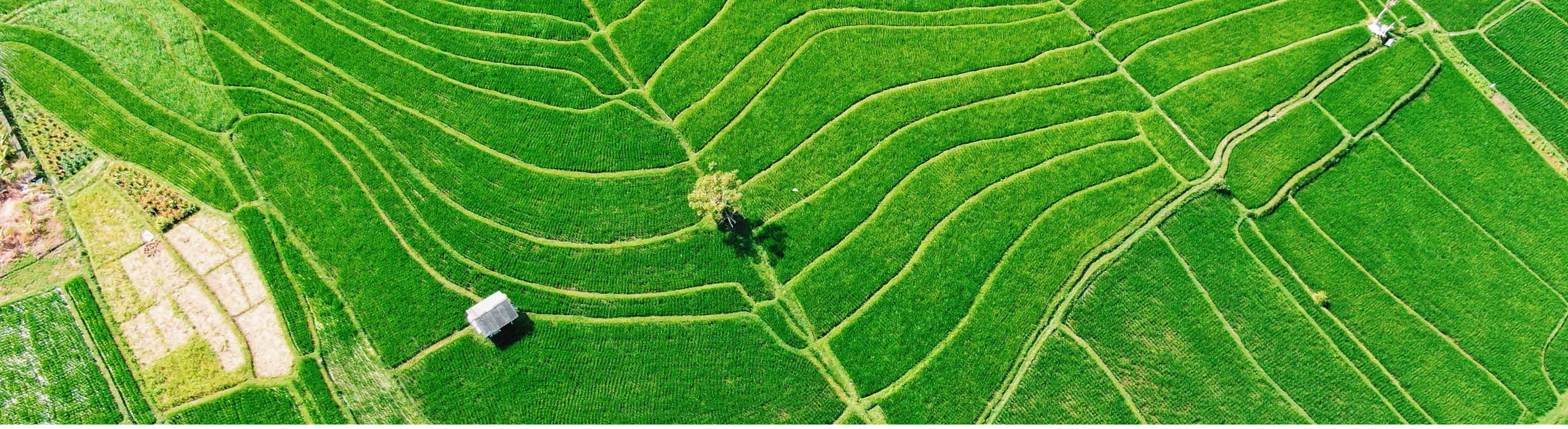
The structure of supply chains and the enterprises involved at each stage vary significantly across products and geographies.[45] Each upstream and downstream activity lead to certain levels of GHG emissions. Some of these emissions come from the company's processing units, while others are indirectly related and distributed across the supply chain. Based on their origin, these emissions are categorized under three scopes by the Greenhouse Gas Protocol, a global corporate GHG accounting and reporting standard.

Figure 5: Scope 1, 2 and 3 emissions of the corporates

Scope 1 emissions	Emitted directly
	Emitted from sources owned by the company
	Ex- Processing unit, Vehicle fleet, cold storages
Scope 2 emissions	Emitted indirectly
	Emitted from the generation of purchased energy
	Ex. Electricity, heating/cooling
Scope 3 emissions	Emitted indirectly but linked to value chain
	Emitted across up and downstream of the value chain
	Ex. Sourcing of materials, transportation, retail etc.



45 OECD



Scope 3 emissions are the highest contributors to the total GHG emissions from any corporation in the agriculture and food system.

A growing number of global food corporates have declared their net-zero targets or are focusing on decarbonization. These targets or decarbonization pathways are further broken down into Scope 1, 2, and 3 based on GHG accounting standards or Science-Based Target Initiative (SBTi) methodology.

Scope 3 emissions account for 92-95% of the total GHG emissions across the supply chain. Within Scope 3 emissions, around 65–75% of emissions occur at the sourcing stage, followed by manufacturing, packaging, and retail. This can be seen from the value chain agnostic mapping of upstream and downstream activities of a typical agriculture and food system corporate represented below:

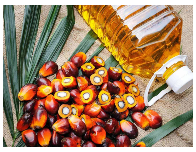
Figure 6: GHG emission mapping across up and downstream activities of a typical agriculture and food system corporate

	↑ Upstream Activities			↓ Downstream Activities				
Share in total GHG emissions	65-75%	1-2%	1-2%	6-9%	5-10%	2-4%	2-5%	3-6%
Activities	Sourcing Procurement	Storage & Handling	Upstream Transportation	Processing	Packaging	Downstream Transportation	Retail & Business Channels	Consumer & End Life
Direct or Indirect sources	• Directly from farmers • Suppliers • Cooperatives • Self managed farms	• Third party storage • Village level collection units	• Third party transporter	• Company operated • Third party manufacturer	• Company operated • Third party packaging units	• Third party transporter	• Dealers • Distributors • Retailers	• Consumers
GHG emission hotspots	*Specific to crops-* • Deforestation & other land use change *Specific to livestock and aquaculture-* • Enteric fermentation • Manure management *Common hotspots across sector-* • Drained organic soils (Tillage/agri practices/ excessive use of inputs) • Synthetic fertilizers • Crop residues • On-farm energy use	• Use of fossil fuel based energy for operating warehouses/ Cold storages/ collection centres • Energy inefficiency	• Use of fossil fuels for operating fleets • Energy inefficiency	• Use of fossil fuel based energy for processing • Energy inefficiency • Waste generation	• Use of fossil fuel based energy for running packaging machines • Using non sustainable packaging materials • Energy inefficiency	• Use of fossil fuels for operating fleets • Energy inefficiency	• Storage (use of refrigerants) • Wastage	• Packaging used to transport products to the point of retail • Packaging that is disposed of prior to the end-of-life of the final product • Waste disposal & treatment

Source: Intellecap analysis of sustainability reports of multiple global corporates in agri and food system

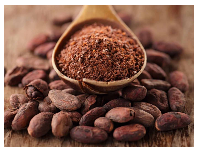
As 65 – 70% of scope 3 emissions occur during procurement, businesses need to measure and reduce these emissions for successful achievement of decarbonization targets.

2.2 EMISSION HOTSPOTS FOR DIFFERENT COMMODITY SPECIFIC VALUE CHAINS



Palm Oil

Tea



Cocoa

Coffee

Spices

Cotton

F&V

Livestock

Aquaculture

Emission concentration points or GHG hotspots may be common at a supply chain (commodity agnostic agri and food system) level, however, there is high variance from a value chain (commodity) perspective.

The study focuses on 9 key value chains that:

- Represent diverse sub-sectors of agriculture and its allied sectors.
- Reflect LMIC's key agricultural and related sub-sectors.
- Reflect some key value chains that IDH focuses on.

A detailed analysis of these value chains demonstrates that even at the farm gate hotspots can vary significantly. For instance- deforestation & land use change is the key causes of GHG emissions across plantation crops while excessive use of inputs like synthetic fertilizers, water, agrochemicals are major contributors to GH emissions for cotton, fruits, and vegetables (F&V) and spices. An analysis of the Carbon Disclosure Project's (CDP) reports as well as sustainability reports of few companies that have declared their scope 3 emissions, has helped identify emission hotspots across these value chains, as discussed below:

Table 2 Emission hotspots across the nine focused supply chains

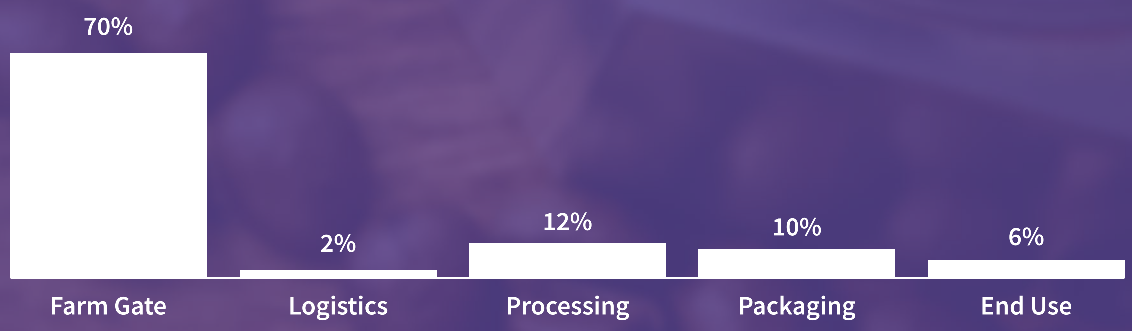
GHG EMISSION HOTSPOTS

Plantation Crops- Palm Oil, Cocoa, Coffee, Tea

At the production stage, deforestation is the leading cause of GHG emissions, followed the use of fertilisers and pesticides.

- ***Palm oil:*** Processing palm oil mill effluent contributes to 12% of GHG emissions as it releases methane. When compared to other plantation crops, palm oil produces significantly more emissions during processing. The annual GHG footprint of palm oil is much higher than that of other plantation crops due to its higher production volume.
- ***Cocoa:*** On an average 1.47 kg CO_2eq are emitted per kilogram of cacao produced[46] for an average yield of 430-440 Kg per hectare. Deforestation and excessive use of farm inputs for increased yield are major sources of GHG emissions.
- ***Coffee:*** Emissions associated with each serving of coffee is about 0.6 to 0.7Kg CO_2eq.[47] Land use change typically contributes a GHG footprint worth half of a cup of coffee.
- ***Tea:*** Emissions occurring at the consumption and packaging stages are much higher as compared to emissions during production and harvesting.

Scope 3 emission mapping



Key emission hotspots across the supply chain of plantation crops:

Farm Gate → Logistics → Processing → Packaging → End Use

Farm Gate
- *Deforestation (65%)*
- *Synthetic fertilizer application (5%)*
- *Composting of residues*
- *Use of thermal fuels in farm equipment*

Logistics
- *Fossil Fuel based vehicles*
- *Warehouse emissions at third party facilities*
- *Poor route management and container space utilization*

Processing
- *Inefficient ovens and steam boilers*
- *Food waste in manufacturing*
- *Using fossil fuel based electricity for running processing machines*

Packaging
- *Non recyclable packaging*
- *Use of single use plastics*

End Use
- *Food waste in retails and distribution*
- *Emissions during retails (Retail refrigeration)*

LMIC region focus:

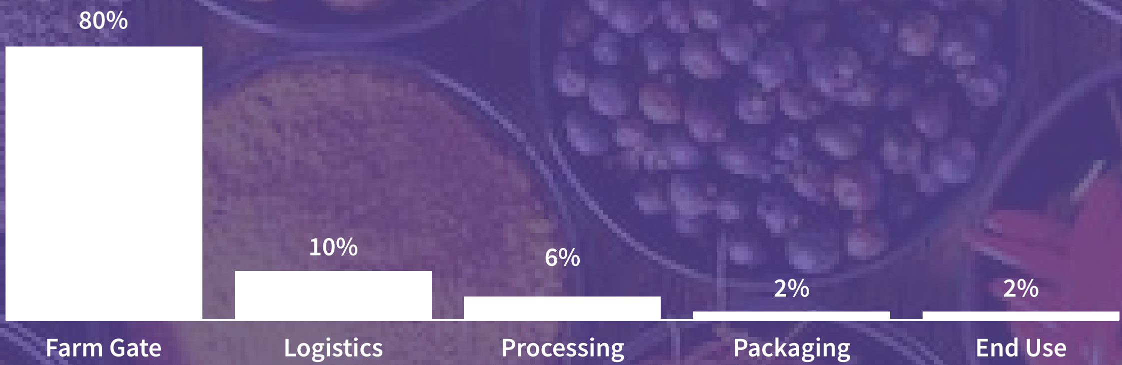
Commodity	LMIC Regions & key countries
Palm Oil	Southeast Asia- Indonesia and Malaysia
Tea	South Asia and Africa-India, Kenya, and Sri Lanka
Cocoa	Sub-Saharan Africa and SE Asia
Coffee	Latin America –Brazil and Colombia, Southeast Asia- Vietnam and Indonesia

46 Agroforestry systems- GHG emissions of cacao production in the Republic of Côte d'Ivoire
47 Costa Coffee climate roadmap

GHG EMISSION HOTSPOTS
Spices

- Spices contribute less than 1% to global GHG emissions from agri-food systems.
- Inefficient use of agricultural inputs, wastage at the plantation stage, and on-farm energy usage are key emission hotspots.

Scope 3 emission mapping[48]



Key emission hotspots across the supply chain:

Farm Gate → **Logistics** → **Processing** → **Packaging** → **End Use**

Farm Gate
- *Input usage*
- *Water usage*
- *Wastage at farm*
- *Crop residue management*
- *On-farm energy usage*
- *Cultivation Practices*

Logistics
- *Upstream transportation and distribution (2.5%)*
- *Downstream transportation and distribution (7.5%)*

Processing
- *Primary Processing (4%)*
- *Wastage (2%)*

Packaging
- *Non recyclable packaging*
- *Single use plastics*
- *Packaging for delivery to end users*

End Use
- *Use of sold products by consumers*
- *Disposal of the packaging*

LMIC Regions & key countries- South Asia-India, Bangladesh

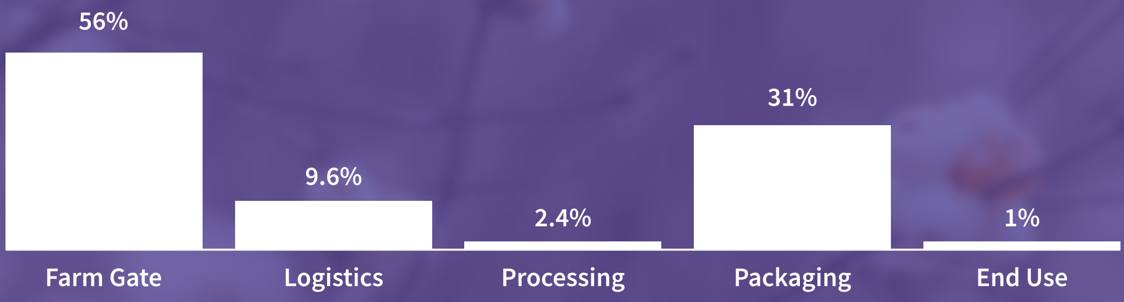
48 McCormick sustainability report 2021, CDP database

GHG EMISSION HOTSPOTS

Cotton

- Cotton accounts for a large and growing share of global GHG emissions. On an average 4,443 Kg CO2eq is emitted in the production of 1,000 kg of lint.[49]
- For a cotton-based textile company, GHG emissions are maximum during raw material procurement and use & disposal of the end products (textiles).
- Inefficient usage of fertilizers, pesticide and water contribute around 40-50% to emissions from cotton cultivation.

Scope 3 emission mapping (for a typical cotton-based textile company)



Key emission hotspots across the supply chain:

Farm Gate
- *Fertilizer production and use (59%)*
- *Irrigation (17%)*
- *Pesticide (5%)*
- *Crop residue management (5%)*
- *FIeld operation (2%)*
- *Transport to gin (1%)*
- *Ginning (11%)*

Logistics
- *Upstream transportation and distribution (2.5%)*
- *Downstream transportation and distribution (~7%)*

Processing
- *Conversion from cotton to textile garments*
- *Waste generated in operations*

Packaging
- *Non recyclable packaging*
- *Single use plastics*
- *Packaging for delivery to end users*

End Use
- *Use of sold products by consumers*
- *End life management*

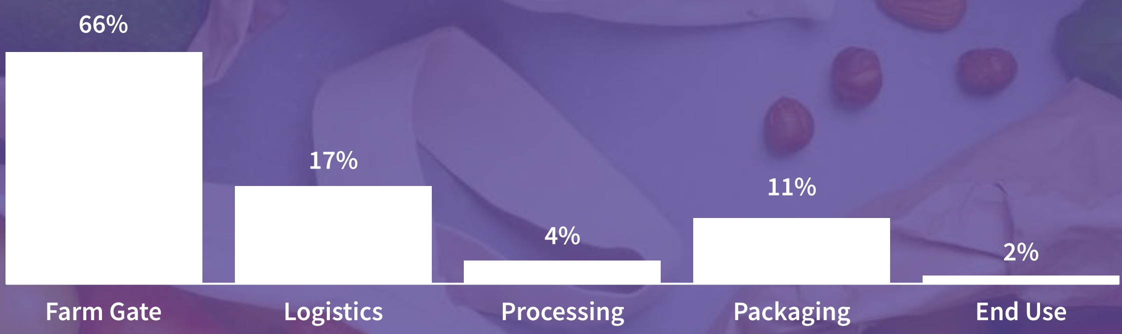
LMIC Regions & key countries- South Asia and Latin America- India, Pakistan, Bangladesh, Brazil

49 Better Cotton Initiative-Anthesis report in GHG emissions

GHG EMISSION HOTSPOTS
Fruits & Vegetables

- Fruits and vegetables account for around 2-3% of global GHG emissions from agri-food systems.
- Key fruits procured by F&V processing companies include bananas, apples, melons, and grapes. Key vegetables procured by F&V processing companies include tomatoes, potatoes, onions, cucumbers, gherkins, and vegetables from the cabbage family.
- Harvest loss or crop wastage in the field and during retail is a major source of GHG emissions in the F&V supply chain.

Scope 3 emission mapping



Key emission hotspots across the supply chain:

Farm Gate → Logistics → Processing → Packaging → End Use

Farm Gate
- *Fertilizer production and use*
- *Agrochemical use*
- *Water management*
- *On farm energy*
- *Wastage at field*

Logistics
- *Upstream transportation and distribution (4%)*
- *Downstream transportation and distribution (13%)*

Processing
- *Primary processing (3.8%)*
- *Wastage (0.2%)*

Packaging
- *Non recyclable packaging*
- *Single use plastics*
- *Packaging for delivery to end users*

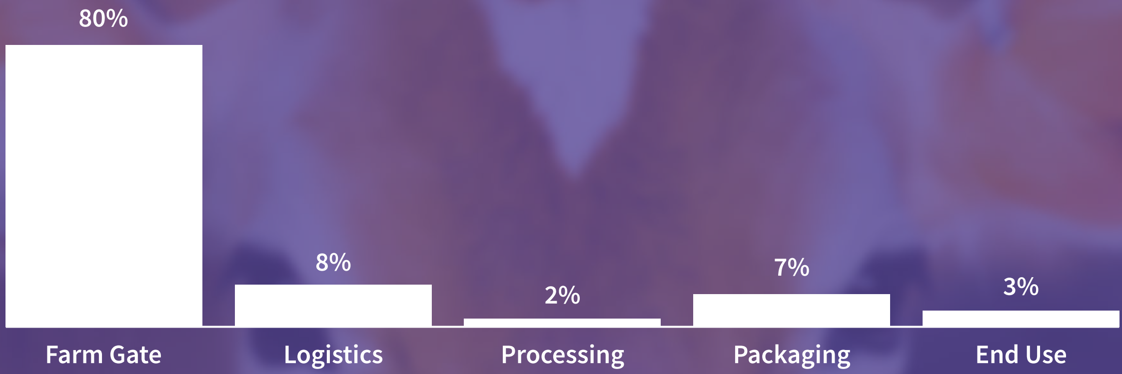
End Use
- *Use of sold products by consumers*
- *Disposal of the packaging*

LMIC Regions & key countries- All. Mostly- India, Vietnam, Nigeria, Mexico

GHG EMISSION HOTSPOTS
Livestock & Dairy

- At almost 40% the livestock and dairy sector is the largest contributor to global GHG emissions from agri-food systems.[50]
- Enteric fermentation, livestock manure, and feed production are key GHG emission hotspots.
- The procurement of raw material (specifically soy, rice, wheat, and maize) for the manufacture of animal feed also contributes to GHG emissions at the production stage. This is largely due to changes in land use and farm-gate activities.

Scope 3 emission mapping[51]



Key emission hotspots across the supply chain:[52]

Farm Gate → **Logistics** → **Processing** → **Packaging** → **End Use**

Farm Gate
- *Enteric Fermentation (44.30%)*
- *Manure management (9.50%)*
- *Applied and deposited manure in Feed (13.50%)*
- *Feed production (13.00%)*
- *Fertilizer residues (6.00%)*
- *Feed land use change (8.60%)*
- *Feed rice (0.50%)*
- *Primary processing, storage, chilling (2.80%)*
- *Direct energy use (1.60%)*
- *Indirect energy use (0.30%)*

Logistics
- *Upstream transportation and distribution (1%)*
- *Upstream energy use (1%)*
- *Downstream transportation and distribution (6%)*

Processing
- *Primary processing*
- *Wastage*

Packaging
- *Non recyclable packaging*
- *Single use plastics*
- *Packaging for delivery to end users*

End Use
- *Use of sold products by consumers*
- *Disposal of the packaging*

LMIC Regions & key countries- South Asia & Latin America- India, Brazil

50 Nature.com- Report on roadmap for achieving net-zero emissions in global food systems by 2050
51 CDP data base, Danone Scope 3 emissions
52 FAO- GHG emission from ruminant supply chain- LCA

GHG EMISSION HOTSPOTS

Aquaculture and Seafood

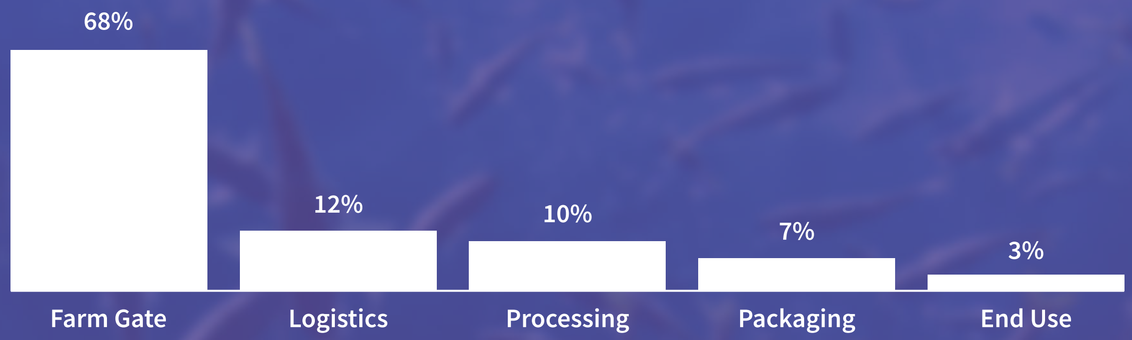
- Aquaculture accounts for 1-1.5% of GHG emissions from the agri-food system. The geographical pattern of emissions closely mirrors production, i.e., most of the emissions arise in regions with the highest production i.e., East Asia (80%) and South Asia (10%).[53]

- In aquaculture value chain 68% emissions occurs at raw material procurement stage. Raw material sourcing for feed manufacturing accounts for around 40% of this 68%.

