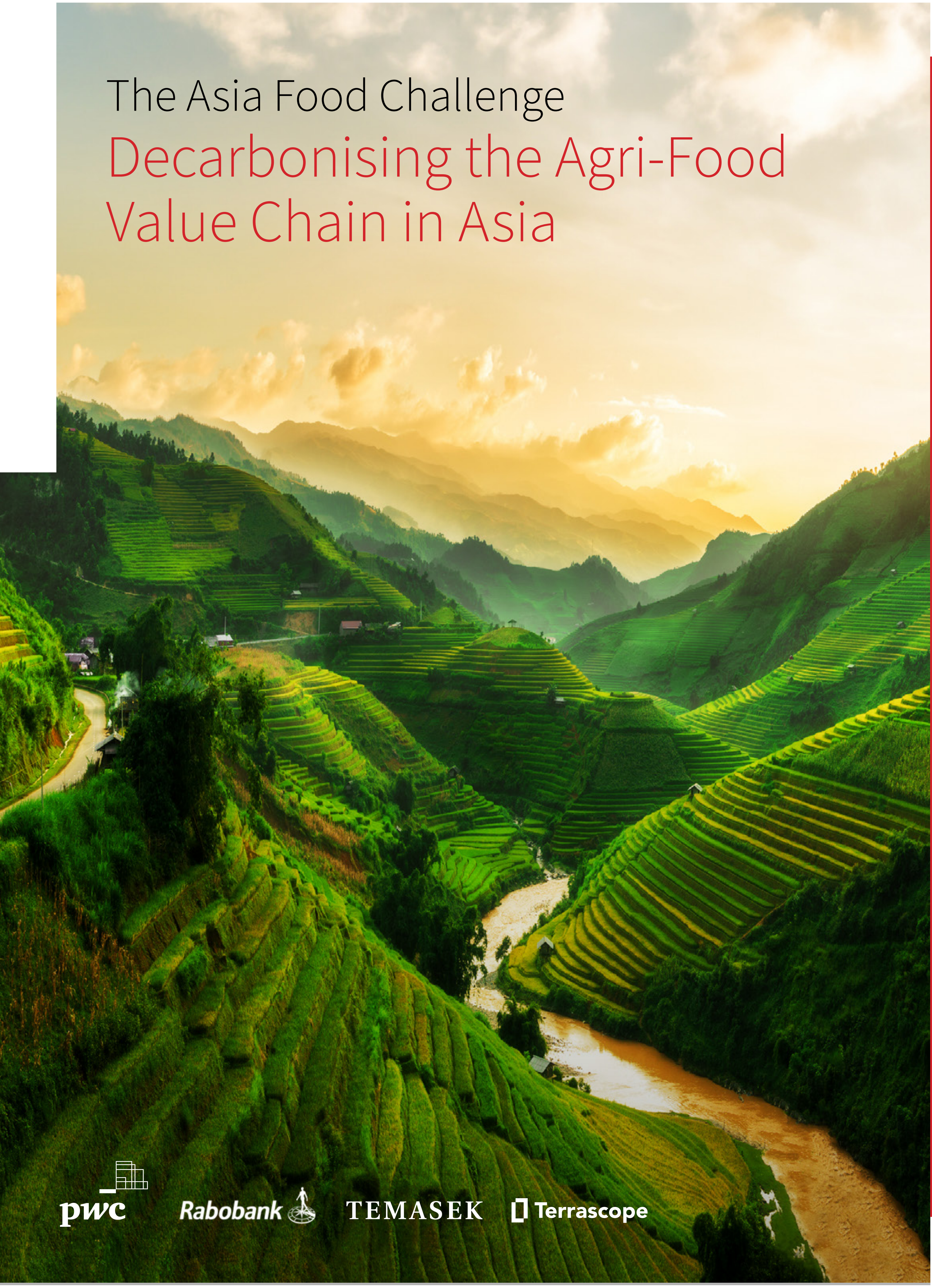
# The Asia Food Challenge

# Decarbonising the Agri-Food Value Chain in Asia



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# Background to the report

In the third edition of The Asia Food Challenge, we seek to highlight the scale of agri-food emissions and the opportunity for action to decarbonise the region, while increasing food production and improving livelihoods.

This report identifies five key sources of emissions along the agri-food value chain in Asia. It also identifies key technologies and practices that can potentially reduce emissions from these sources by 2030, a timeframe chosen to prioritise actions that can be implemented immediately. It makes several recommendations on how such technologies can be applied in the context of Asia, a region where farming systems differ significantly from those in Europe and North America. Uptake of these technologies and practices requires coordinated actions amongst all stakeholders to drive positive change.