- Emissions arising from fishmeal production, feed blending, and transport further adds another 17% to take feed manufacturing related GHG emissions to 57%.

- Most of the non-feed emissions arise from the production of N2O and energy use on the fish farm.[54]

Scope 3 emission mapping



Key emission hotspots across the supply chain:

Farm Gate → Logistics → Processing → Packaging → End Use

Farm Gate

- *Production and supply of eggs, larvae, or propagules*
- *Terrestrial land-use change and degradation (e.g., for crops used in feed)*
- *Feed production and processing (e.g., direct emissions from crop and wild caught fisheries)*
- *Transport of feed to wholesale and mariculture operations*
- *Hatchery and shrimp farms, use of energy*
- *Inputs used in production (for water treatment, liquid oxygen etc.)*

Logistics

- *Upstream transportation and distribution (6%)*
- *Downstream transportation and distribution (6%)*

Processing

- *Primary processing*
- *Wastage*

Packaging

- *Non recyclable packaging*
- *Single use plastics*
- *Packaging of ice*

End Use

- *Retail refrigeration*
- *Use of sold products by consumers (2%)*
- *Disposal of the packaging (1%)*

LMIC Regions & key countries- Southeast Asia, South Asia, Latin America- Thailand, Vietnam, Indonesia, India, Ecuador

53 FAO report- Quantifying and mitigating greenhouse gas emissions from global aquaculture
54 Global Seafood Alliance

2.3 APPROACHES FOR REDUCING EMISSIONS

Reducing GHG emissions at the company level requires a combined approach that focuses on three aspects: a) Emission mapping, b) Insetting- this includes reducing emissions within the company's own supply chain and neutralization[55] of the residual emissions, c) Offsetting beyond value chain mitigation (BVCM).

Corporations seeking to reduce emissions must consider three steps: The first is to be identifying emission hotspots and mapping GHG emissions according to their respective scopes across the supply chain. Next, corporations must focus on reducing GHG emissions within the organization's supply chain (input) either by changing existing practices or adopting technologies (digital and non-digital). Last, to reduce hard-to-abate emissions, corporations must consider a) financing nature-based projects to generate carbon credits or b) purchasing carbon credits generated outside the organization's supply chain (offsetting) from external sources.

Successfully achieving sustainability targets across agricultural supply chains requires a combination of interventions. These interventions may include the adoption of innovative digital and non - digital technologies, skill and capacity building among farmers and supply chain actors and change management within organizations to align procurement teams with sustainability goals.

GHG accounting and mapping	Insetting	Offsetting
Identifying key sources of emissions within a corporate's supply chain and measuring the amount of GHG emissions at each source.	Managing and reducing emissions within the corporate's supply chain by: **(i) Carbon avoidance** through changes in practice or by adopting technogies to implement nature-based solutions, bringing in energy efficiency or changing the source of energy use. **(ii) Neutralization/carbon removal**- to removing carbon by sequestration from its own supply chain.	Financing high quality certified carbon credit projects or purchasing carbon credits generated outside the corporate's supply chain to remove hard-to-abate emissions.

2.4 CURRENT NET-ZERO COMMITMENTS AND ACTION UNDERTAKEN BY CORPORATES

Global agriculture corporates have made ambitious commitments towards decarbonizing their supply chains and achieving net-zero emissions.

GHG emissions from global agriculture corporates are notably high. This is due to complex supply chains, globally diversified procurement, significant processing, and trade volumes. Many of these corporates are part of the 8,000 businesses that have committed to aligning their business models with the goal of limiting global warming to 1.5°C and achieving net-zero emissions by 2050. These companies are signatories to the United Nation Framework Convention on Climate Change (UNFCCC's) Race to Zero campaign. As more corporations commit to reducing carbon emissions, the number of corporates on the list is growing. At COP26, twelve of the world's largest global agricultural trading and processing corporates,[56] issued a joint statement committing to a sectoral roadmap for enhanced supply chain action that is consistent with a 1.5°C pathway. These companies have a combined annual revenue of nearly 500 billion USD and hold a significant global market share in commodities such as soy, palm oil, cocoa, and cattle. The sectoral roadmap adopted by them aims to identify solutions at scale to reduce and eventually eliminate commodity-driven deforestation as well as reduce GHG[57] emissions across the supply chains. These examples highlight how more and more agriculture and food systems corporates are actively focusing on reducing GHG emissions.

A large number of agricultural and food corporates are, however, still in the process of mapping their scope 3 emissions and setting up their science-based net-zero targets. Few global corporates have defined key focus areas towards transitioning to net-zero emissions.

Out of the 4,535 corporates engaged with SBTi,[59] 504 belong to the agri-food sector and are involved in

55 Neutralization: Measures that companies take to remove carbon from the atmosphere and permanently store it to counterbalance the impact of emissions that remain unabated. (SBTi corporate net-zero standard, April 2023)
56 ADM, Amaggi, Bunge, Cargill, Golden Agri-Resources, JBS, Louis Dreyfus Company, Olam, Wilmar, COFCO International, Marfrig, and Viterra
57 Tropical Forest Alliance
58 SBTi data

setting up science-based targets for decarbonization. Out of these 504 corporates, 176 have committed to net-zero emissions. Based on interviews conducted for this study, it was found out that many agriculture and food system corporates are still in the process of mapping their Scope 3 emissions and identifying key GHG emission hotspots. This is also borne out by the findings of the 2022 Reuters Insight Sustainability Survey.[59] As per the survey, only 43% of the 516 senior sustainability practitioners polled indicated that their organizations were addressing scope 3 emissions. However, 55% of respondents indicated that decarbonization is a top priority for them and they have identified key focus areas and set concrete targets towards transitioning to net-zero emissions. Table 3 highlights net-zero commitments and focus areas of some corporates.

Table 3 Example of net-zero commitments and pathways of some of the key agri and food system corporates

Corporate	Net-zero Commitments	Focus
Nestle[60]- Plantation/ Livestock	• Net-zero by 2050. • Committed to reducing emissions by 20% by 2025 from its baseline year of 2018, 50% by 2030, and to reaching net-zero emissions by 2050.	• Focuses on three main areas: practicing regenerative agriculture, reducing emissions from the company's own operations, moving to sustainable packaging. • It is also undertaking pilots for reducing GHG emissions due to enteric fermentation and improper manure management.
PepsiCo[61]- Fruits and vegetables	• Net-zero by 2040. • Committed to reducing absolute GHG emissions across its direct operations by 75% by 2030, compared to a 2015 baseline. The company also plans to cut Scope 3 emissions by 40% by 2030.	• Focuses on adopting sustainable farming practices, undertaking climate resilient projects, helping suppliers adopt renewable energy, moving to sustainable packaging and investing in a new fleet of electric trucks.
Mondelez Internation-al[62]- Cocoa, Dairy	• Net-zero by 2050. • Committed to 100% responsible cocoa sourcing and 100% recyclable packaging by 2025.	• Focuses on responsible sourcing, moving to sustain-able packaging, reducing food waste, increasing energy efficiency across its operations and green logistics. • Committed to sustainable procurement and promoting regenerative agriculture and agroforestry under its Cocoa life program.
Danone[63]- Livestock and dairy	• Net-zero by 2050. • Has set an intermediate carbon reduction target for no deforestation across primary deforestation-linked commodities by 2025, 30% reduction in methane emission related to milk procurement by 2030.	• Focuses on reducing its own emissions, preventing deforestation, supporting afforestation and resilience building. It is also undertaking pilots for reducing GHG emissions due to enteric fermentation and improper manure management.
Olam[64]- Cocoa, coffee, cotton, nuts, spices	• Net-zero by 2050. • Reducing GHG emissions by 50% both in its own operations and across Olam-managed farmer programs.	• Focuses on efficient and effective GHG measurement (Launched Terrascope[65]- a smart carbon manage-ment platform for GHG measurements).
Unilever[66]- plantation, livestock & dairy	• Net-zero by 2039. • Zero deforestation by 2023 in palm oil, tea, soy, cocoa, and paper & board. • No GHG emissions from its operations and committed to halving the green house-gas footprint of products across the value chain by 2030 from a 2010 baseline.	• Focuses on landscape restoration, reforestation, carbon sequestration, moving to sustainable packaging and green logistics as well as wildlife protection and water preservation.

59 Reuters Insights sustainability survey 2022
60 Just Food
61 Pepsico
62 Mondelez
63 Danone
64 Olam
65 Terrasscope
66 Unilever

Corporate	Net-zero Commitments	Focus
Labyrie Fine Foods[67]- Seafood	• Net-zero target not defined. • Has set a target to reduce its scope 3 GHG emissions by 22% by 2030 compared to 2019 baseline.	• Focuses on sustainable procurement, RE based logistics, moving to sustainable packaging and improving energy efficiency.
Fresh Delmonte[68]- Fruits and vegetables, coffee, cocoa	• Net-zero by 2050. • Reduce Scope 3 Emissions by 12.3% compared with 2020 levels by 2030.	• Focuses on promoting regenerative agricultural practices under its responsible sourcing approach, managing food waste, increasing water-use-efficiency, and moving to sustainable packaging.

Most agriculture and food system corporates that are committed towards decarbonization focus on responsible sourcing, reducing deforestation, better waste management, energy efficiency in operations, moving to green logistics, sustainable packaging, and using renewable energy.

Solutions or actions taken by the companies may have a direct correlation with the main emission hotspots in their supply chain. This suggests that grouping technologies or solutions based on these hotspots makes it easier for companies to understand and adopt them. The table below outlines some of the areas where solutions have been identified and implemented.

67 Labeyrie Fine Food
68 Just Food.com

Table 4: Key GHG emission areas and solutions identified for emission reduction.

Area	Solutions identified/ action taken	Example of corporates
Deforestation and land use change	• Satellite based monitoring of the plantation area to track deforestation. • Implementation of traceability to trace the source area of the produce. • Sustainable procurement by mandating No Deforestation, No Peat, and No Exploitation (NDPE) for suppliers. • Implementation of programs for on farm agroforestry in cocoa and coffee plantations.	Bunge, Olam, ADM, LD, Cargill, Viterra, Marfig, Golden Agri Resources, COFCO, Nestle
Energy usage	• Use of renewable energy, optimizing energy consumption and recovering heat energy.	Nestle, Unilever
Soil health management	• Use cover crops for soil carbon sequestration. • Train and advise farmers and suppliers on the best practices for soil management.	Bunge through CoverCress technology, Cargill, Nestle
Enteric fermentation	• Efficient herd management. • Use of alternative feeds- implemented pilots using feed additives to evaluate its impact.	Nestle, Barry Callebaut, Danone
Waste management	• Effective manure management (Cargill sponsors the Yield Lab Institute's Manure Innovation Challenge[69] as an early step in the BeefUp Sustainability initiative to identify the solution providers). • Use of bio-digestors.	Cargill, Nestle, Danone
Raw material procurement	• Practice regenerative agriculture and use organic inputs. • Feed livestock with more sustainable feeds. • Capacity building of farmers and suppliers.	Nestle, Unilever, Danone, Pepsico, other major agri and food corporates.
Logistics	• Optimize logistics network, use of RE vehicles, use of alternate environment friendly fuels.	Multiple
Packaging	• Light weight packaging, use of recycled material for packaging.	Multiple

Source: Sustainability reports of the agri and food sector corporates

69 Cargill Manure Innovation Challenge

2.5 CHALLENGES REGARDING TRANSITIONS TO NET-ZERO EMISSIONS IN AGRI-FOOD SYSTEMS

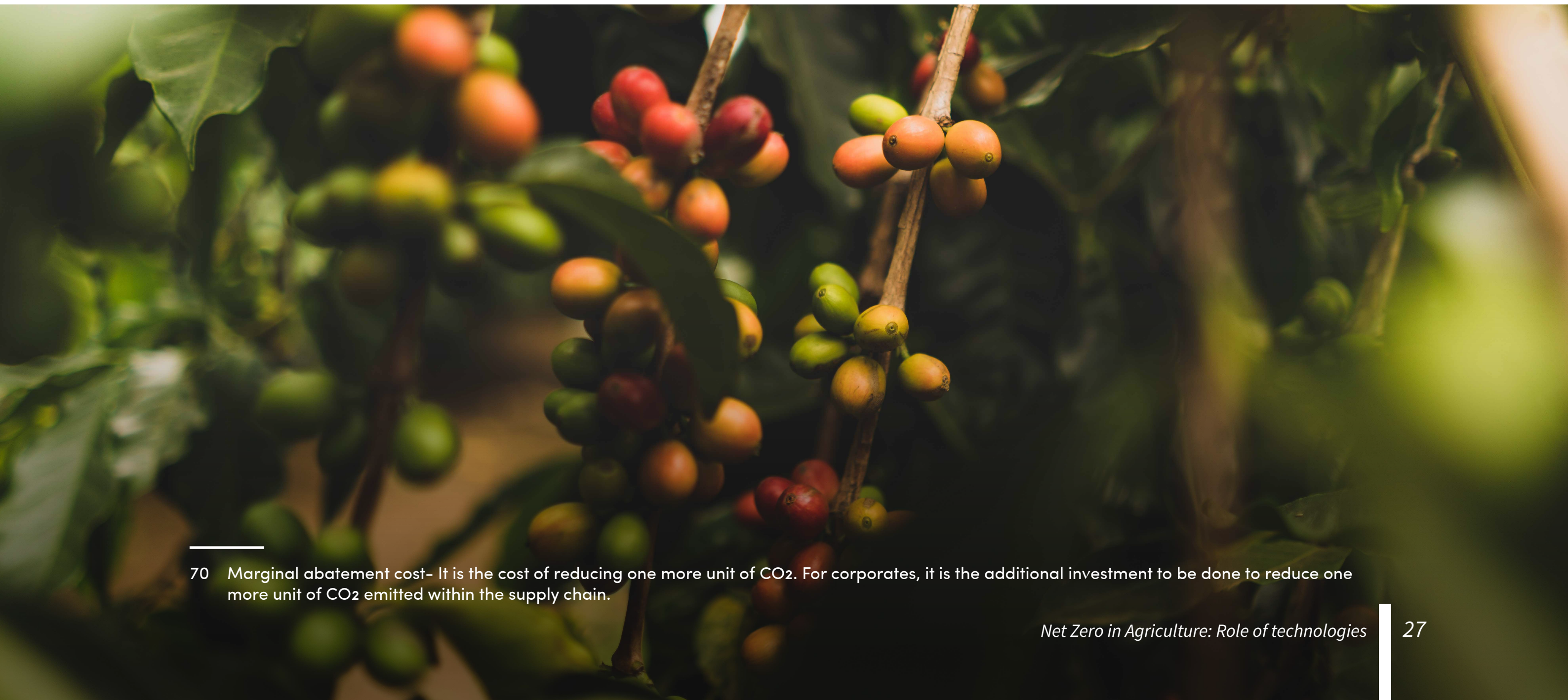
Key challenges towards mapping and reducing scope 3 emissions include dealing with large and diverse suppliers, the perception of high marginal abatement cost[70] for technologies and limited collaboration among the sustainability and procurement teams of corporates.

Large multinational agri-food system corporates can play an important role in driving the entire ecosystem towards decarbonization by investing in capacity building for their supply chain actors in collaboration with governments and multilateral and bi-lateral organizations. However, there exist certain challenges in implementing solutions/ interventions. Some key challenges are-

Figure 7: Key challenges faced by agri and food system corporates pertaining to scope 3 emission mapping and reduction

Difficulties in mapping and measuring emissions across suppliers	Due to large supplier base, corporates find it difficult to map all their suppliers. In most cases corporates are able to map only large or Tier one suppliers. Currently most Corporates rely on industry averages to estimate thier scope 3 emissions.
Convince and align large supplier base towards net-zero	As agri and food system corporates deal with a large number of suppliers, it is difficult to convince all the suppliers to align with company's net-zero targets. Also, at times, suppliers are reluctant to implemrnt solutions since it requires them to share or even bear the total cost.
High marginal abatement cost of the technologies	Identifying low-cost solutions which can result in higher reductions in GHG emission costs is a challenge. Most of the available solutions are not able to justify the marginal abatement cost curve or assure supply chain actors that the cost justifies the eventual reduction in emissions.
Poor lastmile connectivity to implement the interventions	Poor physical and digital infrastructure along with the limited knowledge, capacity and skills of stakerholders in LMICs also poses a considerable challenge. Poor connectivity impacts the implementation of some digital interventions, like the real time tracking of emissions from the supply chain.
Low understanding of the climate aspect of procurement team	Procurement of agri commodities are highly price sensitive. In several cases, the corporate's procurement team is focused on procuring high quality commodities at low prices. Hence, Climate related considerations are often ignored.
Concern over passing increased cost to the customers	Corporates have to demonstrate year on year increases in market share and profitability. Hence, many are concerned about losing market share as a result of passing on costs associated with climate mitigation measures to thier consumers.

Source: Sustainability reports of the agri and food sector corporates



70 Marginal abatement cost- It is the cost of reducing one more unit of CO_2. For corporates, it is the additional investment to be done to reduce one more unit of CO_2 emitted within the supply chain.

3

ROLE OF TECHNOLOGIES IN TRANSITIONING TO NET-ZERO EMISSIONS

3.1 ROLE OF TECHNOLOGIES IN AGRICULTURE AND FOOD SYSTEMS

Figure 8: Evolution of the technologies in Agri and food systems

1900s	1950-1970	1970-1990	1995-2000	2000 onwards	2015 onwards
Plough, Handheld tools, Chemicals	Tractors and machines	Information technology	Satellite and sensors	Mobile and software's	IoT, Artificial Intelligence, Big data, ML, blockchain

Source: Intellecap analysis

Since the 1900s, agriculture and food systems have undergone several technological revolutions. Across traditional and modern practices, digital and non-digital technologies have been instrumental in driving higher productivity. These technologies have led to increased yields, improved efficiency, and greater profitability. The introduction of mechanization in the 1950s and the current usage of advanced digital technologies have brought tremendous benefits to the agriculture and food system. Figure 8 represents the evolution of technologies over time.

The use of modern technologies in agriculture is evident in the sudden increase in the market size of agtechs. From USD 9 billion in 2020, market size for agtechs is expected to reach USD 22.5 billion by 2025.[71] The market has commercially viable solutions across each stage of the supply chain such as production, harvesting, storage, transportation, finance, market linkage, traceability, etc. However, despite the availability of solutions, their uptake seems to be limited due to a lack of understanding of their use and application, as well as their cost- benefits.

3.2 POTENTIAL OF TECHNOLOGIES IN REACHING NET-ZERO EMISSIONS

3.2.1 IMPORTANCE

> **Along with increasing farm productivity and leading to efficient farm management, both advanced digital and non-digital technologies have the potential to drive climate action.**

Several technologies used across agriculture and food systems support climate action – either through adaptation or mitigation. For instance, using a new variety of cotton seed that is resistant to pests can result in both cost savings and reduce GHG emissions. This is because the crop requires less application of agricultural chemicals which leads to lower costs; it also requires lower use of inputs for pest and disease management which leads to lower GHG emissions. Precision agriculture for input optimization also results in low input usage; it can help optimize agricultural processes and capture carbon dioxide before it is released into the atmosphere – thereby leading to climate mitigation. Some examples of technologies supporting climate mitigation and adaptation are mentioned in the table below. The stages of commercial adoption have been mapped across technologies based on their current application across LMICs.

71 Juniper research

Table 5: Climate impact of some of the Agri technologies

Technology	Commercial Adoption	Core usage	Climate action
Disease and pest resistant variety	Medium	Improved yield with low usage of pesticides	Climate change mitigation due to input use avoidance
Mobile based weather alert service/ Farm insurance	High	Better farm advisory/ Protection against climate change	Climate change adaptation due to better preparedness
Efficient farm mechanization	Medium	Better farm management	Climate change mitigation due to reduced loss of soil carbon
Precision agriculture	Low	Optimum use of farm inputs	Climate change mitigation due to reduced input usage
Farm level storage	High	Reduction in harvest loss	Climate change mitigation due to reduced food loss
Farm to fork traceability	High	Efficient supply chain management	Monitoring of carbon emissions across the supply chain

Low commercial adoption   Medium commercial adoption   High commercial adoption

Source: Intellecap Analysis

While the table above represents the role of some technologies in transitioning to net-zero emissions, the next chapter delves into the specific technology clusters that were discussed in the introduction.

4

KEY TECHNOLOGY CLUSTERS TO FACILITATE THE TRANSITION TO NET-ZERO EMISSIONS

Based on primary (in the form of interactions with multiple stakeholders) and secondary research, the team identified five high-impact technology clusters and two enabling clusters for this report. If implemented effectively across corporate supply chains, these clusters have the potential to reduce over 60% of GHG emissions. This section is integral to the report as it highlights these clusters and their potential impact.

Technology clusters

refer to groups of digital and non-digital technologies that share similarities and have the potential to reduce GHG emissions across an agri-corporation's supply chain. These clusters can facilitate the transition to net-zero emissions in agriculture.

Rationale for clustering technologies

To effectively categorize the use of technology in relation to key emission hotspots identified throughout the agriculture supply chain, a clustering process was employed. This approach enables corporations to match specific technology clusters to the identified emission hotspots, thereby avoiding confusion regarding the use of core technology across multiple clusters. For instance, drones may be employed for both fertilizer spray and farm monitoring under carbon offsetting projects.

Types of technology clusters

- ***Potential technology clusters***- long-list of technology clusters that have an impact on GHG emissions.
- ***High-impact technology clusters***- shortlisted clusters based on an assessment of their potential to reduce GHG emissions.
- ***Enabling clusters***- clusters that do not directly impact GHG emissions within a supply chain but enable the transition to net-zero emissions by facilitating the mapping or measurement of GHG emissions or facilitating the trade of carbon credits.

Process followed to derive high impact technology clusters

As a first step, the study team mapped, shortlisted, and clustered 13 potential technology clusters. To identify high impact technology clusters, the team first filtered some clusters by assessing their impact on GHG emissions and then assessed their impact on GHG emissions through an assessment framework. This assessment framework evaluated technologies on two key parameters: technology efficiency and technology feasibility. Technology efficiency consisted of parameters related to abatement potential and cost, maturity of the technologies, and the socio-economic impact of these technologies. The feasibility assessment consisted of parameters related to affordability, capacities required and ease of implementation. The approach is summarized in the following graphic, while a detailed note is presented in the annexure.

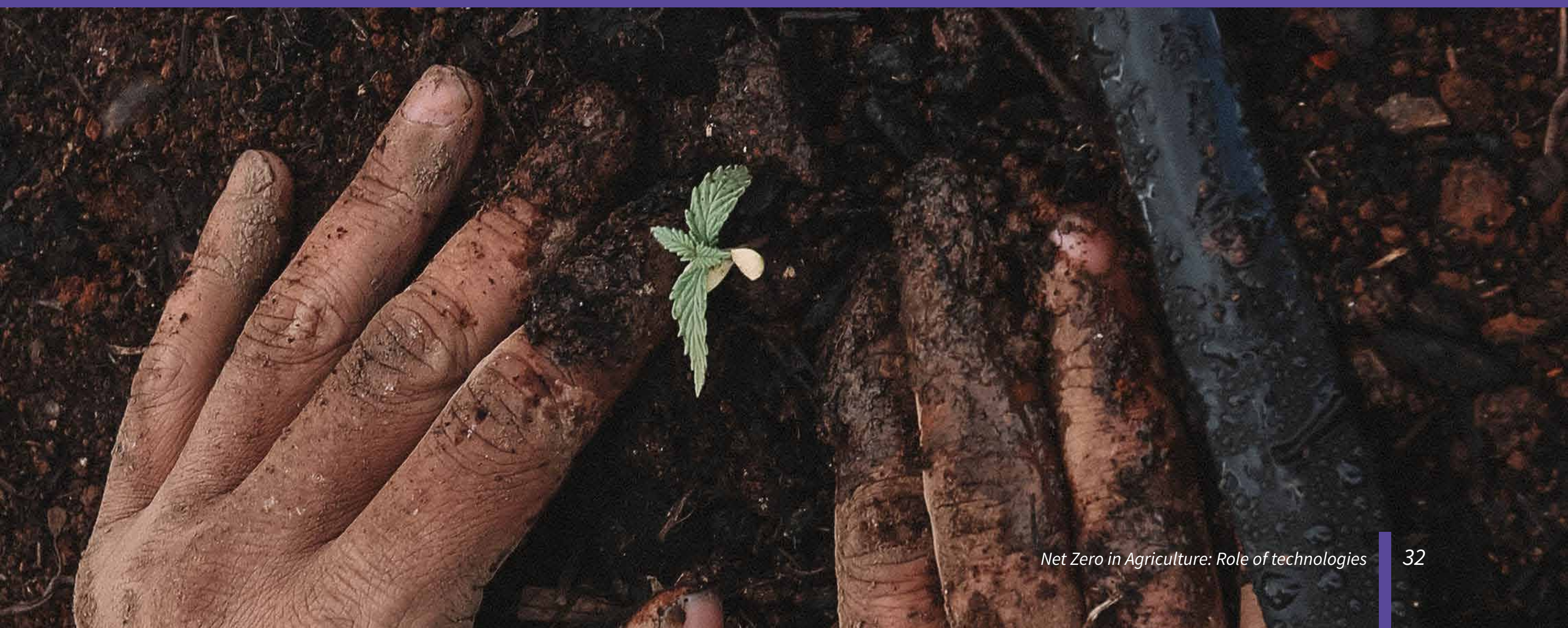
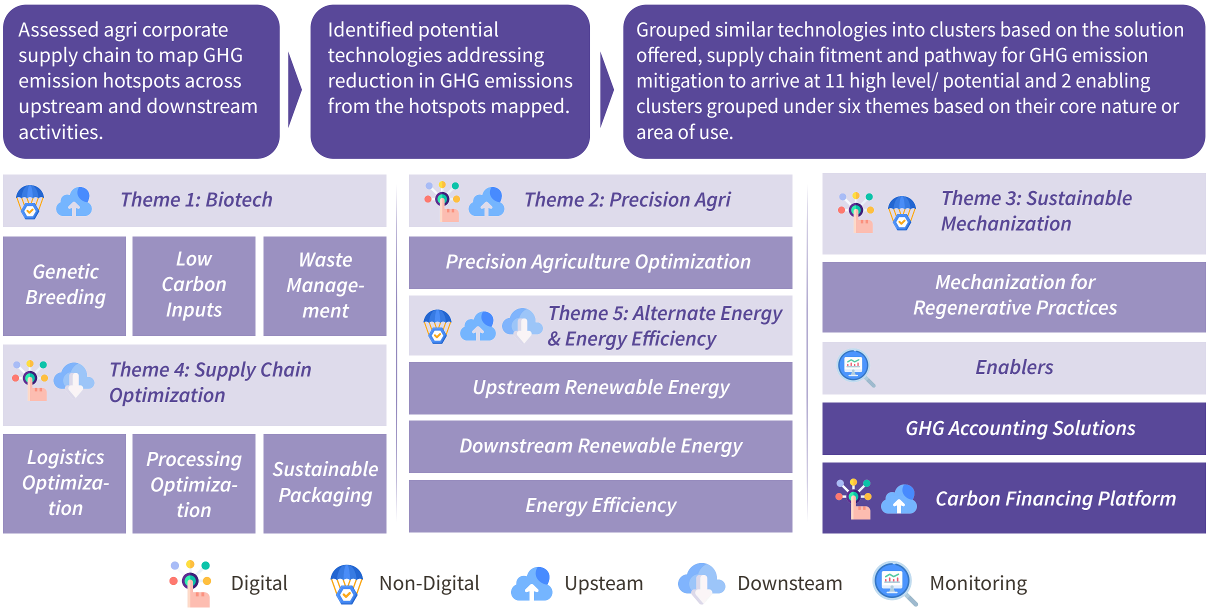


Figure 9: Approach followed to derive high impact technology clusters.



Assessment of eleven potential clusters to identify high impact technology clusters.

Step 1- Filtration- two potential clusters were eliminated at this stage.

Technology clusters targeting hotspots contributing less than 5% of the total GHG emissions were filtered out.

Step 2- Assessment of nine potential clusters to score and rank them.

Nine potential clusters are scored across technology efficiency and feasibility framework parameters and ranked based on their overall scores across these parameters (mentioned in annexure 1).

3. Mapping and Categorization of 9 potential clusters for selection of high impact clusters.

Mapped and categorized 9 clusters in a 2 X 2 matrix based on their score across the technology efficiency and feasibility framework parameters.

Mapping the final clusters in 2 X2 matrixes to select the top clusters.

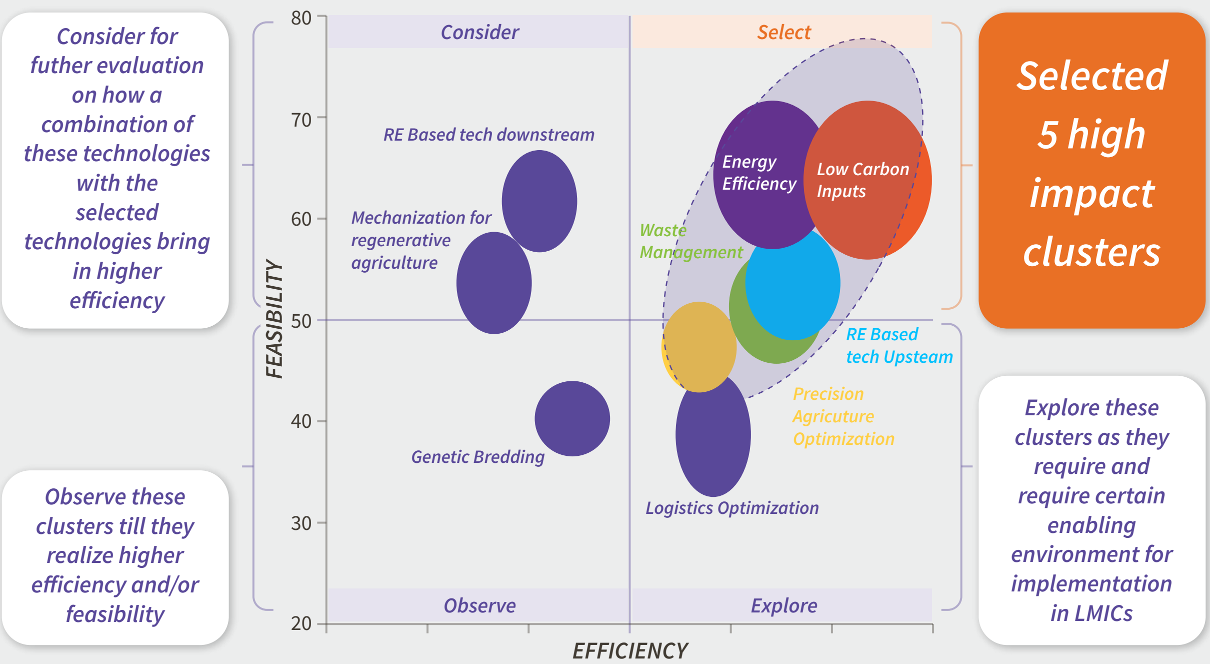


Table 6: Description of the potential clusters

S No	Technology Cluster (Digital/Non-Digital/Both)	Pathway to GHG emission reduction
1	Genetic breeding (non-digital)	Reducing the requirement of inputs like water, fertilizers, pesticides by improving the resistance to drought or pests and disease through genetic breeding. This leads to low GHG emission due to lesser input usage.
2	Low carbon inputs (non-digital)	Replacing existing high GHG emitting farm/ livestock inputs with sustainable low or zero carbon emission inputs.
3	Waste management (non-digital)	Efficiently managing farm and livestock waste through advanced decomposition or fermentation.
4	Precision agriculture optimization (digital)	Optimizing the use of inputs and enabling informed arm decisions by using advanced Agri 4.0 digital technologies. (Agri 4.0 technologies are referred to most advanced stage technologies such as precision agriculture, internet of things, robotics, and artificial intelligence).
5	Upstream renewable energy (non-digital)	Replacing fossil fuels with renewable energy for on farm operations.
6	Downstream renewable energy (non-digital)	Replacing fossil fuels with renewable energy for post-harvest operations, processing, and retail.
7	Energy efficiency (both)	Optimizing the use of fossil fuel-based energy in upstream and/or activities in the agriculture and food system supply chain by using smart controllers, route optimization etc.
8	Logistics optimization (both)	Optimizing the use of fossil fuels and improving space management through decisions guided by advanced Agri 4.0 technologies.
9	Processing optimization (both)	Reducing the use of fossil fuel-based energy in processing.
10	Sustainable packaging (non-digital)	Replacing non-recyclable packaging with innovative materials made from natural or recyclable products.
11	Mechanization of regenerative agriculture (non-digital)	Preventing decrease in soil organic carbon due to excessive mechanization by using small and advanced machinery (ex: equipment for no-till agriculture).
12	GHG accounting (digital)	Facilitating the mapping, monitoring, and accounting of GHG emissions across supply chains.
13	Carbon Financing platforms (both)	Supporting the measurement, reporting and verification of carbon credits generated by implementing the nature-based solutions.

4.1 RECOMMENDED TECHNOLOGY CLUSTERS

4.1.1 OVERALL DESCRIPTION OF RECOMMENDED TECHNOLOGY CLUSTERS

The study identified 5 high-impact technology clusters and 2 enabling clusters that have the potential to mitigate 65-70% of emissions across agriculture and food supply chains.

Based on the primary research and secondary research highlighted above, the study recommends five high impact digital and non-digital technology clusters and two enabling clusters that stakeholders (including corporate and governments) can leverage to meet their net-zero targets. A summary of these clusters is highlighted in the table below, while the following sections provides a deep dive into each cluster:

A. *High-impact technology clusters*

About	Type Of Technologies	Emission Hotspots Targeted	GHG Reduction Pathways	Illustrative Decarbonization Potential	Costs Involved	Other Benefits Beyond Emission Reduction
Low Carbon Inputs						
Technologies that replace existing high GHG emitter farm/ livestock inputs with sustainable low or zero carbon emission inputs.	Alternative fertilizer, controlled release fertilizer[72], Biochar, Low carbon pesticide, Insect/ seaweed-based feed, feed additives.	Farm gate/ procurement related emissions.	• Reduction in the application of synthetic fertilizer. • Prevention in soil carbon loss. • Prevention of deforestation by reducing soy, rice, wheat, corn-based feeds. • Reduction in enteric fermentation.	• Bio-fertilizers and low carbon fertilizers technologies have the potential to reduce GHG emission due to excessive use of chemical fertilizers by 40-50%.[73] • Biochar's mitigation potential varies between 0.41 and 0.78 MT CO2eq yr−1, of which 79% could be attributed to increased soil C stock, and 21% to the coproduction of bioenergy.[74] • Feed additives and alternate feeds have a mitigation potential of 5-15% compared to regular feed.[75]	• ***Technology costs***[76]***:*** Alternative fertilizer, controlled release fertilizer, Biochar, Low carbon pesticide- <USD 20/MT CO2eq; Alterna-tive feed, Feed additives USD 20-100/MT CO2eq. • ***Implementation/ usage costs:*** Capacity building of the farmers, additional labor cost in some cases.[77]	• ***Socio-economic benefits:*** Savings in cultivation costs to the user of technology (15-40% savings) & lesser harm to the health of those applying the fertilizer /pesticide. • ***Environmental benefits:*** Reduction in soil degradation.
Upstream Renewable Energy						
Technologies that replace fossil fuel-based energy for on farm operations.	RE based Irrigation, mechanization, transportation and ventilation & aeration for livestock and aquaculture operations.	Farm gate/ procurement related emissions-due to use of energy for crop/ livestock/aqua-culture farming.	• Replacement of fossil fuels by RE based alternatives.	• Potential reduction of 95-98% in GHG emissions per unit of energy used for water pumping (CO2eq/kWh) as compared to pumps operated with grid electricity and/or diesel-pumps.[78] • Fuel consumption savings potential with mechanization based on renewable energy on average between 35- 40% per ton of crop produced and harvested.[79] • Transportation based technologies can mitigate 5-7% of the total carbon emissions associated with food production.[80] • Aquaculture based RE Technologies can-	• ***Technology Cost:*** USD 20-100/MT CO2eq • ***Implementation/usage costs:*** Cost of support-ive infrastructure like grids, batteries, Maintenance cost.	• ***Socio-economic benefits:*** 40-50% increase in the users' income due to savings in energy, reduced use of fossil fuels and increased yield. It also causes less harm to human health as compared to pollution emitting diesel-powered pumps.

72 Fertiliser that contains plant nutrient in form which delays its availability for plant uptake and use.
73 MDPI Article, 2017, Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation, Farm Productivity and Economics
74 Science Direct, 2022, Climate change mitigation potential of biochar from forestry residues under boreal condition
75 Research Gate 2021, Feed additives as a strategic approach to reduce enteric methane production in cattle: modes of action, effectiveness and safety
76 Technology cost- This is the cost of technology for reduction of one additional unit of CO2eq. This has been taken for all the identified technology clusters, based on inferences drawn from the IPCC AR6 Working Group III report.
77 IPCC AR6 Working Group III report.
78 FAO, 2021, The State of World's Land and Water Resources for Food and Agriculture
79 CEMA, 2022, The role of agricultural machinery in decarbonising agriculture
80 Science Direct, 2022, Farm electrification: A roadmap to decarbonize the agriculture sector
81 Nature, 2020, Quantifying greenhouse gas emissions from global aquaculture

About	Type Of Technologies	Emission Hotspots Targeted	GHG Reduction Pathways	Illustrative Decarbonization Potential	Costs Involved	Other Benefits Beyond Emission Reduction
				reduce emission from on farm energy use which is approximately 15% of the total GHG emissions from aquaculture.[81]		
Waste Management						
Technologies that reduce GHG emissions arising out of inefficient farm and livestock waste management.	Efficient farm waste management technologies like microbe- based decomposition, thermal chemical fermentation. Efficient livestock waste management technologies that mitigate methane and ammonia like bio decomposers, application of nitrification, urease inhibitors amongst others.	Farm gate/ procurement related emissions- caused due to farm waste disposal, crop burning and inefficient animal waste management.	• Reduction in GHG emissions by avoidance of crop burning, landfill, inefficient manure disposal.	• Efficient farm waste management technologies have the potential to reduce GHG emissions from farm waste by 5-15%.[82] • Livestock manure management technologies can reduce global GHG emissions caused by the release of methane and ammonia from manure storage by 18-20% (0.01- 0.26 $GtCO_2eq$ yr^{-1}), with the range depending on the economic and sustainable capacity of the technology.	• ***Technology Cost:*** USD 20-100/MT CO_2eq. • ***Implementation/usage costs:*** Labour and ancillary costs for managing and maintaining waste management solution, Capacity building cost.	• ***Socio-economic benefits:*** Additional income from the sale of farm waste to waste processors and from the self-conversion of farm waste to useful end products. New job opportunities also enhance social well-being.
Energy Efficiency						
Technologies optimize the use of fossil fuel-based energy in upstream and/or downstream activities of the agri and food system supply chain.	Energy efficient solutions for upstream activities like smart water controller, energy saving pump, small farm level cool box for storage of perishable. Energy efficient solutions for downstream processing units having low energy dryers, high speed fans, automated sorting.	Farm gate, Processing, Packaging – use of fossil fuel-based machinery.	• Replace/ Reduce fossil fuel. • Precise use of inputs leading to reduce in soil carbon loss.	• Improving water efficiency by just 10% could reduce diesel consumption by 102 million litres, thus improving energy efficiency. • Technologies for downstream supply chain activities including storage, processing, and retail operations results in 20-23% of GHG emission reduction.[83]	• ***Technology cost:*** USD 20-100 MT CO_2eq.[84] • ***Implementation/ usage costs:*** Operational costs including maintenance and monitoring costs.	• ***Technology cost:*** USD 20-100 MT CO_2eq • ***Implementation/ usage costs:*** Operational costs including maintenance and monitoring costs.

82 Our World in Data website, retrieved in March 2023, Emissions by sector
83 IPCC, 2018, Chapter 8, Agriculture
84 IPCC AR6 Working Group III report.

About	Type Of Technologies	Emission Hotspots Targeted	GHG Reduction Pathways	Illustrative Decarbonization Potential	Costs Involved	Other Benefits Beyond Emission Reduction
Precision agriculture optimization						
Technologies based on agri 4.0 technologies (like Artificial intelligence, block-chain) to undertake precision agriculture for reducing GHG emission through optimizing the use of inputs and enabling guided farm decisions.	Efficient livestock management technologies, Precise aquaculture management technologies.	Across farm gate emissions, including emissions from diesel-powered machinery, fertilizer use and manure management, and from enteric fermentation.	• Reduce the use of synthetic fertilizers, agro chemicals. • Increase soil organic carbon. • Reduce methane emissions due to enteric fermentation in livestock. • Reduce GHG emissions from aquaculture by feed usage optimization.	The impact of the data-driven advisories varies depending on the parameters anlalysed. During Key informant Interviews with technology providers, it was claimed that these technologies can effectively reduce 5-40% of GHG emission from the farm.[85]	• ***Technology cost:*** USD 20-100 MT CO2eq. • ***Implementation/ usage costs:*** operational costs including energy, communications, and capacity building costs.	• ***Socio-economic benefits:*** High income realization due to reduced use of the inputs and increased in productivity. Saving varies in the range of 15-40%.

B. Enabling clusters- clusters that do not directly impact GHG emissions within a supply chain but enable the transition to net-zero emissions by facilitating the mapping or measurement of GHG emissions or facilitating the trade of carbon credits.