This need for action presents both a major challenge but also a significant investment opportunity, given the massive scale of Asia's agri-food sector, as well as the strong demand for new technologies that decarbonisation supports. Many of these technologies also offer the potential for productivity improvements.

To write this report we interviewed 46 leading experts along the agri-food value chain, covering a range of producers, processors, retailers, technology providers and input manufacturers across Asia. This included multiple individuals from large multi-national corporations (MNCs), such as CP Group, Danone, Kellogg, Nestle, PepsiCo, and Thai Wah.

We also analysed emissions data from the United Nations Food and Agriculture Organisation (FAO), reviewed published literature, and modelled the impact of technologies using an assumed current and future penetration, as well as an emissions reduction potential of the technologies and practices.

For this report, we considered Asia as defined by the FAO.[1,2]

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1 This includes Central Asia, East Asia, South Asia, South East Asia and West Asia. In places we refer to 'Industrialised Asia'; this is equivalent to East Asia but excludes the Democratic People's Republic of Korea and Mongolia.

2 Throughout this report we refer to the carbon markets. This reference encompasses both the regulated and voluntary carbon markets unless otherwise specified.

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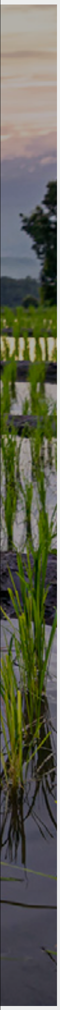


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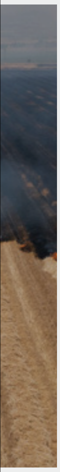

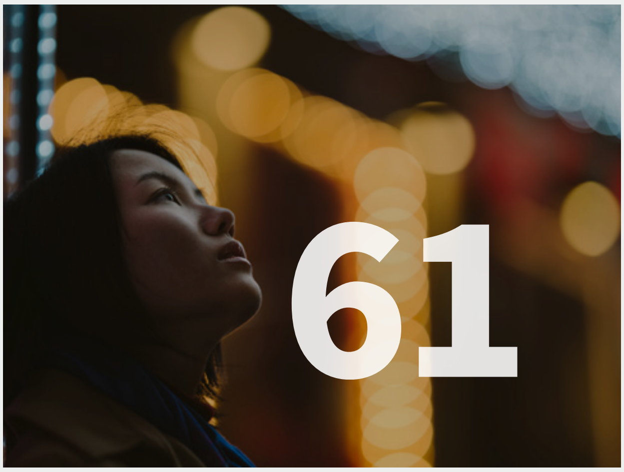
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# Executive summary

## The Asia Food Challenge

Agri-food is a significant source of emissions, accounting for approximately 34% of all carbon dioxide equivalent emissions globally (15.9 Gt $CO_2e$). In Asia, agri-food is around 26% of all emissions (6.7 Gt $CO_2e$), although this statistic varies widely by region. Agri-food emissions are particularly significant in South East and South Asia, accounting for 50% and 45% of all emissions respectively (1.7 Gt $CO_2e$ in South East Asia and 1.8 Gt $CO_2e$ in South Asia). In other regions in Asia, agri-food emissions are a lower proportion of total emissions. This is driven by high emissions in other sectors in these regions, such as industrial manufacturing, energy generation, and construction, but agri-food emissions remain significant in these regions as well. For example, China's agri-food emissions are approximately 2.2 Gt $CO_2e$ or 18% of China's total emissions.

As a whole, agri-food emissions remain significant across Asia - Asia is responsible for approximately

**42%**

**of all agri-food emissions globally.**

Despite the significance of agri-food emissions in Asia, decarbonisation in agri-food currently receives much less consideration than in other sectors, such as energy. The significance of agri-food emissions in Asia means the sector must be a key focus as Asia looks to decarbonise.

Action to reduce emissions from agri-food is possible, and it is possible now. Agri-food is not a sector like energy, which is highly dependent on technological innovation and large-scale infrastructure reinforcement of the power grid. There are many readily available technologies and practices in agri-food that can be applied to significantly reduce emissions.

In this report, we focus on five traditional problem areas in the Asian agri-food sector: rice cultivation, fertiliser use, rearing of ruminant livestock and swine, food loss and waste, and deforestation. Together these problem areas contribute half of all emissions from the Asian agri-food sector.

We have identified more than 20 technologies and practices that are suited to these areas. These include rice varieties suited to less water-intensive cultivation methods, precision agriculture equipment, and digital platforms to support farmers, as well as changes to farming practices, such as Alternate Wetting and Drying (AWD) in rice cultivation.