About	What it includes?	Benefits to stakeholders
Enabling Cluster 1: GHG Accounting Cluster		
Technologies that use remote sensing, AI, IoT sensors to map, monitor and account for GHG emissions across the supply chain.	Remote sensing based geospatial monitoring of biomass and soil carbon. Data driven technologies for tracking climate risks/ tracking deforestation. Emission accounting software- Supply chain mapping for accessing suppliers' GHG emission.	• ***Environmental benefits:*** Allows stakeholders to monitoring emissions, identify hotspots and account for the same in their decarbonisation target. • ***Socio-economic benefits:*** Provides transparent and reliable data, which can be leveraged for the payment for ecosystem services, or results-based financing that can lead to additional income for producers and communities.
Enabling Cluster 2: Carbon financing platform		
Technologies which use remote sensing, AI, drones for measurement, reporting and verification of carbon credits generated by the implementation of nature-based solutions and help in selling/ offsetting of the carbon credits.	Designing and implementing nature-based projects for carbon offsetting. Designing and implementing carbon projects to reduce GHG emissions caused by land use change.	• ***Environmental benefits:*** Incentivizes producers and program owners to undertake sustainable agricultural practices such as agroforestry, which result in carbon sequestration. • ***Socio-economic benefits:*** Agriculture-programs can generate revenue by selling carbon offsets on carbon financing platforms, which can often offset the cost of transitioning to sustainable agricultural practices. Several models also ensure that 60-80% of the economic benefits are transferred back to producers.

The below section provides details of each of the recommended clusters-

85 Nature, 2012, Carbon emissions from forest conversion by Kalimantan oil palm plantations

CLUSTER 1- LOW CARBON INPUTS

Technologies that replace conventional inputs which have high GHG emissions (for nutrient and pest management) with alternative inputs that have a lower environmental footprint

TYPE	*Alternative Fertilisers*	*Controlled Fertilisers*	*Biochar*	*Alternative Feeds*	*Feed Additives*
ABOUT	Fertilisers that use microbes to fix Nitrogen and increase soil carbon. Also includes low carbon ammonia fertilizers.	Fertilisers that contain nutrients which are gradually released for plant uptake and use.	Fertilisers generated from farm waste and other biomass using pyrolysis.	Low carbon feeds made up of raw materials produced without deforestation and carbon intensive farming.	Feed additives that aids faster digestion and reduces enteric fermentation in livestock.
DECARBONISATION POTENTIAL	40-50%[1] due to a reduction in the use of synthetic fertilizers.	30-40%[2] due to a reduction in the use of synthetic fertilizers.	Varies between 0.3-6.6 GtCO2eq per year.	15-50% depending upon the type of feed. For example the CO2 footprint of insect-based feeds is 24 times lower than that of traditional feeds.[5]	30-40%. Moreover, several ongoing research studies and pilot projects seek to establish the exact decarbonisation potential of such feeds.[6]

PATH WAYS				
	Reduces the use of synthetic fertiliser	*Prevents soil carbon loss*	*Prevents deforestation by reducing soy, rice, wheat based feeds*	*Reduces enteric fermentation*

ENABLERS	*Government Policies*	*Financing*	*Capacity Building*
	Existing government subsidies on bio/organic fertilizers promote the adoption of low carbon inputs. **Example:** The Organic Agriculture support initiative in Turkey provided upto 70% subsidy on the purchase of organic fertilisers.[8]	Financial initiatives and emerging funds in LMICs. **Example:** The Bio-Carbon Fund Initiative for Sustainable Forest Landscapes is a WB program that supports developing countries in reducing greenhouse gas emissions from deforestation. It funds pilots, M&E systems, incentive models and interventions for land management.[9]	Capacity building of the farmers and ease of access to low carbon inputs. **Example:** The Vietnam Low Carbon Rice project focusses on building the community's capacity to change farming techniques in order to mitigate GHG emissions from rice production.[10]

EMISSION HOTSPOT IMPACTED

Farm Gate (*30-40%**) ▸ *Logistics* ▸ *Processing* ▸ *Packaging* ▸ *End Use*

**Enteric fermentation, inadequate use of inputs leading to soil degradation and to some extent deforestation*

TECHNOLOGY EFFICIENCY	
Potential for GHG reduction	*High*
Level of Maturity of technologies within cluster	*High*
Cost efficiency (Marginal abatement cost curve)	*Medium*
Potential socio-economic impact	*Medium*

FEASIBILITY	
Feasibility for LMICs	*High*
Affordability for farmers/ end users	*Medium*
Capacity required for implementing the tech	*Medium*
Ease of implementation	*Medium*

COST – BENEFIT ANALYSIS

Capacity Building Costs:
Cost involved in capacity building of farmers to enable them to adopt low input practices can be expensive.

Abatement Costs:
Price of low carbon inputs based on the type ranges from <USD 20/MT CO2eq abated for alternative fertilizer to > USD 100/MT CO2eq abated for alternative feeds and feed additives.[11]

Labour Costs:
Some practices involved in the use of low cost inputs are labour intensive, due to the methods used for application and for the development of cultures.[12]

Environmental Benefits:
It prevents soil degradation, reduces GHG emissions, reduces deforestation, and improves water reserves.

Economic Benefits:
Reduced use of synthetic inputs leads to monetary savings. On an average the savings are in the range of 15-40%.

Social Benefits:
Reducing the use of agrochemicals and synthetic fertilizers also means reducing harm to human health.

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

Sale through dealer distributor retailer	*Direct sale to corporates/ suppliers*	*Direct sale to farmers*

Case Study[13]
Danone has set a goal to achieve carbon neutrality across its entire value chain by 2050. As part of this goal, Danone has prioritized the use of low carbon agriculture inputs & low-emission animal feed to reduce GHG emissions from their dairy and crop production. Danone has formed alliances with technology providers and agriculture companies like MSD Animal Health, Neogen and FutureCow; animal nutrition and health company DSM; crop nutrition company Yara and crop science company Corteva.

Case Study[14]
Pepsico has launched pilot program to reduce the carbon footprints of its Tropicana Premium orange fruit juice. Estimates indicate that the use of synthetic fertilizers in the production of oranges is a major GHG emission source contributing 35% to the GHG emissions across the orange fruit juice supply chain. To address this Pepsico is working with its suppliers in Florida to use to two alternative fertilizers produced by Yara fertilizers and ERTH solutions. These fertilizers have the potential to reduce nitrous oxide emissions by 90%. If successful, the overall GHG emission from Pepsico's Tropicana Pure premium orange fruit juice could be reduced by 15%.

Key Risks
While shifting from conventional agricultural methods to the use of organic fertilizers and bio inputs, there may be a reduction in farm yield in the initial years. However, once the transition is complete, the farms are likely to be more resilient.

CLUSTER 2- UPSTREAM RENEWABLE ENERGY

Technologies that reduce GHG emissions by replacing non-renewable energy for on-farm operations with renewable energy.

TYPE	*Irrigation*	*Mechanisation*	*Transportation*	*Ventilation & energy use in Livestock & Aquaculture*
ABOUT	Irrigation technologies like solar-powered pumps or drip irrigation systems powered by renewable energy.	Mechanization technologies, such as solar- powered or electric-powered machinery for agricultural operations.	Transportation technologies like electric-powered vehicles or biogas-powered tractors for agricultural operations.	Technologies like Solar-powered fans, biogas generators, to provide ventilation and heating for livestock, aquaculture.
PATH WAYS	*Reduce fossil fuel usage*			
DECARBONISATION POTENTIAL	95-98% reduction in GHG emission per unit of energy used for pumping water (CO_2eq/kWh) compared to pumps operated with grid electricity and/or diesel-pumps.[15] [16]	34-40% savings in fuel consumption per ton of crop produced and harvested.[17]	Potential to mitigate 5-7% of the total carbon emissions associated with upstream logistics.[18]	A reduction of approximately 15% in GHG emissions due to reduction in the use of on farm energy for aquaculture operations.[19]

ENABLERS	*Government Policies*	*Financing*	*Capacity Building*
	Existing government subsidies that promote the adoption and use of renewable energy. **Example:** The PM KUSUM Scheme in India is facilitating the use of solar based irrigation pumps by providing a subsidy of up to 60% and loan facilitation of 30%.[20]	Innovative financial products and mechanisms makes it easier and more affordable to access RE solutions. **Example:** Sun Culture's PAY-As-You-Grow model, of paying in monthly installments, has helped over 6,000 farmers in Kenya access solar-powered irrigation systems and other equipment.[21]	Capacity building initiatives expose farmers to available RE solutions and enhance their technical skills to adopt these solutions. **Example:** Solar Irrigation for Agricultural Resilience (SoLAR) aims to enhance climate interlinkages in South Asia by promoting solar irrigation pumps and by training farmers to use them.[22]

EMISSION HOTSPOT IMPACTED

Farm Gate (6-8%*) ▶ *Logistics* ▶ *Processing* ▶ *Packaging* ▶ *End Use*

**Use of on farm energy and upstream transportation*

TECHNOLOGY EFFICIENCY		*FEASIBILITY*	
Potential for GHG reduction	*Medium*	Feasibility for LMICs	*Medium*
Level of Maturity of technologies within cluster	*High*	Affordability for farmers/ end users	*Medium*
Cost efficiency (Marginal abatement cost curve)	*Medium*	Capacity required for implementing the tech	*Medium*
Potential socio-economic impact	*Medium*	Ease of implementation	*Medium*

COST – BENEFIT ANALYSIS

COSTS-BENEFITS

Capacity Costs:
Solar pumps can be 5-10 times more expensive than conventional pumps. However, lifetime costs are likely to be lower.

Abatement Costs:
Price of RE based technologies varies from USD 20-100/MTCO2eq.

Technology deployment Cost:
Cost involved in providing technology demonstration to farmers.

Environmental Benefits:
Reduction in pollution and reduced GHG emissions from the avoidance of fossil fuel usage.

Economic Benefits:
Increased savings of 15-20% due to replacement of fossil fuel usage. Compared to rain-fed irrigation, the use of solar pumps has raised farmers' incomes by 50% or more in India.

Social Benefits:
It causes lesser harm to human health due to reduced exposure to pollution emitted from fossil fuel usage.

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

Sale through dealer distributor retailer	Direct sale to corporates/ suppliers	Direct sale to farmers

Case Study[25]
Syngenta has implemented several initiatives to promote the use of renewable energy in agriculture. It is working to increase the use of renewable energy such as solar power and biogas in its own operations as well as the operations of its suppliers and customers. The company is also investing in R&D to create sustainable agriculture practices and technologies that can reduce emissions and improve energy efficiency in farming.

Case Study[26]
In 2022, Bunge finalized a joint venture with Chevron to help meet the global demand for renewable fuels and to develop lower carbon intensity feedstocks. This partnership builds on Bunge's current biofuel operations and will increase its involvement in developing next generation renewable fuels, enabling it to better connect farmers to the growing renewable fuels industry and to play a role in reducing carbon emissions throughout the energy value chain. Through this partnership, Bunge is supporting the expansion of CoverCress technology, a new winter oilseed crop that provides farmers with a lower carbon intensity feedstock to help meet the growing demand for renewable fuels.

Key Risks

The energy outcome from alternative sources of energy may vary widely across regions based on climatic conditions such as the quality and quantum of solar irradiation, wind speed, etc.

CLUSTER 3- WASTE MANAGEMENT

Technologies that reduce GHG emissions through efficient farm and livestock waste management.

TYPE	*Farm Waste Management*	*Livestock Waste Management*
ABOUT	Technologies like microbe-based decomposition; gasification, pyrolysis using thermos-chemical pathways and fermentative and oil plant based biorefineries using biochemical and chemical conversion pathways that convert agricultural farm waste and crop residue into useful products like packaging materials, fuel, fertilizer, specialty chemicals etc.	Technologies that mitigate methane and ammonia emissions from manure storage and deposition. Examples include anaerobic digestion, applying nitrification or urease inhibitors to stored manure, composting and bio-digestion.
PATH WAYS	*Reduce GHG emissions due to farm waste disposal and crop burning*	*Reduce methane & ammonia emission from livestock manure*
DECARBONISATION POTENTIAL	Efficient farm waste management technologies have the potential to reduce GHG emissions by 5-15%.[27]	Livestock manure management technologies can reduce emission of methane and ammonia from manure storage by 18-20% (0.01- 0.26 GtCO2eq yr-1), with the range depending on the economic potential and sustainability of the technology.[28]

ENABLERS

Government Policies	*Financing*	*Capacity Building*
Government incentives to adopt crop residue management. **Example:** India's mission on crop residue management aims to reduce air pollution caused by stubble burning by promoting alternative uses for stubble such as biomass energy and composting, as well as by providing financial incentives to farmers to adopt these practices.	Capital investment for waste management technologies for scaling up agri-waste management solutions. **Example:** Programme National de Biodigesteurs du Burkina Faso (PNB-BF) promoted the installation of biodigesters by providing a credit line to MFIs to increase their liquidity and gain more working capita to provide lending to farmers and small enterprises.	Capacity building initiatives by local extension agencies that provide farmers with the technical knowledge required to adopt sustainable waste management practices. **Example:** ICAR in India has identified various agri-waste technologies. It develops prototypes for these technologies and trains farmers on how to use them.

EMISSION HOTSPOT IMPACTED

Farm Gate (*10-12%**) → *Logistics* → *Processing* → *Packaging* → *End Use*

**Crop residue management and livestock manure management*

TECHNOLOGY EFFICIENCY		*FEASIBILITY*	
Potential for GHG reduction	*Low*	Feasibility for LMICs	*High*
Level of Maturity of technologies within cluster	*Medium*	Affordability for farmers/ end users	*Low*
Cost efficiency (Marginal abatement cost curve)	*Medium*	Capacity required for implementing the tech	*Medium*
Potential socio-economic impact	*High*	Ease of implementation	*Medium*

COST – BENEFIT ANALYSIS

Equipment/Infrastructure Costs:
Setting up and managing most waste management solutions like anaerobic digestion and waste-to-energy conversion.

Abatement Costs:
Varies from USD 20-100/ MTCO2eq for farm waste management technologies. May exceed USD 100/MT CO2eq for setting up large bio-digesters for livestock waste management.

Labour Costs:
All waste management systems require additional labour and incur ancillary costs for managing and executing the waste solution. Additional labour is required if waste is translated into a product sellable in the market.

Environmental Benefits:
Efficient waste management reduces excess GHG emissions from the farm and also avoids biodiversity loss.

Economic Benefits:
Additional income from:
a) The sale of farm waste to the farm waste processors, b) The self-conversion of farm waste to useful end products and c) The sale of converted products like fuel, fertilizer, packaging materials etc.

Social Benefits:
It helps in creating a circular economy by converting farm waste into manure which is then reused for cultivation in the same farms. New ways of waste management can also support the creation of new jobs.

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

Sale through dealer distributor retailer	*Direct sale to corporates/ suppliers*	*Providing decomposition of farm waste as service*	*Collecting waste from field and selling final product*

Case Study [29]
Nestle is focusing on the farm waste management and circularity. To utilize the coffee berry (Casara) which surrounds the coffee beans and is usually treated as farm waste, the company has leveraged technological innovations and created a delicious beverage named NESCAFÉ NATIV Cascara. This is a unique coffee berry-based carbonated soft drink with floral and fruity notes, launched in Australia. Nestle also implemented similar innovations to utilize cocoa pulp such as launching Incoa, a 70% dark chocolate bar which uses cocoa pulp under its Les Recettes de L'Atelier brand.

Case Study [30]
COFCO's sugar team is shifting away from the use of agrochemicals to more natural solutions instead. The team has swapped Synthetic fertilizers for organic residues from nearby sugar mills and replaced pesticides with natural predators. This ranges from sugarcane leaves and boiler ash, to filtered cake and nutrient-rich effluent as an alternative to synthetic inputs.
By reusing this residue, COFCO reduces synthetic fertilizer use and conserves the soil and environment.

Key Risks
The use of alternative measures for crop waste management may result in the delayed sowing of subsequent crops, which can reduce germination rates and ultimately impact productivity. The limited availability of sufficient time and labor can pose as a risk to the adoption of waste management technologies.

CLUSTER 4- ENERGY EFFICIENCY

Technologies that reduce GHG emissions by optimizing the use of fossil-fuel-based energy during upstream and/or downstream activities in the agri and food system supply chain.

TYPE	*Energy efficiency solution for upstream*	*Energy efficiency solution for downstream*
ABOUT	Technologies like smart water controllers, energy saving pumps, farm equipment route management, small farm level coolboxes for storing perishables, which help optimize fuel and energy at the farm level.	Technologies like logistic route optimization, hybrid engines, and smart energy meters for warehouses and cold storage units, that reduce energy consumption and improve energy efficiency in various activities such as transportation, storage, and processing of agricultural products.
PATH WAYS	*Optimize usage of fossil fuel and other farm inputs*	*Reduce methane & ammonia emission from livestock manure*
DECARBONISATION POTENTIAL	Using energy efficient technologies to improve water efficiency by just 10% could reduce diesel consumption by 102 million liters, resulting improving energy efficiency.[31]	20-23% GHG savings can be achieved by using energy efficient technologies for downstream supply chain activities such as storage, processing and retail operations.[32]

ENABLERS

Government Policies	*Financing*	*Capacity Building*
Government support in the form of incentives to farmers to reduce the use of fossil fuel-based energy. **Example:** The South African National Energy Development Institute (SANEDI)[32] aims to improve energy efficiency in the agro-processing sector through initiatives such as the installation of energy-efficient lighting, motors, and heating and cooling systems.	Concessional finance to SMEs providing energy efficient solutions through blended finance approach. **Example:** The Aceli Africa fund[33] covers the first loss across the lender portfolio for qualifying loans by depositing 2%-8% of the loan value into a reserve account. It also provides additional incentives for loans that meet criteria related to gender inclusion, food security and nutrition, and/or climate resilience.	Training and technical assistance to farmers, processors, and other stakeholders on adopting energy-efficient technologies and practices. **Example:** Tanzania's Sustainable Energy for All[34] aims to promote the use of renewable energy and improve energy efficiency in the agriculture sector. The program provides training and education to farmers on sustainable agricultural practices and renewable energy technologies, such as solar water pumps and biogas systems.

EMISSION HOTSPOT IMPACTED

Farm Gate	Logistics	Processing	Packaging	End Use
3%	3%	4%	1%	

TECHNOLOGY EFFICIENCY		FEASIBILITY	
Potential for GHG reduction	Low	Feasibility for LMICs	High
Level of Maturity of technologies within cluster	Medium	Affordability for farmers/ end users	Medium
Cost efficiency (Marginal abatement cost curve)	Medium	Capacity required for implementing the tech	Medium
Potential socio-economic impact	Medium	Ease of implementation	Medium

COST – BENEFIT ANALYSIS

Capital Costs:
Energy-efficient technologies may require significant upfront investments in new equipment and infrastructure. For example, upgrading equipment such as refrigeration systems or irrigation systems to more energy-efficient models may involve capital investments.

Abatement Costs:
Varies from USD 20/MT-CO_2eq to 100/ MTCO_2eq.

Operational Costs:
Energy-efficient technologies may require substantial working capital for ongoing operational expenses, such as maintenance and monitoring.

COSTS-BENEFITS

Environmental Benefits:
It reduces GHG emission from fossil fuel-based electricity or diesel.

Economic Benefits:
Reduction in the use of fossil fuel- based energy reduces costs associated with production, post harvesting, storage, processing retail etc.

Social Benefits:
Use of energy efficient technologies leads to efficient farm operations which in turn results in freeing up time for the the farm household.

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

Sale through dealer distributor retailer	*Direct sale to corporates/ suppliers*	*Providing EE as service to corporates for energy optimisation*	*Lease to own or pay per use model for farmers*

Case Study [34]
Unilever has committed to achieving net-zero emissions from its products by 2039 and has adopted energy efficiency measures across its operations. Unilever has upgraded some of its equipment, such as refrigeration systems and boilers, to more energy-efficient models. Unilever's Lipton tea factory in Kericho, Kenya, uses energy-efficient equipment, including high-efficiency boilers and heat recovery systems, which have helped reduce the factory's energy consumption by 50%. Further downstream, Unilever's subsidiary, Ben & Jerry's, partnered with a dairy farm in Vermont in 2019 to install a more energy-efficient milk chiller. The new chiller uses 80% less electricity than the previous model, resulting in significant energy savings.

Case Study [35]
Del Monte Foods has undertaken initiatives to explore more efficient energy sources, strengthen energy conservation at worksites, and reduce process waste, to reduce GHG emissions.
In FY22, the Company reduced its total energy consumption by 35,345 megawatt-hours despite increasing total production. This reduction is partly due the use of solar panels in Hanford, which produce 401 megawatt-hours of electricity. Del Monte Philippines, Inc. (DMPI) became one of the few companies in the Philippines to be certified carbon negative for scopes 1, 2 and 3 (air travel and fuel used by vehicles) for its pineapple operations.

Key Risks
The quantum of savings may not be enough to convince supply chain players to move away from conventional technologies leading to low adoption.

CLUSTER 5- OPTIMIZATION OF PRECISION AGRICULTURE

Agri 4.0 technologies help to reduce GHG emissions by providing precise advisory to optimize the use of inputs and enable more informed decision at the farm level.

TYPE	*Precise input use at farm level*	*Efficient livestock management*	*Precise aquaculture management*
ABOUT	Technologies like smart water controllers, energy saving pumps, farm equipment route management, small farm level coolboxes for storing perishables, which help optimize fuel and energy at the farm level.	Technologies used to provide data-driven guidance to livestock owners for effective herd management and tracking livestock health and feeding patterns.	Technologies like AI, ML and computer vision that help farmers monitor the growth of fish and shrimps and use this data to guide farmers on the use of other inputs, as well as on production processes.