Importantly, these technologies and practices are readily available and can be implemented ahead of 2030. Carbon emissions have a time value, meaning that emissions reduction today has an outsized impact compared to emissions reduction in the future. Delaying action may lead to runaway warming caused by passing climate tipping points, such as changes to ocean circulation, ice loss and permafrost loss.

We have not considered longer term, 'Next Generation' technologies that are less likely to have a significant impact ahead of 2030, nor have we considered changing energy systems due to the challenges this presents to individual organisations looking to act quickly. We have instead selected technologies and practices that are either ready for implementation or have addressable social (e.g. regulatory) or financial barriers to use today, where our conversations and research have indicated these are a high priority ahead of 2030.

# The Decarbonisation Matrix

*Illustrative & non-exhaustive – intended to highlight various technologies and practices*

Key
- ■ Low Technology Readiness Level
- □ High financial or social barriers exist ahead of 2030
- ★ Technology considered
- ● High existing penetration
- ▲ Enabler considered as part of other technologies / practices

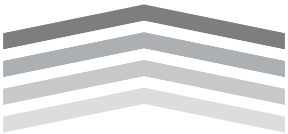
**Carbon Return on Investment (CROI)**

$ spend per tonne of carbon removed / avoided

High

## Next Generation Solutions

*The carbon return on investment of Next Generation Solutions depends on their cost at the time of implementation, some will have a high carbon return on investment. Cost of technology typically comes down over time with scale and maturity.*



- ■ Animal cell cultured food
- ■ Autonomous farm vehicles
- ■ Biological manufacturing
- ■ Biologicals
- ■ Blockchain in supply chain
- ■ Future genetic improvements
- ■ Green ammonia
- ■ Other novel foods
- ■ Predictive informatics (AI)*
- ■ Robotics
- ■ Smart supply chain infrastructure
- ■ Waste nitrogen salvation

* AI is being used in some applications today, such as in some digital smallholder engagement platforms

## What are we waiting for?

- ★ Artificial selection
- ● Basic farm machinery and infrastructure
- ★ Crop residue management
- ★ Improved farming practices (e.g. Alternate Wetting and Drying, Direct Seeded Rice)
- ★ Improved irrigation
- ★ Improved fertiliser efficiency
- ★ Improved packaging
- ● Low-mid tech. barns
- ● Net houses and low tech greenhouses
- ★ Precision application of farming inputs
- ▲ Digital smallholder engagement platforms
- ★ Supply chain management
- ★ Supply chain traceability
- ▲ Sustainable certification
- ▲ Training software

## Address the barriers to uptake

*We have considered some technologies that currently have social or financial barriers to use, but that our conversations in the market indicate have high potential ahead of 2030 if the barrier can be addressed (e.g. financial or regulatory).*

- □ Agroforestry
- ★ Anaerobic digestors
- □ Blended land uses
- □ Connected maintenance (e.g. telematics)
- □ Drones
- ★ Emissions-reducing animal feed additives
- □ Genetically modified organisms
- □ High tech. barns
- □ High tech. greenhouses
- □ Crop diversification and change to local crops
- □ Improved processing equipment
- □ Mid tech. greenhouses and seed nurseries
- ★ Nitrification inhibitors
- □ Plant-based alternative foods
- □ Returnable packaging
- ★ Supply chain infrastructure (e.g. cold chain, storage)
- ★ Valorisation of food loss and waste
- □ Vertical farms

Low

Low

**Time Value of Carbon**

Relative scale

High

**The lower the unit cost of removing or avoiding a tonne of carbon dioxide emissions, the higher the CROI**

- Factor in costs, potential savings and additional revenue streams from decarbonisation
- When considering the unit cost, use the life cycle $CO_2e$ emissions incurred in the implementation and usage, and avoided, reduced or removed by the technology or practice, as well as the life cycle cost

**Can it be done now? When will the decarbonization impact materialise?**

- It is critical to deliver immediate impact as we approach climate tipping points - a tonne of carbon avoided, reduced or removed today is more valuable than a tonne in the future
- Assign higher time value to levers that are ready for widespread adoption given their technological maturity and commerciality
- Differentiate between constraints due to physics, chemistry and input costs vs. constraints that are a human construct (e.g., regulatory hurdles, financing arrangements and public sentiment)

Large MNCs can start to prioritise actions that are relevant to their operations. The first step is to measure their emissions across the value chain and prioritise 'hot spots' to act on. They can then assess which technologies and practices are optimal for their operations as part of a cost-out programme, as many of these technologies and practices also reduce costs or improve profitability. For example, organisations are able to reduce their fertiliser spend by tracking its usage better or using methods to reduce leaching (such as bioplastic coating), and they are able to create additional revenue streams from side-streams that would otherwise be wasted.