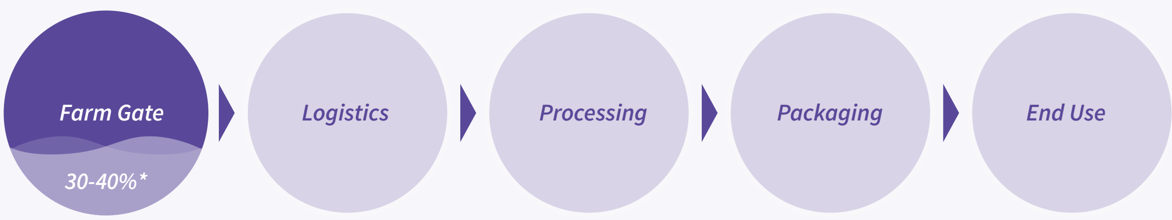
PATH WAYS				
	Reduce usage of synthetic fertilizers and agro-chemicals	*Increase soil organic carbon, prevent the degradation and leaching of soil*	*Reduce methane emissions from enteric fermentation in livestock*	*Reduce GHG emissions from aquaculture by optimizing the use of feed*

DECARBONISATION POTENTIAL

5-40% of GHG emissions from the farm by guiding farmers on input use optimization and use of better alternatives.[36] However, the quantum of impact from the use of data driven advisories varies based on parameters analysed.

ENABLERS	*Government Policies*	*Financing*	*Capacity Building*
	Government support through enabling policies and the promotion of R&D in scaling agri-4.0 technologies like drones, AI, big data, etc. **Example:** The Government of India provides grants of up to 75% of the cost of drone to farmer collectives for the purchase of drones. It also provides subsidies to entrepreneurs setting up custom hiring centres for drones.[37]	Investments in digital infrastructure as well as financing for setting up the data driven advisory and establishing the soft components of the service. **Example:** The Government of Korea has invested in several open data platforms for agriculture. The data from these platforms is being used by several precision agricultural companies for training their production models.	Training and capacity building of local resources to operate devices associated with the technology. Moreover, there is a need to provide farmers and farmer collectives with extensive training in digital literacy to encourage the adoption of precision agricultural technologies.

EMISSION HOTSPOT IMPACTED



**Enteric fermentation, inadequate use of inputs leading to soil degradation and to some extent deforestation*

TECHNOLOGY EFFICIENCY		*FEASIBILITY*	
Potential for GHG reduction	*Medium*	Feasibility for LMICs	*Medium*
Level of Maturity of technologies within cluster	*Medium*	Affordability for farmers/ end users	*Medium*
Cost efficiency (Marginal abatement cost curve)	*Medium*	Capacity required for implementing the tech	*Low*
Potential socio-economic impact	*High*	Ease of implementation	*Medium*

COST – BENEFIT ANALYSIS

Equipment and Hardware Costs
The cost of purchasing necessary hardware such as sensors, drones, and other equipment for collecting and analyzing data.
Software and Development Costs: The cost of developing or purchasing software for data collection, analysis, and automation.

Abatement Costs:
Varies from USD 20-100/ $MTCO_2eq$ to >100 MT CO_2eq.

Maintenance & Training Costs:
The cost of operating and maintaining the technology including energy and communication costs. The cost of training personnel on how to use the technology and analyze the data.

Environmental Benefits:
It reduces GHG emissions by optimizing the use of synthetic fertilisers and agrochemicals, and traditional livestock and aquaculture feeds.

Economic Benefits:
It leads to high income realization due to a reduction in the use of the inputs and increase in productivity. Saving varies in the range of 15-40%.

Social Benefits:
It leads to efficient farm operations, reduces drudgery, improves health since it reduces the use of agrochemicals.

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

Sale through dealer distributor retailer	*Direct sale to corporates/ suppliers*	*Ecosystem service, contract at pre-season and sale via data based app*	*Lease to own or pay per use model for farmers*

Case Study [38-39]
Cargill is a multinational corporation that operates in the food, agricultural, and industrial sectors. Cargill uses digital tools to help farmers improve their productivity while reducing their environmental impact. It has developed a platform called the Cargill Cocoa Promise, which uses satellite imagery and machine learning to provide cocoa farmers with personalized recommendations on crop management practices. This helps them optimize their yields while minimizing the use of water and chemicals.

Case Study [40]
Innovasea in partnership with Open Blue has implemented a full turn-key solution for its cobia farm - this includes submersible sea station pens, innovative feeding systems, morning systems and predator proof brass alloy mesh netting. The solution maximizes efficiency, particularly its feed conversion ratio and minimizes its impact on the surrounding ecosystem. Open Blue now has the largest open ocean fish farm in the world with 22 pens and 1,200 tons of fish harvested annually. The cleaner, healthier offshore environment leads to better growth rates and harvests.

Key Risks
While precision agriculture technologies are often adopted due to associated subsidies and grants, their long-term use can be limited amongst smallholder farmers, especially when deployment is not accompanied by capacity building.

ENABLING CLUSTER 1- GHG ACCOUNTING

Technologies enabling a reduction in GHG emissions by assisting corporates to map, monitor and account for GHG emissions across their supply chain.

TYPE	*Geospatial monitoring of biomass and soil carbon*	*Emission accounting software- Supply chain mapping for accessing suppliers' GHG emission*
ABOUT	Satellite or aerial imagery, machine learning, and Geographic Information Systems (GIS) used to monitor used to monitor and analyze changes in climate and land cover.	Digital tools used to track and quantify GHG emissions from suppliers, with the aim of identifying opportunities to reduce emissions and improve sustainability.
DECARBONISATION POTENTIAL	Potential to contribute to GHG mitigation efforts by providing accurate and timely information about land use changes, forest carbon stocks, soil carbon stocks, and GHG emissions. A study estimated that satellite-based monitoring of deforestation could reduce emissions caused by tropical deforestation by up to 18% by 2030. This is the equivalent of taking about 1 billion cars off the road each year.[41]	A study found that by using supply chain mapping and other tools to reduce emissions in the soybean supply chain, it is possible to achieve a reduction in emissions of up to 41% by 2025, compared to a business-as-usual scenario.[42]

	Government Policies	*Financing*	*Capacity Building*
ENABLERS	Governments can provide financial incentives and technical assistance to farmers, agribusinesses, and researchers for developing and implementing GHG measurement and reporting systems. **Example:** The EU Deforestation Regulation is likely to influence the adoption of such technologies amongst corporates.	Investing in digitisation of data and in building the infrastructure systems required for enabling GHG accounting systems. **Example:** The Climate Public Private Partnership (CP3) was set up to boost investments in climate projects. Under CP3, several funds have invested in GHG accounting systems in developing countries.[43]	Training and capacity building of resources/ suppliers. **Example:** UNITAR conducts GHG accounting training programmes for interested professionals in developing countries.[44]

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

Software as a service model	*Charging service fees for the use of software, remote sensing maps, etc.*
Case Study[45] [46] **Mondelez International,** under its Cocoa Life programme in partnership with Global Forest Watch, tracks deforestation across six cocoa-growing regions in LMICs and helps farmers adopt climate-friendly practises like agroforestry, optimum input usage, etc. to reduce the deforestation percentage. This programme is backed by the Payment of Ecosystem Services to Farmers Act, where farmers receive payments in return for planting non-cocoa trees on their farms and for protecting and renewing forest areas.	*Case Study*[47] **Olam International,** a leading global agri-business, is set to launch a new venture, GreenPass[1] to enable companies to better measure and manage carbon emissions across their operations and their supply chains including Scope 3 emissions. Olam has developed the digital platform internally, drawing upon its extensive expertise and capabilities in sustainability, digitalization and business incubation gained over many years.

Key Risks

The robustness of many GHG accounting solutions especially for complex estimations such as below-the- ground carbon stocks are still to be verified. Additionally, accounting systems that leverage farm records for GHG accounting can provide inaccurate estimations if the data in farm records is incorrect or not of good quality.

ENABLING CLUSTER 2- CARBON FINANCING PLATFORMS

Technologies that enable the reduction of GHG emissions by measuring, reporting and verifying (MRV) carbon credits generated in carbon offset/ inset projects, and facilitate the trade of carbon credits by connecting buyers and sellers.

TYPE	Carbon trading platforms for carbon offsetting outside own supply chain	Designing and implementing carbon removal projects within own supply chain
ABOUT	Online platforms based on advanced digital technologies with real-time monitoring capabilities used to track carbon credits generated from offsetting projects like agroforestry, avoiding crop waste burning, and regenerative agriculture that take place outside a company's value chain.	Advanced digital technologies like satellite imaging, GIS and AI models for MRV of carbon removal programs like regenerative practices and agroforestry within a company's supply chain.
DECARBONISATION POTENTIAL	Carbon trading platforms can provide a market-based mechanism to incentivize farmers and other stakeholders in the agricultural sector to reduce their emissions. A study by the World Bank found that the use of carbon trading platforms can enable reduction of up to 1.5 billon tones of CO2eq per year in GHG emissions from the agricultural sector by 2030. This represents a significant contribution to global efforts for mitigating climate change.	

ENABLERS	Government Policies	Financing	Capacity Building
	Incentivise and facilitate the use of carbon trading solutions by agri-based corporates. This includes tax incentives for companies that participate in carbon trading and developing supportive regulations, etc.	Providing pre-finance to farmers for implementing the nature based solutions like planting of trees, following regenerative agriculture practices. This could be backed up by the carbon credits expected to be generated from the project.	Training and capacity building for resources/ suppliers. Capacity building of various stakeholders for improving the accuracy of digital MRV using satellite imaging. Training of farmers to implement nature based solutions.

BUSINESS MODELS OF TECHNOLOGY PROVIDERS

- *End to end implementation of carbon projects*
- *Designing the project and registering it to the registries*
- *Implementation of carbon projects based on carbon credit sharing mechanisms*

Case Study [48] [49] [50]

PepsiCo has committed to achieving net zero GHG emissions by 2040 and has implemented several initiatives to reduce its carbon footprint. The company has partnered with organizations such as The Nature Conservancy to develop carbon offset projects that promote sustainable agricultural practices and reforestation across its supply chains. PepsiCo also participates in carbon trading platforms to offset emissions from its operations and supply chains.

Case Study [51]

Indigo Ag, an agricultural technology company, has launched the "Terraton Initiative" with the goal of removing one trillion tons of carbon dioxide from the atmosphere across 12 billion acres. To achieve this, the initiative encourages farmers to adopt regenerative farming practices such as planting cover crops, reducing the use of chemicals and fertilizers, rotating different crops and integrating livestock to improve soil health. So far, this initiative has sequestered about 40-60 MMT CO2eq. Moreover, farmers who adopt these practices can expect an increase of $30-$45/acre/year in potential gross income due to the enrichment of their soils.

Key Risks

There have been several instances of greenwashing based on carbon offsetting. This mostly happens when larger corporates trade unverified credits. There is also the risk that a corporate may only engage in offsetting without making any effort to reduce its own Scope 3 emissions.

5

CO-BENEFITS OF NET-ZERO TECHNOLOGIES ON CLIMATE RESILIENCE

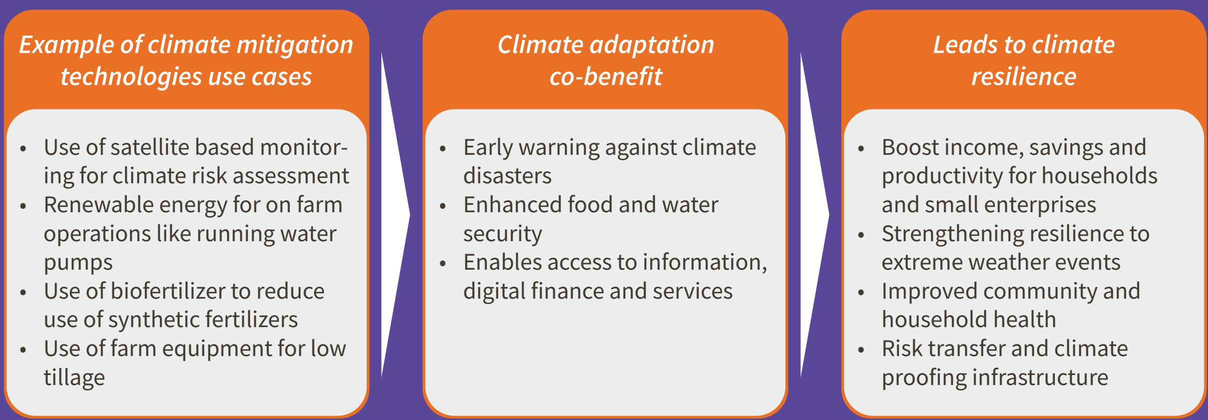
5.1 INTERLINKAGES BETWEEN CLIMATE MITIGATION, ADAPTATION, AND RESILIENCE

Climate resilience refers to the "Capacity of social, economic, and ecosystem to cope with a hazardous event, trend, or disturbance."[86] Climate resilience is achieved by decreasing communities' vulnerability to climate change by increasing climate related shock absorptive and adaptive capacities of farmers.

> **Most of the technologies under the high-impact clusters are effective not only in reducing emissions but also in building resilience against climate shocks.**

Climate change events such as droughts, floods, cyclones, and other changes in weather can harm the agricultural sector, causing losses in produce and affecting local communities' ability to cope. In addition to climate-related disasters, increases in GHG emissions cause increases in temperature and fluctuations in rainfall patterns which lead to changes in weather and eventually changes in weather resulting in yield loss. Further, indiscriminate usage of chemical inputs deteriorates soil quality and eventually affects the yield. As a result, a diverse set of climate mitigation and adaptation solutions are required to address these issues and build climate resilience to deal with vulnerabilities. Climate mitigation technologies with adaptation co-benefits increase community income, strengthen agricultural practices, improve knowledge sharing, and reduce risks from climate change, and thus add to the resilience.

Figure 10: Interlinkages among climate mitigation, adaptation, and resilience



5.2 TECHNOLOGIES WITH CO-BENEFITS OF CLIMATE RESILIENCE

Not only do the seven technology clusters identified in this study reduce GHG emissions across different activities, but they also lead to climate resilience. Climate resilience is developed by increasing a sector or community's adaptive and absorptive capacity to bear climate related shocks. While adaptive capacity provides the means to see through decisions to change the farm system, absorptive capacity provides the ability to withstand or deal with the impacts of climate threats.[87]

The sections below describe the process and resilience linkages for each shortlisted technology cluster:

86 IPCC

Table 7: Climate resilience linkages of high impact technology clusters

High impact tech clusters	Process	Leading to climate resilience
Low carbon inputs	• Strengthens the root ecosystem, leading to better germination of seeds in drought prone or climate affected areas. • Enhances ecosystem biodiversity.	• Increases water holding capacity of the soil to withstand drought, heavy rains, and heat waves. • Improves income since a reduction in usage of synthetic fertilizer, agro-chemicals and livestock feeds, results in increased stock/ savings and hence increases absorptive capacity. • Builds knowledge of farmers on sustainable crop cultivation in rain-fed regions.
Upstream renewable energy	• Reduces dependencies on fossil fuels and helps in sustainable water management by using solar/ wind energy for powering farm operations like irrigation.	• Reduces irrigation expenses and results in higher savings in the long run, building the absorptive capacity of farmers.
Waste management	• Maintains the farm's productivity by avoiding the disposal of farm waste in landfills.	• Increased productivity helps in high net income realization. • Diversification of sources of income by generating additional revenues from sustainable waste management.
Energy efficiency	• Increase in productivity and efficient farm operations help in sustainable soil and water management.	• Increase in economic savings due to reduced use of electricity for farm operations. • Maximizing output to increase the financial capacity to adapt to climate change.
Precision agriculture optimization	• Enhanced knowledge about farms to tackle climate change. • Reduced service delivery cost. • Sustainable soil and water management due to input use optimization advisory. • Enhanced natural resource use efficiency.	• Increased financial capacity due to output maximization. • Increased financial capacity due to input use optimization. • Increased knowledge capacity to adapt to climate change.

Climate resilience linkages of the enabling clusters-

Table 8: Climate adaptation and resilience linkages of enabling technology clusters.

Enabling clusters	Process	Leading to climate resilience
GHG accounting	• Supports deployment of climate information services like Early Warning Systems (EWS) and deployment of crop insurance by monitoring weather trends and predicting crop loss. • Helps in crop calendar optimization and in making farm practices climate impact ready. • Enhance knowledge of practices to be adapted in case of droughts, floods, heat waves, and pest attacks. • Certification of organic farming regenerative agriculture.	• Increased readiness to tackle climate disasters. • Increased income realization due to climate ready farm management and certification of the produce. This results in increased saving stock with farmers.
Carbon financing platforms	• Increased information about the farm, based on satellite data, remote sensing. • Aids the implementation of nature-based solutions like agroforestry, regenerative agriculture, deforestation prevention farming.	• Increased financial capacity due to enablement of carbon finance, Payment of Ecosystem Services (PES). • Increased biodiversity due to diversification of farm activities.

87 Standing strong: Towards deeper implementation of climate resilience- IDH knowledge report

6

CHALLENGES IN SCALING HIGH IMPACT TECHNOLOGY CLUSTERS

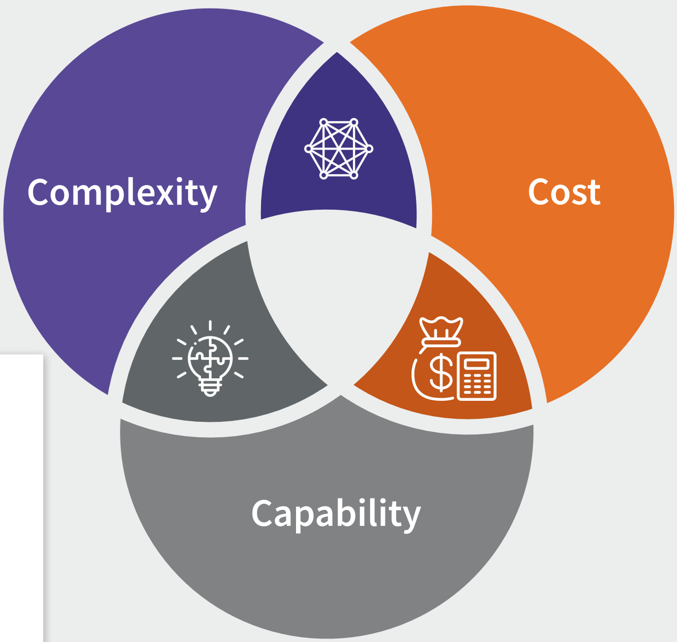
Cost, complexity, and capability related challenges impact the adoption and scaling up of high impact technology clusters by corporates, especially in LMICs.

Scaling high-impact technology clusters is critical for corporates to mitigate GHG emissions across their supply chains and for them to meet their net-zero targets. However, it can be challenging to implement these technologies in low and middle-income countries (LMICs).

The critical challenges that impact the adoption of these technologies can be analyzed using the 3C model[88] of ***Cost, Complexity and Capability*** developed by Overseas Development Institute (ODI).

Cost related challenges includes-

- High capital and operational expenditure for corporate/suppliers/end users.
- High marginal abatement cost.
- High implementation cost (Capacity building of suppliers/ farmers).
- Conundrum on who should pay - corporate, supplier or farmers.



Complexity related challenges includes-

- Understanding and implementing the technology.
- Incentivizing value chain actors to adopt the technology.
- Convincing a large supplier base to adopt net-zero technologies.
- Ensuring effective collaboration between procurement and sustainability teams.

Capability related challenges includes-

- The technology providers ability to justify the cost (lack of evidence and proof of concept, limited success stories, fragmented technology availability).
- Capability of corporate/suppliers to identify and implement the technology (limited awareness on technology clusters).
- Limited skills or resources available amongst end-users to successfully implement technologies (such as low digital literacy).

88 3C model developed by ODI

In addition to these overarching challenges, each shortlisted technology cluster has its own set of challenges which restrict their adoption. These are highlighted below:

Table 9: Challenges pertaining to each shortlisted technology cluster.

Technology Clusters	Cost	Complexity	Capability
Low Carbon Inputs	Innovative inputs such as feed additives and alternative fertilizers may cost more than their existing counterparts.	There is a lack of under-standing on how to effectively use low carbon inputs. There is also limited evidence and guidance on dosages as compared to conventional inputs.	Suppliers need to engage in intensive efforts to support farmers in changing their practices. Additionally, the impact of several inputs is still uncertain as they are in the pilot phase.
Upstream Renewable Energy	High upfront costs of installing RE based solutions compared to the abatement potential. Conundrum on who should bear the cost for adopting technologies.	-	Requires specialized capacity to operate and maintain renewable energy systems.
Waste Management	Revenue from Waste management may not justify the investments required to aggregate waste.	-	Farmers may not be fully aligned to waste management behaviors and practices and may require significant capacity building.
Energy Efficiency	Require upfront investment for purchasing new equipment or upgrading existing infrastructure.	-	Lack of knowledge and motivation to opt for energy efficient solutions unless there is a clear economic benefit.
Precision Agricul-ture Optimization	High marginal abatement cost which includes investments in assets. Conundrum on who should bear the cost for adopting technologies.	Substantial technical expertise required to effectively operate such advanced technologies.	Farmers/ suppliers may lack the awareness, skills, and resources required to adopt such solutions. Lack of evidence and proof of concept for some technologies.
GHG Accounting	High implementation cost requires investment in technology, data manage-ment, and human resources.	Fairly complex, and requires algorithms contextualized to the regions.	Field staff may need additional training to collect adequate data for GHG accounting.
Carbon Financing Platforms	High costs including that of measuring, reporting, and verifying emissions, as well as developing carbon offset projects.	Quite complex and requires technical expertise as the regulatory frameworks are still evolving. Lack of data infrastructure for training models for monitoring and verifying credits.	Lack of evidence or proof of concept in LMIC regions. Also, as returns are long term for such projects, finding funding for the initial implementation is a challenge.

7

RECOMMENDATIONS FOR IMPLEMENTING NET-ZERO TECHNOLOGIES

Wide scale adoption of technologies that support net-zero emissions needs definitive actions from the stakeholders involved in agricultural supply chain activities - both individually and collaboratively.