If these technologies and practices are applied at the rate we forecast is possible there is the potential to reduce carbon dioxide equivalent emissions in the Asian agri-food sector by approximately

**12% by 2030**

**– a reduction of nearly 840 Mt $CO_2e$ emissions.** This is equivalent to the emissions from the entire global aviation industry in 2022.

The cost of action in agri-food would be significantly lower than completely decarbonising global aviation, or the equivalent impact on the energy sector. Achieving net zero in global aviation is only estimated to be achievable by 2050 with investment of over US$5 trillion[3], while funding the energy transition in Asia in-line with the target of limiting the average global temperature rise to 1.5 degrees Celsius is estimated to require US$5.7 trillion of investment by 2030.[4] The lower cost of acting on emissions from agri-food is in large part due to the relatively low capital expenditure of the solutions (many are simple practices rather than large infrastructure or machinery investments) and the high technology readiness level of the solutions.

Additional revenue streams may be available from the carbon markets, based on the price of carbon. Any assumptions on revenue from the regulated carbon markets require a degree of regulatory change to apply them to agri-food across Asia, and to increase the validity of credits and offsets. In agri-food, this source of revenue could be between US$2 billion – the potential revenue from the voluntary carbon markets, using an optimistic assumption of US$10 per tonne and 20% penetration of the 840 Mt $CO_2e$ emissions reduction – and US$59 billion – assuming regulated carbon markets encompass the agri-food sector in Asia (facilitated by technology and alignment of emissions measurements), with a carbon price of US$70 per tonne.[5]

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[3] Mission Possible Partnership / World Economic Forum

[4,5] Asian Development Bank

## Emissions in Asian agri-food

There are multiple geographical, environmental, social, and political reasons for such a high proportion of emissions from agri-food. These reasons include the high number of smallholder farmers, which can be less efficient than large, mechanised farms; the importance of rice in Asia; and the focus of historical investment into technologies and machinery designed for Western mega-farms, that may not be applicable to the Asian agri-food sector.

There is a growing focus on decarbonising agri-food globally. The benefits of regenerative farming practices (such as no-till farming and reduced fertiliser overuse) are increasingly well known, not just in terms of emissions reduction, but also improvements to the yield of the farm and cost-savings (for example lower spend on fertiliser).

The benefits of these practices, combined with technological innovations and suitable machinery for use in the Asian agri-food sector offer the potential to significantly reduce emissions. The challenges are therefore how to drive penetration amongst a group of highly fragmented smallholders, and how to increase the availability of alternative revenue streams, such as from carbon markets and targeted incentivisation, to support widespread adoption of less profitable technologies and practices, or those that require a high up-front investment.

Crucially these technologies and practices must work at both the smallholder level and the large farm level; they must improve smallholder livelihoods and be simple to use, particularly in a region that continues to urbanise, which will decrease the availability of labour. The investments needed for smallholders to implement these technologies and practices must be financed and the risk must be reduced through insurance and offtake agreements. This risk will increasingly be an important consideration as climate change threatens agri-food production. Governments must be aware of the increasing food security challenge climate change poses and act now to make their agri-food supply chains resilient and sustainable, which many of these technologies do through improved soil health, less water usage and improved crop resilience.

These actions must be coordinated. Emissions measurements must be standardised, and accurate regional data must be made available to accurately estimate emissions factors. Carbon markets must be regulated and adapted to incentivise the most effective actions. Infrastructure must be developed. Access to smallholders must be improved, particularly for the institutions and regulatory frameworks that can support them.

This is only possible through a roadmap to align the efforts of all stakeholders involved. This may be done at a global, regional or national level but it should be prioritised to incentivise action today, using existing technologies and practices. Emissions reduced today will have an outsized impact in the global mission to limit climate change, compared with emissions reductions in the distant future.

Decarbonisation also presents a significant investment opportunity given the huge scale of the Asian agri-food sector and need for technology implementation, which can also drive large productivity gains. We estimate that applying these technologies and practices across just rice and cattle farms in Asia would require US$125bn of investment in physical farm-level technologies and assets and improve farm-level gross margin by up to 16 ppt.

This is only part of the cost, there is also a need for investment in infrastructure and technology along the supply chain, including storage, processing, cold chain, waste management facilities, and downstream valorisation technologies. Investment is then required in the next generation of technologies, that will help to further decarbonise the Asian agri-food sector beyond 2030. These include technologies such as biological fertilisers, biological stimulants, improved pesticides, genetically modified crops, animal cell cultured meat and green ammonia.

## Upstream emissions are everyone's problem

At least two thirds of emissions in Asia's agri-food value chain occur before the produce has left the farm. These upstream agricultural activities are space and resource-intensive, and typically less efficient than many of the industrial processes further down the value chain, leading to higher emissions.

Historically, the upstream segment of the agri-food value chain has been challenging to invest in. This is partly due to its fragmented nature across many smallholders, which have limited resources to invest.

They also lack security, as they face challenges from pest and weather risks, and they face uncertainty when it comes to realising any returns on investment, for example they may not be guaranteed to sell their produce and they may face issues with land ownership or rights.

Downstream businesses (e.g. processors, traders, consumer products brands, retailers, etc.) have historically focused on their own operations and many have limited visibility over the upstream partners they work with as they procure through intermediaries, such as traders or aggregators. However, many of these large downstream businesses – which are often multinational corporations (MNCs) – have now made public commitments on emissions. This has driven them to measure their emissions, and a significant proportion of these emissions (up to 95%) are Scope 3, particularly in cases where they have taken action to reduce the Scope 1 and 2 emissions in their own operations already.

Measuring and mapping their emissions, and identifying these upstream 'hot spots', allows these large downstream businesses to focus on supporting their upstream partners – to improve their livelihoods and reduce emissions, through more sustainable and efficient farming practices.

Additionally, many MNCs now realise that there is a business case for decarbonisation – reducing emissions often involves using fewer resources, and this process can therefore be part of a cost-out programme if implemented properly.

However, the complexities behind accurately measuring and prioritising emissions reduction technologies and practices mean organisations can struggle to take action, particularly in situations where there is limited government or regulatory incentivisation to do so.

The emergence of digital platforms (often supported by trained people on the ground), such as those of Jiva, Rize and Yara, to access smallholders, means that action on emissions at the upstream level is increasingly possible and it will be a high priority for action in the immediate future. However, the focus on reducing emissions at this stage of the value chain must be balanced with other positive impacts on livelihoods and food production, in accordance with the full spectrum of UN Sustainable Development Goals. Large MNCs we have spoken with acknowledge this and their upstream decarbonisation efforts are often part of a holistic programme to improve farmer livelihoods. Additionally, many technologies and practices that reduce emissions have positive impacts on the yield, revenue and profitability of these farmers.

Consumers can adjust their behaviour to prioritise environmental and emissions concerns when making purchasing decisions.

Surveys (including in our previous report, 'The Asia Food Challenge: Understanding the New Asian Consumer') indicate they would prefer to purchase low emissions food when all else is equal.

However, we have seen limited willingness to pay more to date, outside of a small segment at the premium end of the market. Paying more for low emissions produce would be likely to significantly accelerate action upstream.

Alternative foods have the potential to significantly decarbonise agri-food – today, a plant-based burger emits up to 90% fewer emissions than a beef burger. However, uptake of these alternative foods has stuttered as consumers evaluate their performance against key criteria, including taste, price and healthiness.

The next generation of alternative foods, using new or improved technologies in food, such as precision fermentation, biomass fermentation and novel fat development, are likely to be closer to meeting these criteria. However, this should not delay action on livestock emissions. Decarbonising livestock to the extent possible using available technologies and practices, while recognising the value of these products to livelihoods, economies, and consumers, and creating better alternative foods to meet a proportion of consumer demand in a carbon-efficient way, are not conflicting approaches to agri-food decarbonisation. They should be pursued together, and flexitarian diets, where consumers eat less, higher quality meat, are an increasingly popular dietary choice.

## Overcoming barriers to action

There are significant hurdles to decarbonising Asia's agri-food sector, from aligning actions amongst all stakeholders, to the challenges of providing sufficient and appropriate financing and incentives for smallholders to adopt new technologies, and of scaling the smallholder engagement platforms used to reach them.

One common challenge, particularly for downstream organisations like producers, processors and retailers, is the difficulty of mapping and measuring emissions accurately, as well as the challenge of prioritising the optimal actions for decarbonisation. These organisations should follow a clear, tested process to identify their emissions in the Scope 1, 2 and 3 areas; prioritise actions based on their business needs and the potential impact in their operations; and set out an action plan, which should include ongoing measurements and reporting.