We have identified the following stakeholders who can play a substantial role in ensuring the adoption of net-zero technologies:

Farmers and farmer collectives have been excluded from the list of stakeholders since they are the prime implementors and beneficiaries of actions initiated by other actors in the supply chain. Limitation of farmers and farmer groups to invest in research and pay for net-zero technologies are other reasons for their exclusion.

Corporates	*Technology providers*	*Government*	*Financial Institutions*	*Industry Associa-tions and Coalitions*
Companies that are engaged in agricul-ture and allied sector-related input products and services, production, value addition and trade.	Companies and social enterprises engaged in providing techno-logical solutions to governments, companies, farmers, and associations are included in this segment.	Relevant ministries and departments of country govern-ments.	Includes MFIs, Non Banking Financial Companies, Banks, Venture Capital providers, Development Finance Institu-tions, and Donors.	Includes various associations of companies based on either the scale of operations or specific to the sector of operation.

7.1 STAKEHOLDER WISE RECOMMENDATIONS FOR TECHNOLOGY IMPLEMENTATION

Corporates- Corporates can take the lead in driving demand for sustainable agricultural practices and invest in R&D as well as implementation of high impact technologies.

Why: This will help Corporates mitigate risks resulting from climate change, enhance their brand value, meet ESG compliance and voluntary net-zero commitments, and meet social and community expectations.

WHAT: Create knowledge on GHG accounting and mapping across the supply chain	
How	**Example**
Inform Tier 1 suppliers about publicly available tools (SBTi, GHG protocol), and guide them on their application. Arrange extensive training and capacity-building programs for Tier 2 and Tier 3 suppliers. ***Procurement criteria:*** define and establish clear criteria for suppliers. ***Working with existing suppliers***- corporates can provide training on GHG emission mapping and encourage them to adopt carbon reduction targets to reduce their emissions. Companies can segment suppliers based on the region of procurement to ensure targeted training programs.	***Unilever has launched the Unilever Climate Promise and the Unilever Climate Program.*** Under the former, the suppliers set SBTi targets, publicly report their progress and share their product level GHG emission footprints with Unilever. Under the latter, Unilever supports 300 suppliers whose products have highest climate impacts, by building their knowledge of GHG accounting and mapping.[89]

WHAT: Recognize, incentivize, and support suppliers for technology adoption	
How	**Example**
Recognize the supplier's performance publicly through felicitations and awards, and establish preferential procurement conditions (improved payment terms, long-term contracts linked to identified climate goals) for suppliers that adopt technologies for emission reduction. ***Leverage a better credit rating to facilitate supplier loans*** and arrange discounted credit facilities for suppliers that adopt promising technologies. ***Support and collaborate with suppliers by directly financing technology*** adoption or sharing the cost of the technology.	***Puma is working with BNP Paribas*** to offer a financing program to its suppliers to improve social and environmental standards.[90] ***In 2021, IKEA launched a program*** to support its 1,600 direct suppliers in switching to 100% renewable electricity. This is expected to save 670,000 metric tonnes of CO_2 emissions per year. IKEA provided support for local solutions such as bundled framework agreements and power purchase agreements for suppliers to purchase renewable electricity from the grid. This was in addition to assisting them in installing onsite renewable energy-based solutions under the IKEA 100-million-euro financing facility, announced in 2019.[91]

WHAT: Incentivize farmers to adopt technologies that support sustainable cultivation practices	
How	**Example**
Corporates can incentivize farmers to adopt technologies that support sustainable farming practices which have been certified by authorized agencies. There are multiple ways to incentivize technology adoption: 1. By offering ***sustainability differential (SD)***, which is the additional cash per metric ton of produce paid to farmers in lieu of the effort undertaken by them to farm sustainably. 2. By sharing the cost of ***sustainability investment (SI).*** This is an in-kind or cash payment to farmers to cover their investment in obtaining certifications. ***3. Payment for Ecosystem Services (PES)***- PES are voluntary transactions between service providers and users. These transactions are conditional and depend on farmers observing agreed-upon rules of natural resource management. For example, corporations may pay farmers to maintain biodiversity.	***The Rainforest Alliance's Sustainable Agriculture Standard*** outlines a minimum sustainability differential of USD 70 per MT for cocoa as well as sustainability investment requirements for cocoa buyers.[92] ***Nescafe Plan 2030*** aims to source 50% of its coffee from coffee cultivated through regenerative agriculture. To accelerate this transition, Nestle is piloting a financial support scheme in Mexico, Côte d'Ivoire, and Indonesia. The company provides: conditional cash incentives for adopting regenerative agriculture; income protection by using weather insurance; and access to credit lines for farmers. For this program, Nestle has partnered with the Rainforest Alliance for M&E. This is in line with meeting the Nestle's 2030 GHG emission reduction target.[93] As part of its ***Cocoa Life sustainability programme***, in 2017, Mondelez International launched the Nawa PES pilot project in collaboration with Côte d'Ivoire's Ministry of Environment as part of the country's REDD+ program

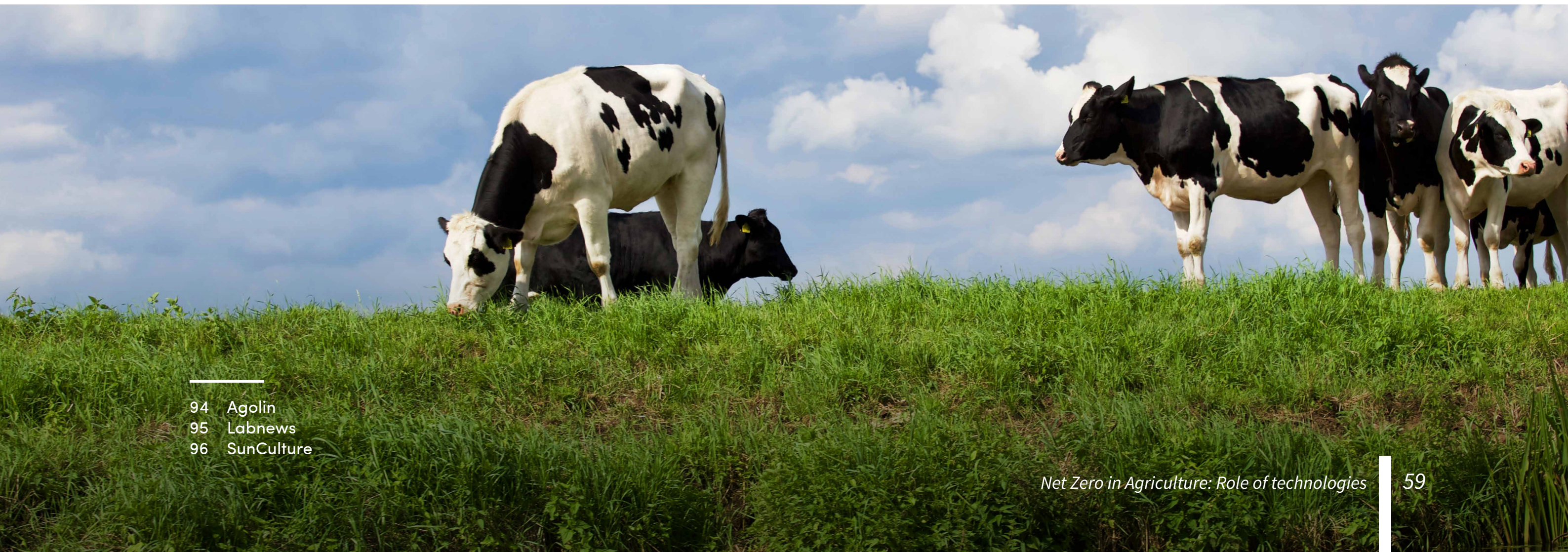
89 Unilever Climate Promise and Climate Programme
90 Puma-BNP Paribas
91 IKEA programme
92 Rainforest Alliance
93 Nestle sustainability

How	Example
4. Enabling monetization of emission reduction through ***carbon finance***: These are incentives shared with farmers from the sale of carbon credits generated by emission reducing emissions in their fields through interventions like agroforestry and regenerative agriculture, etc.	to support Country's goal to reach zero deforestation in cocoa. The project aimed to reduce deforestation in Mondelez's supply chain. Farmers were provided PES individually and collectively to support agroforestry, reforestation, and forest conservation activities.

Technology Providers- can support Corporate Net-zero transitions by developing products tailored to the needs of individual companies and bundling services to increase the adoption of sustainable solutions at the farm level.

Why: Technology providers develop net-zero solutions that are in high-demand and invest in their technology to increase their market share and revenues.

WHAT: Develop and provide custom made solutions for corporates	
How	**Example**
Undertake a detailed assessment to understand the corporate's needs and accordingly design/customize solutions. This requires an understanding of the supply chain, geography, stakeholder involvement, GHG reduction potential, etc.	***Agolin ruminant,*** a plant-based feed additive technology provider has collaborated with Nestle and Barry Callebaut to help them meet their commitments towards carbon footprint reduction.[94] Data advisory-based tech provider ***BovControl*** provides Brazilian farmers with easy-to-use tools to collect animal data in the field. They have developed a white label customized version of the solution for Nestle, ***"Leitera." This allows Nestle to*** trace the milk collected and to measure associated GHG emissions.[95]
WHAT: Bundle GHG-reducing technologies with other services, such as financing and building market linkages, to improve adoption.	
Provide add-on services along with core technology solutions. Such add-on services may include measuring and monitoring GHG emissions mitigated, providing finance for technology adoption, setting up centers of excellence to build farmers' capacity to use the technology, and creating net-zero demonstration plots that corporates can visit to validate the effectiveness of the technology. A pay-as-you-go financing model could be considered for some technologies. In this model, the end user makes either partial fixed payments (lease-to-own model) or payments based on use (usage-based payment model) rather than the upfront capital cost of the technology. This model can be used for the deployment of solar pumps, drone-based spray services, etc.	***Sunculture designs*** and manufactures, IoT-enabled solar energy systems and irrigation equipment (solar pumps) in Kenya, Uganda, Ethiopia, Zambia, Togo, and Cote d'Ivoire. It offers installation services, training, and ongoing customer support. More importantly, it offers the pumps under a pay as you go model to farmers. The farmers make a down payment and then monthly payments for a fixed period. SunCulture has built a credit scoring framework to select potential users for its Pay-Go services and mobilize in-house finance.[96]



94 Agolin
95 Labnews
96 SunCulture

Government- can create an enabling environment for sustainable agriculture by facilitating data sharing, providing incentives for technology adoption, engaging with the private sector, and mobilizing funds to facilitate low-cost finance.

Why: To meet the country's nationally determined contributions and to enhance the livelihoods of farmers by increasing their income realization.

WHAT: Create an enabling environment for data sharing	
How	**Example**
Create a federated farmers database, which technology providers, ecosystem players, and corporations can refer to while designing targeted products and services.	The Ministry of Agriculture and Farmers Welfare, Government of India, is creating ***AgriStack,*** which is a federated farmers data base at the country level. For this, the Ministry has conceptualized the India Digital ***Ecosystem for Agriculture (IDEA)***, which lays down the framework for agricultural software development. The government has signed a memorandum of understanding with a diverse set of service providers to develop proof of concept. For example, the Ministry entered a MoU with Microsoft India Pvt. Ltd. to use data analytics to empower farmers in 100 villages by consolidating the agri-ecosystem across the supply chain (farm to fork). Similarly, it signed an MoU with Wadhwani AI to create an AI/ML-based solution to scale a pest management solution for cotton farmers. The program covered about 50,000 lead farmers and 500,000+ cascade farmers.[97]

WHAT: Provide incentives to farmers for adopting technologies	
Governments can offer tax incentives, subsidies, reduced interest rates for loans, to encourage farmers to adopt agricultural technologies. These measures can be funded by decreasing subsidies for fossil fuels.	The Government of India, under its PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan), plan installation of 2 Mn off-grid solar agricultural pumps by 2026. Under PM-KUSUM, the government provides subsidies of up to 40% and facilitates loans of up to 50% through the commercial banks to support the installation of standalone solar agriculture pumps with a capacity of up to 7.5 HP. The availability of loans and subsidies eases the upfront payment contribution for farmers to only 10% of the cost of the solar pump. Moreover, the program supports the solarization of 1.5 Mn grid-connected agriculture pumps through its subsidies.[98]

WHAT: Engage with the private sector, technology providers, and industry associations to understand their challenges in meeting mtheir net-zero targets.	
Organize roundtable conferences, workshops, joint publications, etc. to understand the challenges faced by the industries and design a sectoral or industry-level programme that addresses these challenges. For example, a programme on the circular economy can be developed to encourage the adoption of waste management technology by farmers. This can be supported by incentives and industry initiatives.	The governments of Côte d'Ivoire and Ghana and 36 leading cocoa and chocolate companies have joined together in the ***Cocoa & Forests Initiative*** to end cocoa-related deforestation and restore forest areas. In Colombia, the government and cocoa and chocolate companies signed the Cocoa, Forest & Peace Initiative in 2017, to eliminate cocoa-related deforestation.[99]

WHAT: Mobilize funds to facilitate designing of blended finance vehicles by the financial institutions	
Mobilize low-cost funds from developmental financial institutions, large foundations, and donors to encourage local FIs to design and offer low-cost finance to technology providers which will help scale up high-impact technologies.	***Green Taxonomy 1.0 Indonesia*** was developed in 2022 by the Financial Service Authority of Indonesia with the objective of encouraging innovation in green product development, projects, and initiatives and for preventing the green washing practices. It provides guidelines for information openness, risk management, and the development of innovative sustainable finance for climate change adaptation and mitigation projects.[100]

97 Press Information Bureau, Government of India
98 PM KUSUM Scheme, GoI
99 World Cocoa Foundation
100 Green Finance Platform

Financiers and Funders- can promote sustainable agriculture by linking finance to climate outcomes, ESG scores, offering customized low-cost finance, and designing innovative financial products to promote the adoption of high-impact technology clusters.

Why: To meet their voluntary or compliance-based sustainability funding targets; to support a larger decarbonization goal; and to realize high returns from investing in potential technologies.

WHAT: Link lending terms and finance to ESG scores	
How	**Example**
Financiers shall provide incentives to suppliers and businesses that have a high ESG (Environmental, Social, and Governance) score based on their financial disclosures, such as the CDP, Task Force on Climate Related Financial Disclosure (TCFD), and International Sustainability Standard Board (ISSB). Financial institutions can encourage companies to prioritize net-zero targets by offering them capital at lower interest rates compared to rates offered to other businesses.	***COFCO International, a Chinese commodity trader received USD 1.6 Bn sustainability-linked loan*** in 2022. The facility has been signed by a ***consortium of 19 banks.*** The loan offered at a lower interest rate based on the achievement of the Key Performance Indicators (KPI) sustainability targets. The KPI are linked to the ESG score and measured by a rating agency. COFCO will use the saving in the interest margin to fund activities that enables responsible sourcing and invest some portion in its various landscape projects to further its sustainability goals.[101]

WHAT: Design and offer innovative financing mechanisms to suppliers and technology providers	
Design innovative funding models through collaboration with development financial institutions and commercial banks to leverage private funds. There are three key models to finance technology providers: ***Result based financing:*** These financing models link payments for agri-tech solutions to their actual outcomes i.e., their effectiveness in reducing greenhouse gas emissions or increasing the resilience of the farming system. ***Risk mitigation instruments:*** blending public and private funding to offer concessional loans and low-cost finance to borrowers while also leveraging resources and reducing risks for investors. For instance, DFIs and commercial banks could provide concessional loans to agri-tech startups or corporates, while private investors could provide equity or debt financing. ***Bundle financial instruments with technical assistance to FIs:*** bundled products (senior debt with medium- and long-term tenure, guarantees and risk sharing mechanisms on concessional terms, local bonds to enhance the availability of local-currency financing, patience capital, etc.) provide comprehensive solutions to FIs to improve and expand agriculture lending.	***The Global Agriculture and Food Security Programme (GAFSP)*** was developed to increase climate resilience and offset any negative effects on or due to climate change. It works through complementary public and private sector investment. The public sector provides grant financing for strategic, country-owned, and country-led programs while the private sector provides a range of blended finance solutions to support early-stage private-sector activities that find it difficult to get commercial funding.[102] ***Unlocking Forest Finance (UFF)*** is a project by U.K. Global. UFF's Canopy program provides smallholder farmers in Peru with o low-cost, long-term financing along with training in sustainable farming practices. To fund this program, an international bond was issued which provides billions in global debt capital to local financial institutions (FIs). These FIs use this funding to invest in cocoa and coffee supply chains. Major global climate funds like the Global Environment Facility can provide a first loss guarantee or junior equity to cover the repayment guarantee. [103] Launched in 2021, the ***Temasek and Blackrock Decarbonization Investment Partnership*** invests in technology providers focusing on net-zero solutions. The target is to raise $1 billion in funds. These funds will then be deployed to support early-stage growth companies with proven models in renewable and mobility technologies.[104]

101 COFCO International
102 Global Agriculture and Food Security Programme
103 Tropical Forest Alliance
104 Blackrock

Industry associations and coalitions- can promote sustainable agriculture practices by creating awareness, facilitating collaborations, developing technology standards, recognizing corporates implementing net-zero solutions, co-financing pilot implementation and providing incubation support to the technology providers.

Why: To ensure the industry's business continuity and to drive the industry towards meeting its net-zero targets.

WHAT: Create awareness among global corporates on the advantages of adopting available technologies

How	Example
Use campaigns and outreach programs to raise awareness about the benefits of net-zero technologies among agri-based corporations. Industry associations can work with corporations, suppliers, and other players in the supply chain to organize workshops and training sessions to educate corporations about the benefits and importance of adopting sustainable practices.	The Agriculture Hub of the ***Climate and Clean Air Coalition (CCAC)*** brings together governments, inter-governmental and non-governmental organizations along with private sector leaders in the agricultural sector to share their expertise and support countries in mitigating Short Lived Climate Pollutants (SLCPs) from paddy rice cultivation, livestock, and open burning of farm waste.[105]

WHAT: Facilitate pre-competitive collaboration among corporates to identify, test, and implement technologies at the supplier level

Design a value chain-specific initiative where all key corporations procuring specific commodities from the same suppliers or same geographies can collaborate to study the effectiveness and implementation of high-impact technologies. For example, using microbe-based decomposition or utilising farm waste for processing could become a widespread waste management practice among all suppliers. This would benefit every company in the concerned industry by reducing their waste generation related GHG emissions.	***Alliance among agricultural value chain:*** Animal health and welfare companies, MSD Animal Health, Neogen and FutureCow; animal nutrition and health company, DSM; crop nutrition leader, Yara; crop science company, Corteva; artificial intelligence agri-food start-up, Connecterra; WWF France; Danone; Compassion in World Farming (CIWF) and Netherlands-based Wageningen University have formed an alliance to pilot sustainable and low carbon solutions across the dairy value chain.[106] IDH, along with Mondelez International, CIAT, Olam, and the Sustainable Food Lab, launched and co-funded ***Landscapes for Cocoa Livelihoods in Ghana***. This initiative aims to generate additional living income through PES for the cocoa farmers while also preventing cocoa-related deforestation.[107]

WHAT: Setting up a platform to facilitate collaboration among corporates to identify, test, and implement technologies at the supplier level

Establish a platform that brings corporate working on common value chains, themes, and solution providers to work together to collaborate on pilots and scale up innovative solutions.

WHAT: Develop and disseminate industry wide high-impact technology standards

Develop a technology index, to evaluate and list net-zero technologies for the agricultural sector. Industry bodies and certification agencies can collaborate to create sustainable agricultural standards and certifications.

WHAT: Recognize corporates for adopting net-zero technologies

Encourage agri-based corporates to adopt sustainable practices and technologies by designing certification programs. Industry bodies and certification agencies can develop sustainable agriculture standards and certifications that recognize corporates adopting net-zero technologies. Recognize and incentivize agri-based corporates that adopt sustainable practices and technologies by instituting awards for net-zero agriculture.

WHAT: Co-finance and implement pilot programs to support technology providers and corporates

Co-funding pilot programs can improve their monitoring and implementation. For instance, IDH and the Agri3 Fund could collaborate to establish a dedicated fund for net-zero technologies. Such a fund would provide loans and grants to encourage the adoption of sustainable practices and technologies, making it easier for agri-based corporations to transition to net-zero agriculture practices.

WHAT: Provide incubation support to technology providers

How: Incubate net-zero technologies by providing start-ups and corporates with appropriate mentoring and partnerships to scale up their sustainable solutions. Build the capacity of the technology providers to integrate GHG emissions accounting into their products and services and develop guidelines and methodologies for technology providers to accurately calculate the reduction in GHG emissions resulting from the use of these technologies.

105 CCAC
106 Danone
107 IDH- Landscape for cocoa livelihood

7.2 GUIDELINES FOR CORPORATES TO SCALE UP TECHNOLOGY ADOPTION FOR NET-ZERO TRANSITIONS

This section outlines the necessary steps and actions that corporates and technology service providers can take to scale up technology adoption. Additionally, this section discusses the pros and cons of the various engagement models that can be adopted by corporates and technology service providers.

For Corporates: Corporates need to begin by building a detailed understanding of their key emission hotspots and then building pilots and programs to address these hotspots through the appropriate technology. A broad set of steps for Corporates is described below:

Figure 11: Roadmap for the corporates

1. Map Scope 3 emissions
2. Identify and engage with technology providers
3. Collaborate with finance and capital providers for technology adoption
4. Customize payment mechanisms for different technologies
5. Build capacity of the farmers and the suppliers chain partners
6. Align with the sustainability certification and standards

a) **Map scope 3 emissions across all tiers of suppliers to understand emission hotspots:** To build a comprehensive understanding of emissions from each hotspot, emissions must be mapped for all tier 1, tier 2, and tier 3 suppliers. This can provide a baseline for measuring a company's progress towards net-zero emissions and help companies set ambitious targets for reducing emissions. To achieve this, companies can use digital technology platforms which incorporate tools such as Life Cycle Assessment and the GHG Protocol to measure and report their emissions. This also requires improved coordination between a corporate's procurement and sustainability teams.