Following this process properly offers the potential to decarbonise a company's operations, while removing cost. Afterall, many of these sources of emissions are cost items, such as fertiliser use, food loss and waste.

Many companies are already starting to implement such processes and direct resources across parts of their supply chain to address carbon dioxide equivalent emissions across all three scopes.

While barriers to action do exist, the impact of climate change on agri-food production and the recent geopolitical stresses on agri-food supply chains have put the decarbonisation of agri-food in Asia in the spotlight to drive resilient regional production. This pressure is likely to increase further as we enter a new El Nino cycle in 2023-24, which will likely stress global food supply further.

| Key barriers to action | Solutions |
|---|---|
| Absence of global and country-level roadmaps to guide and align action and prioritisation for agri-food decarbonisation. | • Development of roadmaps to decarbonise agri-food. At a global level, this can be led by the FAO, and made specific to each country by national governments, supported by inputs from academia and regulatory bodies. |
| Incomplete mapping of Scope 3 emissions by downstream organisations (e.g. processors, traders, consumer products brands), limiting their drive to act. | • Mapping of Scope 3 emissions by large downstream organisations, as the technology to map these emissions becomes more established and accessible.<br>• Standardised methodologies and regional emissions factors implemented and managed by regulatory bodies, supported by inputs from academia |
| Challenges accessing, guiding, financing and supporting smallholders as they undertake changes to the technologies and practices they use. | • Support of smallholders from a collection of large companies along the value chain invested in reducing their Scope 3 emissions, as well as governments. This support can be facilitated through the use of smallholder engagement platforms to provide 360-degree support to smallholders and access to favourable financing and insurance from financial institutions. |
| High investment requirements for some technologies. | • Some functional consolidation amongst smallholder farms in situations that are beneficial to the farmers and the use of agricultural co-operatives and collectives, and equipment rental businesses to pool capital expenditure (capex).<br>• Government support for one-off investment required at a farm level (particularly where there is an additional social benefit, e.g. irrigation that can reduce water usage in water-stressed areas) and downstream support for investments required to secure production resilience.<br>• Smallholder support from large downstream partners, such as producers, processors and retailer. |
| Reduced profitability from some technologies and practices through a higher cost of goods sold (COGS) without equivalent revenue improvements. | • Additional revenue streams to incentivise positive emissions reduction and carbon sequestration behaviours, valued on a basis that accounts for the time carbon is removed from the atmosphere, and at a price level that drives action. Regulated carbon markets in agri-food should be introduced to support this. This can be further supported by new validation technologies and methodologies to maintain the integrity of the carbon markets. |

## The time for action is now

Despite these barriers, there are grounds for optimism that Asia's agri-food industry can realise strong opportunities for rapid, significant decarbonisation, thanks to the availability of technologies and solutions at a high technology readiness level.

# 1

# The Asia Food Challenge and the opportunity for decarbonisation

Asia contributes a significant share of the world's agri-food carbon dioxide equivalent emissions, generating 6.7 Gt $CO_2e$ – or 42% – of the 15.9 Gt $CO_2e$ of global agri-food emissions produced in 2020.

In Asia, 26% (6.7 Gt $CO_2e$) of carbon dioxide equivalent emissions are from agri-food. However, there are regional variations within this statistic. In some regions, other sectors are responsible for high emissions, such as industrial manufacturing, energy generation, and construction. While this reduces agri-food emissions as a proportion of total emissions, emissions from agri-food remain high – for example, China's agri-food emissions are approximately 2.2 Gt $CO_2e$ or 18% of China's total emissions. However, agri-food emissions are particularly significant in South East and South Asia, accounting for 50% and 45% of all emissions respectively (1.7 Gt $CO_2e$ in South East Asia and 1.8 Gt $CO_2e$ in South Asia). Focusing on agri-food is therefore essential in these regions to achieve emissions reduction targets.

We have considered at five traditional emissions problem areas in the Asian agri-food sector:

Rice cultivation

Rearing of ruminant livestock and swine

Fertiliser use

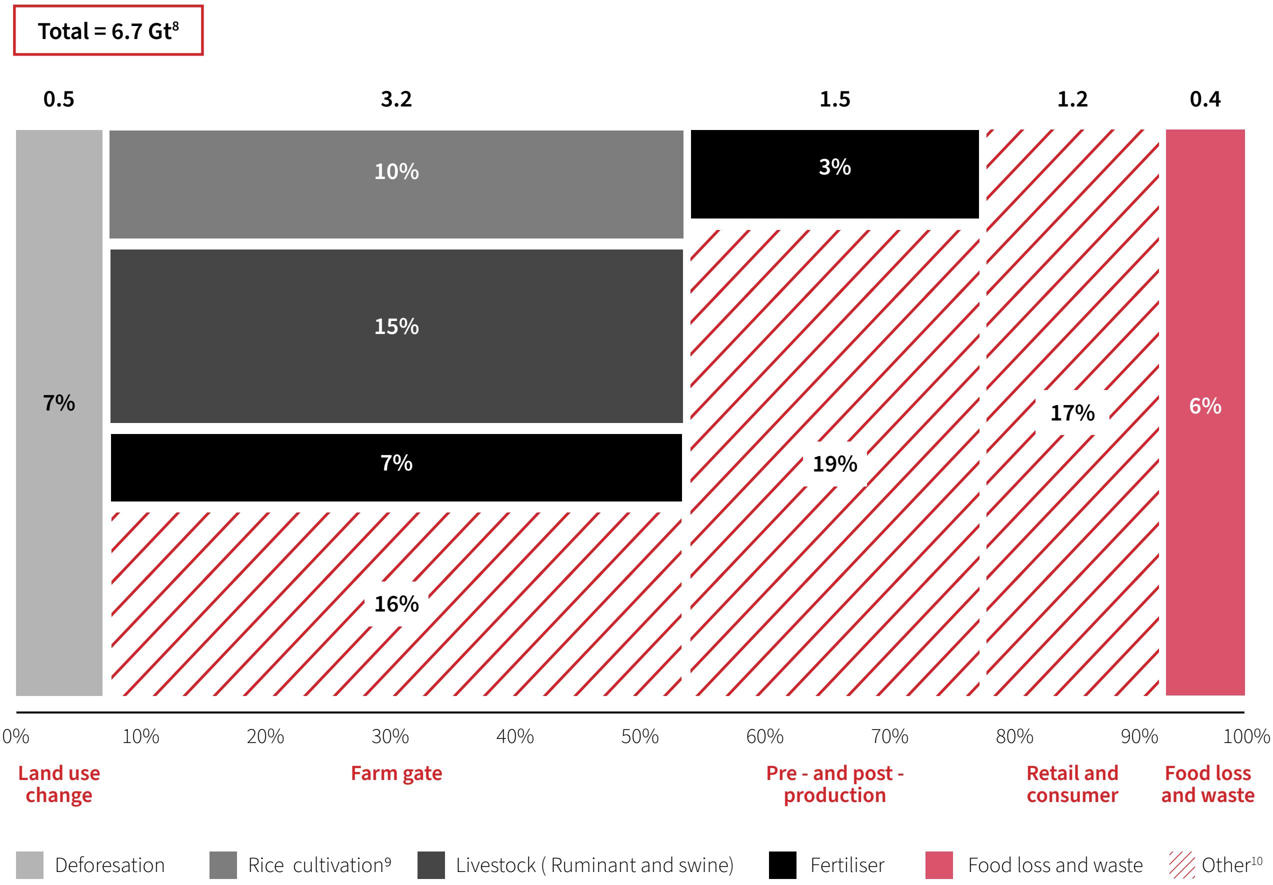
Food loss and waste

Deforestation

Together these problem areas contribute half of all emissions from the Asian agri-food sector.

Carbon dioxide equivalent emissions from agri-food in Asia

Gt $CO_2e$, 2020[6,7]



Source: FAO

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6 $CO_2e$ emissions calculated using a 100 year global warming potential (GWP) under the guidance in the Sixth Assessment Report (AR6) from the Intergovernmental Panel on Climate Change (IPCC)

7 2020 data is the latest available from the FAO

8 Totals of segments do not sum to 6.7 Gt due to rounding

9 Rice cultivation excludes emissions from fertiliser use, deforestation and food loss and waste

10 Other emissions are those not included in the problem areas, such as emissions from downstream operations, agri-food electricity use and wastewater, transport, and crop / livestock management beyond rice, ruminants and swine, other than fertiliser, which is fully included

## Sources of agri-food emissions in Asia compared to global agri-food emissions

Asia emits 43% of the world's carbon dioxide equivalent emissions generated by farming; 15% of the world's emissions caused by land use change (LUC), and 57% of the world's emissions generated by pre-harvest (e.g. fertiliser production) and post-harvest (e.g. food processing) activities. This is despite having only approximately 35% of the world's arable land.