> *Example:* Olam International, a leading global agri-business, is set to launch a new venture, GreenPass[1] to enable companies to better measure and manage their carbon emissions across their operations and their supply chains including Scope 3 emissions.

b) **Identify and engage with technology providers:** After gathering information on emission hotspots, the next step is to identify and select the right technologies for reducing GHG emissions. Companies must first design pilot programs to validate the technology's effectiveness in reducing GHG emissions from the key hotspots. Evaluating the costs and benefits as well as the feasibility of implementing each technology helps in selecting solutions that are most appropriate for the supplier's/farmer's specific needs and objectives.

> *Example:* In 2022, Bunge finalized a joint venture with Chevron to develop lower carbon intensity feedstocks and to help meet the global demand for renewable fuels. This partnership leverages Bunge's existing biofuel operations and will increase Bunge's participation in the development of next generation renewable fuels.

c) **Collaborate with financial institutions and capital providers to design and finance technology adoption-** Corporates can collaborate with financial institutions to establish mechanisms/facilities that provide affordable capital to stakeholders implementing solutions. This can involve partnering with development finance institutions (DFIs) to access green financing instruments as well as working with private capital providers and financiers to design sustainable procurement programs.

Example: *Unilever, AXA and Tikehau Capital* collaborated to invest EUR 100 Million across three main areas of regenerative agriculture i.e. promote soil health to enhance biodiversity, preserve water sources and combat climate change through technology-based solutions. Unilever brings industry and value chain expertise, while Tikehau capital and Axa bring financial expertise and satellite-based risk monitoring capabilities, respectively.

d) **Customize payment mechanisms for different technologies to incentivize adoption:** Adequate deployment of technologies requires collaboration between a company's procurement team and its sustainability team. Such collaboration can range from supplier selection, to developing sustainability criteria for procurement, to monitoring supplier performance. There are three typical technology deployment models which can be followed:

Technology cost is paid and managed by the Corporate	*In this model, agri corporates invest in the technology, own it, and manage its deployment and maintenance. For example, monitoring farms and using data driven advisory technologies, which result in reduced yield loss and assure quality and quantity for procurement.*
Technology cost is partially paid by the farmers collectives	*In this model, agri-corporates partner with farmers collectives or cooperatives to invest in and manage the technology. The cost and on field management is shared between the suppliers/corporate and the farmers collective. Eaxmples include agri-waste management, farm mechanization, upstream RE, and energy efficiency solutions.*
Technology is distributed to willing farmers through innovative models (such as pay-as-you-go) facilitated by suppliers	*In this model suppliers work with technology providers to provide technology/ services to farmers through a Pay-as-you–go model or adjust part payment for the technology against the procurement price paid to the farmers (trade financing).*

Example: Under its *Nescafe plan 2030*, which aims at sourcing 50% of coffee from regenerative agriculture, Nestle is piloting a financial support scheme in Mexico, Côte d'Ivoire and Indonesia to accelerate the transition to regenerative agriculture.

e) **Build capacity of the farmers and supply chain partners:** As farmers and supply chain actors is prioritize increasing productivity and procuring good quality products at reasonable prices, respectively, it is crucial for corporates to organize capacity building and training programs for their suppliers and farmers. These efforts must emphasize the importance of sustainable/ climate resilient agriculture as well as technologies that promote these practices. Corporates can partner with technology providers and use digital training tools to deliver these programs effectively.

Example: Danone has developed a *handbook for regenerative agriculture* and a *scorecard* focusing on soil, manure, biodiversity and water, to guide and encourage farmers to adopt sustainable practices by scoring them across related parameters . The company has also co-created and funded more than 45 projects with NGOs to help farmers transition to regenerative agriculture under its *Ecosystem Fund.*

Corporates can establish detailed sustainability sourcing criteria and stringent standards for suppliers, along with a list of recommended technologies they can adopt to meet such criteria. This will help align suppliers with the corporate's net-zero strategy.

f) **Align with the sustainability certification and standards for better business growth:** Align with the sustainability certification and standards for better business growth:

Corporates can make a commitment and finance the sourcing of sustainably produced agricultural and food produce and provide support for the cost of certifications (like Rainforest alliance, fairtrade certification etc.). This can help them improve business growth by providing a competitive edge, enhancing brand reputation, and improving market access while also reducing GHG emissions.

Example: Under its *Cocoa Life* programme Mondelez International in partnership with Global Forest Watch, tracks deforestation across the six cocoa-growing regions in LMICs. This programme is backed by the Payment of Ecosystem Services to Farmers Act.

7.3 CORPORATE ENGAGEMENT MODEL WITH TECHNOLOGY PROVIDERS

- *Direct engagement with the technology provider*

Figure 12: Engagement model 1: Direct engagement with the technology provider

Role	• Bear the entire cost of the technology • Undertake CDP/ SBTi reporting	• Supplies technology • Monitor the change in GHG emission	• Implement pilot • Track & report the outcome	• Use product/ services as guided
Players	Corporates	Technology Provider	Suppliers	Farmers
Advantage	• Reduced GHG emissions • Positives gain towards net zero declarations	• Scaling of the technology • Increase in revenue	• Assured buyback from the corporate	• Reduction in cost of production due to reduced input usage
	Facilitates (Corporates → Technology Provider)	*Provides technologies (Product Services)* (Technology Provider → Suppliers)	*Advise farmer for implementation of the pilot* (Suppliers → Farmers)	

- *Corporate directs while supplier drives the engagement with the technology provider*

Under this model suppliers incur cost of the technology and manage the entire implementation process to meet the sustainable sourcing norms mandated by the corporate. The disadvantage of this model is the high operational cost for the supplier unless the corporate pays a high procurement price.

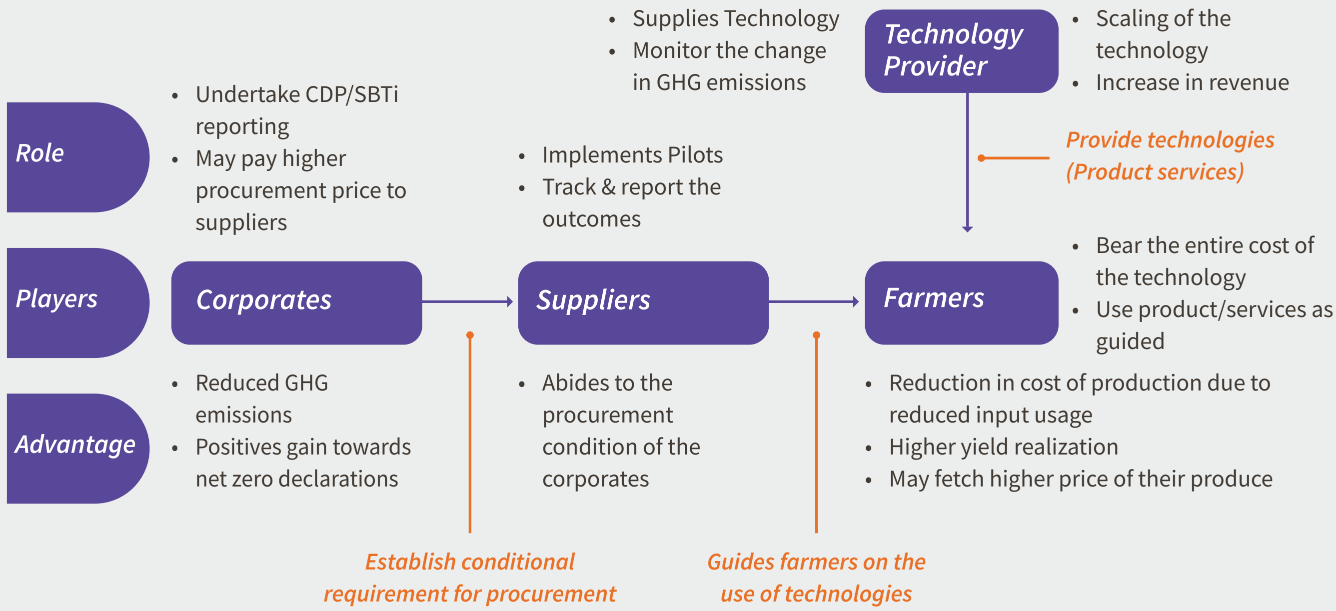
Figure 13: Engagement model 2: Corporate directs while supplier drives the engagement with the technology provider

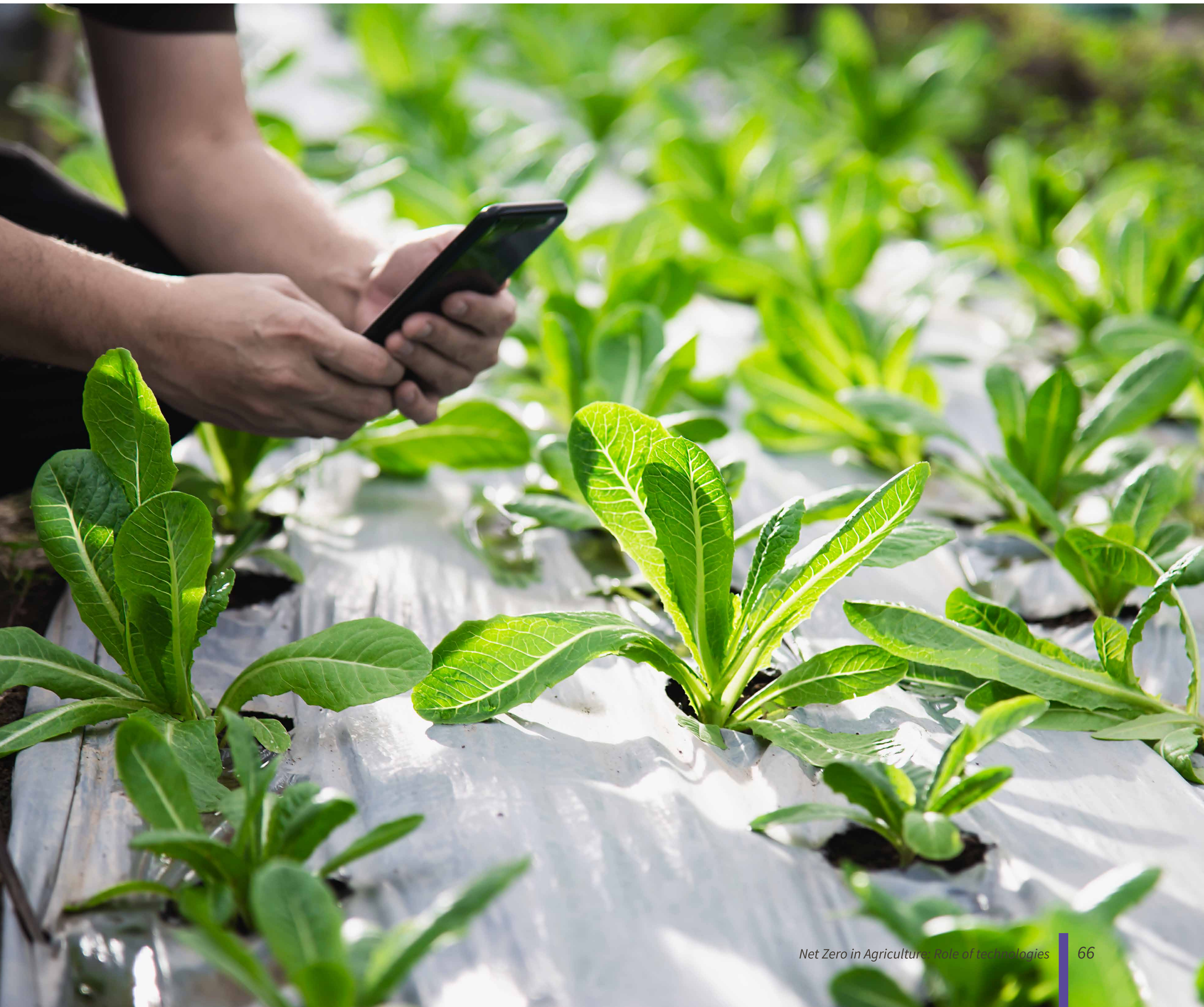
Role	• Undertake CDP/ SBTi reporting • May pay higher procurement price to suppliers	• Bear the entire cost of the technology • Implements pilot • Track & report the outcome	• Supplies technology • Monitor the change in GHG emission	• Use product/ services as guided
Players	Corporates	Suppliers	Technology Provider	Farmers
Advantage	• Reduced GHG emissions • Positives gain towards net zero declarations	• Abides to the procure-ment condition of the corporate • May fetch higher price of the supply	• Scaling of the technology • Increase in revenue	• Reduction in cost of production due to reduced input usage
	Establish conditional requirement for procurement (Corporates → Suppliers)	*Direct Engagement* (Suppliers → Technology Provider)	*Provides technologies (Product Services)* (Technology Provider → Farmers)	

- *Direct engagement of the technology provider with the farmers, facilitated by corporates*

Under this model, the role of the corporate is to the technology provider demonstrate the effectiveness of the technology through an initial pilot, after which the technology provider directly engages with the farmers for further use. Corporations can assist farmers in obtaining certificates for their produce and offer to pay above-market prices for sustainable produce. Additionally, corporations can provide financial support to farmers through Payment for Ecosystem Services (PES), which can help cover the cost of implementing new technologies.

Figure 14: Engagement model 3: Direct engagement of the technology provider with the farmers, facilitated by the corporates





8

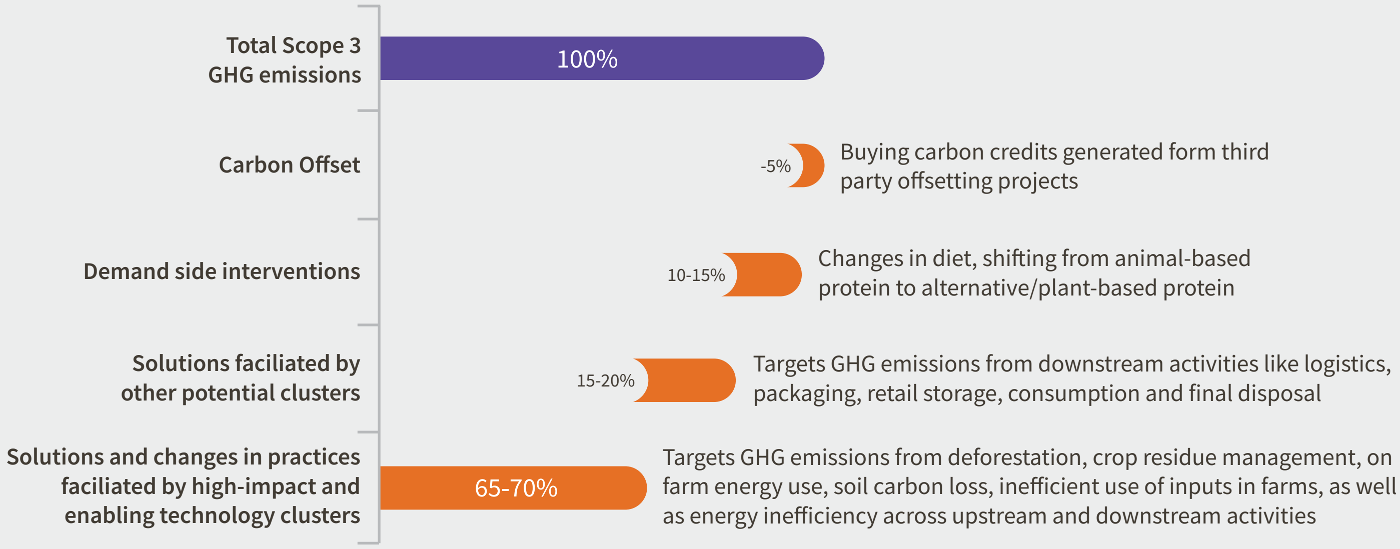
CONCLUSION

The agricultural sector has the potential to significantly reduce GHG emissions especially by leveraging digital and non-digital technologies.

As per the IPCC's sixth assessment report, the agriculture and food system sector have a likely mitigation potential of 9 to 14 $GtCO_2$ eq yr-1 between 2020 and 2050.[108] Thirty to fifty percent of this can be achieved under USD 20 tCO_2-eq. Reducing GHG emissions due to deforestation has the largest mitigation potential with a mean of 7.3 $GtCO_2$eq/yr; whereas farm soil carbon management, agroforestry, the use of biochar, improved rice cultivation, and livestock and nutrient management, have the second largest mitigation potential. The SBTi Forest, Land, and Agriculture Sector Guidelines (FLAG) also represents a cumulative mitigation potential of 13.9 $GtCO_2$eq/yr in 2050.[109]

The five high-impact clusters and two enabling clusters identified in this study have the potential to impact 65–70% of the total GHG emissions from agricultural supply chains. Other potential technology clusters identified in this study have the potential to affect 15-20% of the remaining 30–35%. Remaining GHG emissions can be mitigated through demand-side measures like encouraging people to change their dietary habits such as replacing animal-based proteins with plant-based or alternative proteins. This approach to reducing GHG emissions is summarized in the following schematic:

Figure 15: Pathway to net-zero facilitated by the use of digital and non-digital technologies



Nevertheless, there are significant challenges to the implementation of these technologies. These challenges are related to 3Cs: cost, complexity, and capability, which become even more critical in the context of low and middle-income countries and smallholder farmers. Innovative solutions and pre-competitive collaboration across multiple fronts such as GHG emission mapping, supplier engagement, innovative financing, capacity building of producers, and designing sectoral pathways, can help address these challenges and accelerate climate action.

Furthermore, if these technology clusters are scaled through collaborative action, they will not only improve the agricultural sector's environmental footprint, but also help build climate resilience and enhance the quality of life for millions of smallholder farmers in low-and-middle income countries.

108 OPCC, AR6 Working group III report.
109 SBTi, FLAG

9

ANNEXURES

9.1 DETAILED METHODOLOGY AND APPROACH OF THE STUDY

Objective of the study:

- **Objectives and Scope of the Study:**

The key objectives of this study are to identify clusters of relevant digital and non-digital technologies which can play a role in facilitating the transition of agricultural corporates to Net-zero emissions.

- **Approach followed:**

The key activities undertaken to identify the high-impact technology clusters are mentioned below-

No.	Activity	Description
1	**Understood corporates commitments to net-zero**	Mapped carbon emissions across upstream and downstream supply chain activities for agri and food system corporates and identified key carbon emission concentration points. Mapped the applicability of carbon emission concentration points to specific value chains selected for this study, i.e., Palm Oil, Cocoa, Tea, Coffee, Cotton, Spices, F&V, Livestock, and Aquaculture. Evaluated how the identified emission concentration points applied to these value chains.
2	**Created a non-exhaustive list of digital and non-digital agriculture technologies effective in reducing GHG emissions**	Studied the landscape of existing technologies and grouped them based on their applicability to supply chains, value chains, and geographies. To develop a non-exhaustive list of technologies, the team relied on: i. Aavishkaar group's and Intellecap's network and experience, deal databases. ii. Global climate technology promoters and databases of global capital providers, accelerators, and incubators.
3	**Mapped the information in the analytical framework for high level clustering of the technologies**	Mapped all the information gathered through secondary research in an analytical framework for further analysis. After capturing the technology details against each GHG emission activity of the agricultural corporate supply chain, we grouped different technologies into clusters.
4	**Developed a shortlist of key informants for primary interviews**	Key technology solution providers, agriculture corporates, government agencies, capital provider, and ecosystem builders were identified for primary interviews.
5	**Developed draft research tools**	Developed assessment frameworks, interview questionnaires, and data collection and analysis templates for analyzing the information gathered.
6	**Analyzed potential/ high level clusters to identify the final high-impact clusters**	Using the frameworks developed, the team assessed the potential technology clusters and finally identified 5 high-impact technology clusters and two enabling clusters.

The process to identify high-impact technology clusters started with mapping the agri food supply chain to understand the GHG emission hotspots across upstream and downstream activities of the supply chain. This was followed by detailed exploration and listing of digital and non-digital technologies that mitigate GHG emissions across the identified hotspots.

Figure 16: Approach used to identify the high-level technology clusters

- *Mapped agri-food supply chain to list upstream and downstream activities.*
- *Identified GHG emission concentration points across each activity of the supply.*
- *Understood each concentration point's share in total GHG emissions across the AFOLU sector.*
- *Explored digital and non-digital solutions that mitigate GHG emissions across each of the concentration points identified.*
- *Conducted research to discover existing digital and non-digital technologies.*
- *Developed a non-exhaustive list of technology providers and understood the key technologies behind the solutions as well as their GHG emission mitigation.*
- *Grouped similar technologies into a technology cluster.*
- *Organized 13 high level clusters in to six broader themes for further analysis.*

**AFOLU- Agriculture, Forestry, and Other Land Use*

The team developed a detailed list of more than 110 technologies. Next, similar technologies were grouped into a cluster. The team adopted a three- tier approach to select 11 potential/ high-level technology clusters and 2 enabling clusters. This process included input from more than 40 stakeholders/ key informants who represented solution providers, corporates, and ecosystem players, among others.

The Final high-level technology clustering was done based on a combination of the key solution offered by the technology, fitment to the supply chain and its GHG emission mitigation pathway as shown below-

Evaluated multiple options for clustering technologies →
- *Core technology based*
- *Technology use case based*
- *Supply chain based*
- *GHG emission point based*

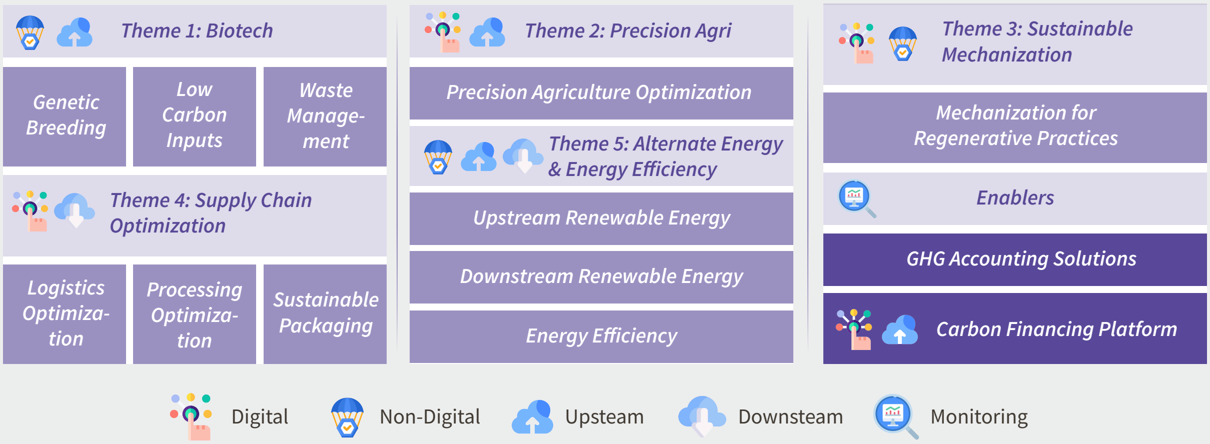
Referred to existing reports and research papers →
- *Referred to reports by specific solution providers and consulting firms.*
- *Referred to multiple research studies by CGIAR, OECD, ADB, World Bank etc.*

Expert validation
- *Discussed the approach with climate experts and advisors and incorporated thier feedback in the methodology.*

Figure 17: Criteria used for clustering technologies.

Cluster Name	*Solution Offered*	*Supply Chain Fitment*	*GHG Emission Mitigation Pathway*
Data-driven advisory and automation to optimize input use	*Advisory and recommen-dations on the use of fertilizers, water and/or agro-chemicals*	*Farm gate at crop cultivation stage* *Accounts ~9% of total GHG emissions from AFOLU*	*Reduction in the overuse of fertilizers/ agro- chemicals/water*

Based on secondary research and key informant interviews, 11 high-level clusters across 5 themes and two theme-agnostic clusters are identified.



Further, to identify the high-impact technology clusters a detailed assessment was undertaken.

Process followed to identify high-impact technology clusters-

Step 1- The team eliminated technology clusters contributing less than 5% to abating / facilitating the mitigation of GHG emissions from the identified concentration points identified. As a result, processing optimization and sustainable packaging clusters were disqualified for the study, leaving 9 clusters for further assessment.

Step 2: Assessment of filtered technology clusters using Assessment Framework.

In this step we assessed technical efficiency and feasibility for each of the 9 identified clusters.

- The assessment framework was designed as a two-by-two matrix- a combination of two specific aspects i.e., technology efficiency and feasibility.

- The parameters under technology efficiency were related to the cost, efficiency, effectiveness, and maturity of the technology, while the parameters under feasibility examined the feasibility of implementing identified technologies in LMICs.

- Each parameter was classified as high, medium, and low according to their level of importance, which was determined based on certain identified criteria.

- Each technology cluster was evaluated through both assessment matrixes and mapped accordingly to the final assessment framework.

- *Technology efficiency framework*

Weightage of criteria			*Parameters*	*Technology efficiency criteria related to technology*		
H	M	L		High	Medium	Low
30	15	7.5	Potential for GHG reduction	High reduction potential (>30%)	Medium reduction potential (10-30%)	Low reduction potential (<10%)
20	10	5	Cost efficiency (Marginal abatement cost curve)	Commercialized technologies, easy to scale	Patented technologies, with limited usage having potential to scale	Initial stages (theoretical, prototype)
30	15	7.5	Level of Maturity of technologies within cluster	Low investment required in relation to efficiency in reducing emissions	Relatively high investment required in relation to efficiency in reducing emissions	Very high investment required in relation to efficiency in reducing emissions
20	10	5	Potential socio-economic impact	Enhance farmers/ value chain actors' income significantly. Reduce drudgery of farm labour specifically women Reduce wastage across supply chain	Enhance income marginally. (By saving in cost of cultivation) No significant impact on wastage and drudgery reduction	Business as usual

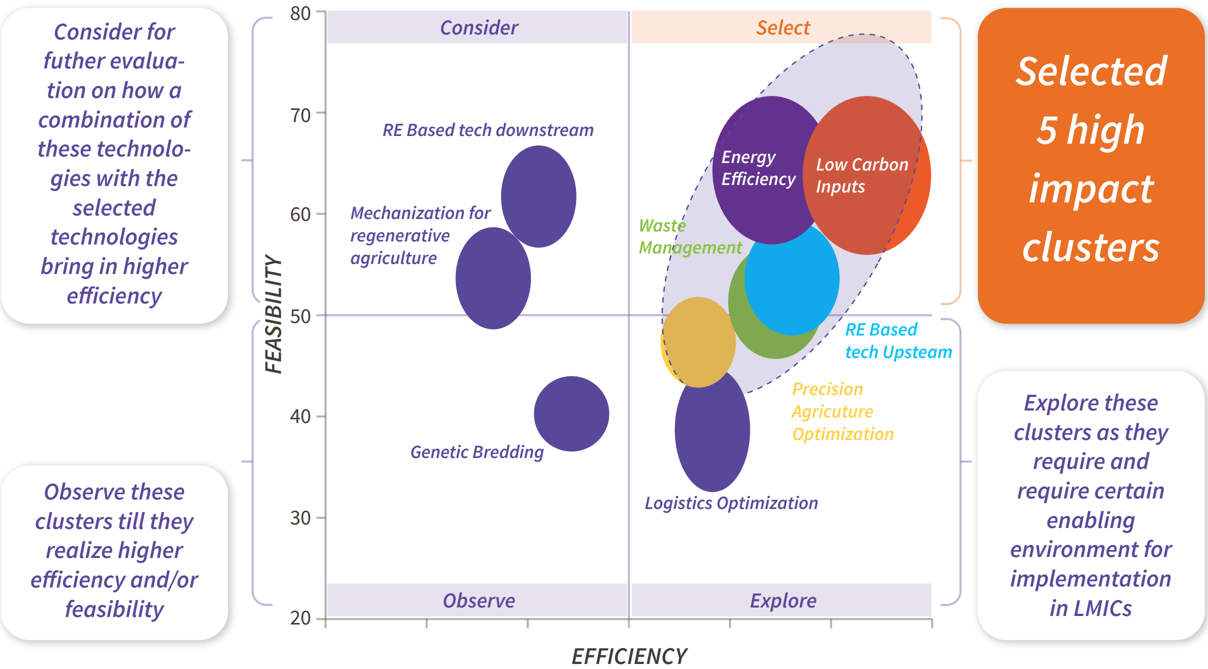
- *Feasibility assessment framework*

Weightage of criteria			Parameters	Feasibility Criteria		
H	M	L		High	Medium	Low
30	15	7.5	Feasibility for LMICs	Compatible with existing infrastructure	Some basic infrastructure required like electricity, mobile networks	High infra or new setting required like 5G network or high-speed internet
30	15	7.5	Affordability for farmers/ end users	Initial capital required is low and is bearable by the farmers	Medium investment required compared to cost of change of entire process	Significantly higher initial investment required which may prove a deterrence
20	10	5	Capacity required for implementing the technology	Existing capacities, due to similar experience in using other technologies	Some capacity building/ skill development required	Complete new set of training/ capacity building program required
20	10	5	Ease of implementation	Easy to implement and maintain the technology offered, by the farmers/ value chain actors	Implementation requires intermediaries support for technology intervention/ maintenance	Larger support form ecosystem

Final Scoring- each of the 11 potential clusters are given weightage on technology & feasibility assessment parameters. The final scores are added for both technology efficiency and feasibility assessment. The addition of both these scores are plotted on a 2 X 2 matrix as shown below. The five clusters having advantage in both technical efficiency and feasibility assessment are considered as high-impact technology clusters.

The top five high scored clusters are selected, while others are put under explore, consider, and observe category. This means the remaining technology clusters require a certain push from ecosystem players to become high impact clusters.

Mapping the final clusters in 2 X2 matrixes to select the top clusters.



9.2 KEY DEFINITIONS

Technology-related definitions

- ***Climate smart agricultural technologies (Technologies):*** Technologies in the form of products or services that have the potential to help address the adverse effect of climate change, through mitigation, adaptation, and resilience and optimize food systems. For example, bio-modified and genetically engineered inputs, sensors, devices, machines, and information technology.[110]

- ***Climate smart agricultural solutions (Solutions):*** Solutions that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals[111], such as soil management, crop management, water management, livestock management, forestry, fisheries and aquaculture, and energy management.[112] Solutions are the outcomes/result out of using technologies and have the potential to contribute towards reducing GHG emissions or lead to sustainable agriculture practices, such as waste management at field, crop rotation, and optimum input management (for example: reduction of the use of synthetic fertilizers and pesticides, water, etc).

- ***Digital technologies:*** are data-driven industry 4.0 technologies for automation, advanced data management & analysis, connecting systems and processes. It includes internet of Things (IoT), Cloud computing, Artificial Intelligence (AI), Machine Learning (ML), cognitive computing etc. These technologies are used develop solutions for providing actionable insights to farmers and other stakeholders for better resource management, increased profitability etc.

- ***Non-digital technologies*** are physical technologies that provide effective solutions in mitigating GHG emissions. For example, solar technology to develop green storage solutions, microbe-based bio solutions to decompose crop residues in the field etc.

- ***Technology clusters:*** Technology clusters are groups of digital and non-digital technologies that have the potential to reduce GHG emission across an agri-corporate's supply chain and can facilitate the transition to net-zero emissions across supply chain.

Agriculture production-related definitions

- ***Supply chain:*** The processes of moving and transforming commodities into products from producers to consumers[113] or farm-to-fork. This involves stages such as storage, processing, logistics, distribution, and retail.

- ***Value chain:*** The sequence of steps and participants involved in the process from production to delivery of a product to market is called a value chain[114]. It builds on the concept of supply chain and is a process in which a company adds value to its raw materials to produce products sold to consumers. For the purpose of this study, we would be focusing on Palm Oil, Cocoa, Tea, Coffee, Cotton, Spices, Fruits and Vegetables, Livestock, and Aquaculture value chain as indicated by IDH.

Net-zero transition related definitions

- ***Net-zero transition:*** Refers to the alteration of production, consumption, and transportation systems so that the net greenhouse gas (GHG) emissions from these activities are as close to zero as possible.

- ***Net positive:*** Net-positive is the approach in which businesses produce benefits for the environment and society which are more than the harm caused by their business processes and operations.

- ***Scope 1 emission:*** GHG emissions produced directly by businesses because of their processes and operations, i.e., emissions produced by their core business.

- ***Scope 2 emissions:*** GHG emissions produced indirectly by businesses, such as their consumption of electricity, heating and fuel used for their premises, etc.

- ***Scope 3 emissions:*** All GHG emissions associated with businesses caused directly and indirectly across the entirety of their supply chain, including procurement from suppliers, transportation to distributors and end-consumers, etc.

- ***Carbon reduction:*** Approaches to prevent the emission of carbon into the atmosphere, such as usage of renewable energy (carbon offsets), reducing usage of fossil-fuel based energy, and waste reduction and management.

110 USDA
111 CSA: Definition
112 CSA: Practices
113 ADB – Supply chain
114 ADB - Value chain

- ***Carbon removal:*** Approaches to remove carbon that has already been emitted into the atmosphere, such as afforestation, carbon sequestration, and direct air capture of carbon.
- Upstream emissions are indirect GHG emissions related to purchased or acquired goods and services.
- Downstream emissions are indirect GHG emissions related to sold 2 goods and services.

Region-specific definition

- ***Low- and Middle-Income Countries (LMICs):*** LMICs are considered to be countries that fall into the low income and lower middle-income groups as categorized by the World Bank in 2022.[115]

9.3 LIST OF STAKEHOLDERS CONSULTED

1. Experts/ Ecosystem players

Table 10: List of experts/ ecosystem respondents connected for undertaking Key Informant Interviews

Sr. No.	Organization	Name of the informant	Designation
1	GIZ, Germany	Dr. Elke Suemnick Matthaei	Agriculture Technology Project Team Lead
2	WE4F, Southeast Asia	Sasmita Patnaik	Technical Assistance facilitator Tetratech
3	IDH, Netherlands	Lisa Van Wageningen	Program Manager, FC&I
4	MercyCorps Agfin, Africa	Victoria Clause	Climate Smart Agriculture Lead
5	Ex-ITC, India	Sanjiv Rangrass	Co-founder TAC
6	Independent Consultant, India	Abhijeet Hazarika	Consultant for Tea and Process Innovation Ex-Head Process Innovation Tata Global Beverages
7	ThinkAg, India	Hemendra Matur	Co-founder
8	Rainmatter Foundation, India	Sameer Sisodia	CEO
9	The Nature Conservancy, US	Saswati Bora	Global Director of Regenerative Food Systems
10	The Nature Conservancy, India	Manoj Singh	Project Head – Crop Residue Manage-ment
11	CLEAN, India	Rekha Krishnan	CEO
12	The India Climate Collaborative	Edel Monteiro	Program Lead
13	DAI, Costa Rica	Alejandro Solis	Principal Climate Technologist
14	Aqua-Spark, Netherland	Flavio Corsin	Director of Partnership
15	IFC, India	Suparna Jain	Lead, Agribusiness

2. Agri and Food system Corporates

Table 11 List of Agri and food system corporate respondents connected for undertaking Key Informant Interviews

Sr. No.	Organization	Value chain(s)	Name of the informant	Designation
1	ITC	Spices, F&V	Madhulika Sharma	VP and Chief Sustainability Officer
2	Nestle	Coffee, Cocoa, Palm Oil, Livestock	Sonakshi Tripathi	Sustainability Manager, India

115 W2orld Bank

Sr. No.	Organization	Value chain(s)	Name of the informant	Designation
3	Unilever	Tea Dairy	Daleram Gulia	Procurement Lead Sustainability - South Asia
4	Labeyrie-fine foods	Aqua	Estelle Brennan	Head of Sustainability
5	DCM Shriram	Sugar	Daleram Gulia	Joint VP
6	Sea Farm Fresh	Aqua	Sonakshi Tripathi	Head Corporate Sustainability

3. Technology Service Providers

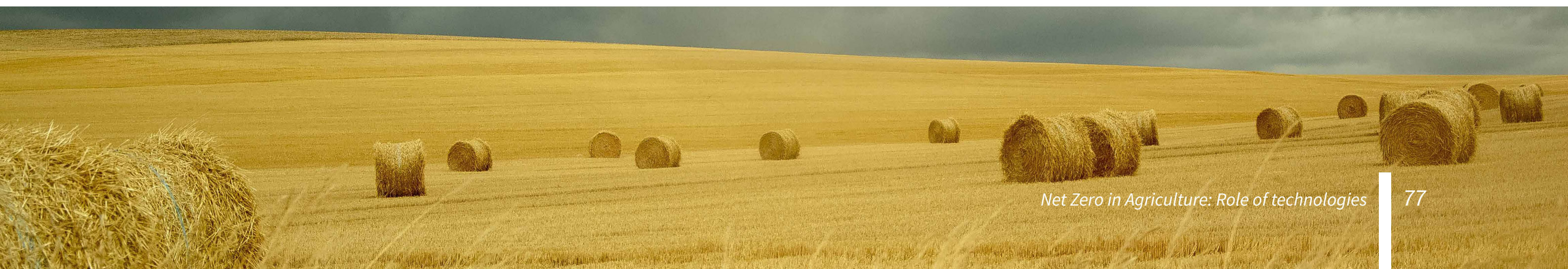
Table 12 List of technology providers connected for undertaking Key Informant Interviews

Sr. No.	Organization	Value chain(s)	Name of the informant	Designation
1	Stellaapps	India	Ranjith Mukundan	CEO & Co-founder
2	Solar Floppy Irrigation Ltd. & Regen360 Ltd.	Kenya	Dr. Chip Stem	Group CEO
3	Boomitra	India, Mexico	Anirudh Keny	Director, Business Development
4	Oorja	India	Amit Saraogi	CEO
5	Rural Farmers Hub	Nigeria	Olusegun Adegun	CEO & Co-founder
6	TraceX	India	Manu Bhardwaj	VP-TraceX Tech
7	Wadhwani Ai	India	JP Tripathi	Associate Director - Agriculture
8	Xpertsea	Canada	Roxanne Nanninga	Chief Sustainability Officer
9	GeoGecko	Uganda	Isaac Nangoli	Director
10	Senseitout	India	Jasveer Singh	Founder and CEO
11	Protix	Netherland	Michel van Spankeren	Business Development Manager
12	Farmsio	India	Surajit Sinha	Director
13	Distinct Horizon	India	Ayush Nigam	Co-founder & CEO
14	Farmforce	Norway	Knut Rand	Head of Product and Development
15	Bharat Rohan	India	Amandeep Panwar	Executive Director & CEO
16	Intech Harness	India	Tarang Patel	Founder and CEO
17	IFFCO Kisan Suvidha	India	Morup Namgail	Head Agritech Development
18	Agronxt	India	Rajat Vardhan	CEO
19	SenseAcre	India	Vinod Kumar Samanthula	Founder & Director
20	Bioprime Agri Solutions	India	Renuka Diwan	CEO
21	Suncuture	Kenya	Hack Stiernblad	Director of Business Development
22	Dvara E-Registry	India	Tarun Katoch	Co-founder
23	Phyfarm	India	Navin Singh	Co-founder
24	Biota	Mexico	Alejandro Soilis	Founder / Lead

9.4 EXAMPLE OF TECHNOLOGY PROVIDERS FOR HIGH IMPACT TECHNOLOGY CLUSTERS AND ENABLING CLUSTERS

Table 13 Example of the technology providers for the proposed technology clusters

Clusters	Example of Technology Providers
Low Carbon Inputs	• Alternative fertiliser: Bioprime India, Crop Biome, Kulabio, Concentric, Nitricity, Pivot Bio, Yara. • Controlled release and stabilized fertilisers: Yara, Philom bios, Koch Agronomic. • Biochar: Farm2 Energy, Shraddha Agrozone, Seedballs Kenya, Carbofex, Pacific biochar. • Low carbon pesticides: Evonik, Loam bio. • Urease Inhibitors – Entobel, Helix, BASF. • Alternative/ low carbon Feed: Agronutris, Protix, Inseco, Agriprotein, Mootral, String Bio, Volta greentech, DSM, Alga bioscience.
Upstream Renewable energy	• Irrigation: Sun Culture, Oorja; Mechanisation: Agri Vijay • Transportation: Tata; Ventilation: E-Fishery
Waste Management	• Farm waste: Agricycle, Biolutions, Craste, Dyrt, Fermentech labs, Fifax, GreenPod Labs, Takachar • Manure management: HoSt, Flexibuster, Homebiogas, Erisha Agritech Private Limited, Fieldking, Atechbio
Energy Efficiency	• Upstream: (Smart irrigation water controller- Intechcharness, senseitout), (Energy saving pumps- Tatva, Xylem), (Route optimization for farm equipment- hello tractor), (Farm level storage of perishables- Fenik cool box, CoolBot), (Small equipment for farm mechanization), energy-efficient fixtures and equipment for animal housing, Material Flow analysis for fish and livestock feeds • Downstream: Energy efficient milk chilling (Prompt), Prometheon technologies, Data-driven energy optimization with IOT technologies combined with a pay-as-you-save business model (Smart Joules, deMITasse Energies)
Waste Management	• Data driven advisory for optimum fertilizer usage optimization- Agronxt, AfSIS, Climavision CropX, Deep Agro, Arable, Continuum AG, Distinct Horizon, Gamya, Garuda, Hortau, Mothive, Teralytic • Data driven advisory for agro-chemical usage optimization- Aerobotics, Agri Intel, Bharatrohan, ceres imaging, Greeneye, Gamya, Semios, Terramera, Algenix, Wadhwani AI, SenseAcre Data driven advisory for efficient water management- Captahydro, Senseitout, LYNKS, Mimosa Tek, Supplant, Yellow Beast, Phyfarm • Livestock: AgriWebb, Mootral, Bovcontrol, Stellapp, Greengage, Zelp, Farmnote, Halter, HerdX, Jaguza farm, Vence • Aquaculture: XpertSea, E-fishery, Aquabyte, jala, Umitron, Ecto, aquaconnect, Manolin, Aquaeasy, Hydroneo, bluegrove, Smart Precision farming, Optoscale, Ace Aquatec, algaeba, Scootscience
GHG Accounting	• Geospatial monitoring: TraceX, Farms.io, TCS, Bharatrohan, Satelligence, Satsure, Earthblanc, Agerpoint • Climate risk mapping: Cervest, Climavision, Cropin, CarbonSpace, GHGSAT • Emission accounting: SourceMap, Farms.io, Sphera, Klimate.co, South pole, TraceX
Carbon Financing Platform	• Carbon project designing and implementation: Pachama, Biota, Varaha, Boomitra, Intellecap Inclimate solutions, ACORN-Rabobank, GoIndigo, Agora, Enking International, VNV advisory etc.



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