### Farming emissions

Asia's farming emissions are driven by several factors:

- It has a high proportion of smallholder farms, approximately two thirds of the world's 600m smallholder farms are located in Asia. This leads to relatively low on-farm productivity as smallholder farms typically do not have access to as much technology to optimise their farming practices as larger farms do.
- Asia produces nearly 90% of the world's rice. Rice is a significant source of methane emissions, in large part due to the practice of flooding rice paddies. Methane is a particularly potent greenhouse gas (GHG) – it has a global warming potential (GWP) 28 times higher than carbon dioxide over a 100-year period.
- Asia is home to approximately 40% of the world's cattle. The vast majority of these are in India, which rears about a third of the world's cattle. Up to 60% of the cattle farms in India have herds of five cattle or fewer.

### Land use change

Emissions from land use change (e.g. deforestation, peatland drainage) in Asia are notably lower than its share of global agri-food emissions. In fact, land use change represents only 7% of Asia's agri-food emissions, comparable to Europe (4%) and Oceania (6%). Emissions from land use change in Asia have reduced by 60% from 2015 to 2020, driven in large part by positive actions taken within the palm oil industry.

### Pre- and post-harvest emissions

Asia accounts for around 60% of global nitrogen fertiliser usage despite having only 35% of the world's agricultural land. Although nitrogen application is the single most effective tool to increase crop yields, Asia's yields are only two-thirds of the highest wheat yields and half of the highest corn yields globally. This is because the types of fertilisers applied and the application rates (e.g. high quantities of fertiliser in one application, followed by very little ongoing fertiliser application) mean that a high proportion of the applied fertiliser is not available to plants. Instead of being taken up by crops, excess fertiliser enters the water table or breaks down into nitrous oxide.

Many farms in Asia are not efficiently irrigated, using the latest technologies such as micro-irrigation. This increases emissions from the overuse of clean water.

Globally, about a third of the food harvested is not consumed – this is also the case in Asia. Food loss is defined as food lost between the point of harvest and retail, while food waste is food wasted at the retail or consumer level. Food loss is a particular challenge in Asia due to less developed storage, transportation and cold chain infrastructure. However, food loss and waste vary by region within Asia – parts of Asia where food is more scarce have very little waste (although still have high proportions of food loss). Other regions in Asia have high food waste. According to the FAO, Asia accounts for over 50% of the world's total food waste. China is responsible for more than 30% of Asia's food waste, and food-service is a big contributor.

## Lowering emissions through higher productivity

Asia has scope to improve the productivity of its agri- food system. This is important from a decarbonisation perspective; more food produced per hectare or per animal is typically more efficient from an emissions perspective. This is also important from a food security perspective; for every Asian person, there is just 0.4 hectares of agricultural land, compared with 0.6 hectares in the EU, 1.3 hectares in the US and 9.0 hectares in Oceania – productivity must be as high or higher than other regions in order to feed the Asian population efficiently.

Solutions to productivity improvement across the region must differ from those in advanced agricultural markets. In Asia, productivity improvements must be available on a smallholder level – in palm oil, smallholder farms experience a 30% productivity gap with corporate plantations. This spread in productivity between smallholders and their professional peers is a characteristic of most agricultural sectors in Asia.

This means that Asia's farming productivity improvements come down to two high-level solution buckets:

1. Invest in technologies and practices to bridge the gap with global best-in-class benchmarks; and

2. Develop approaches to increase uptake of these technologies and practices at a smallholder level.

## Harnessing digitalisation

Digital technology is key to fixing the smallholder conundrum. Aggregation of smallholders with better and tighter connections across the value chain enables them to access technology to increase productivity, access markets to secure profitability, and access funds to invest in climate risk mitigation and overall sustainability.

Digitalisation also paves the way towards a more demand-driven agricultural production platform. A more demand-focused production system, producing food to meet the demand of consumers within the constraints of agronomy and biology, will also help to reduce food loss and waste, as well as emissions from transport.

## Strong investment potential

Asia is home to the world's largest number of farmers and consumers, yet its economies are transitioning away from agriculture. As the share of agricultural GDP in Asia's total is likely to drop further, labour availability is likely to become an increasing challenge, and a huge market for companies that facilitate the upgrade of Asia's farming sector will emerge, as efficiency and mechanisation becomes essential.

Investments in Asia's farmers are bound to significantly increase the return per hectare of arable land. These returns are currently substantially lower compared to mature agricultural markets such as Northwest Europe, which is the most comparable region in terms of a crop portfolio that is based on food grains and fruit and vegetables. On average, the value of agricultural output per hectare in Asia is about 40% of that in Northwest Europe. However, there are big regional differences across Asia. Agricultural output per hectare is approximately 60% that of Northwest Europe in China, while it is around 40% in South East Asia and 20% in India. There is scope to reduce these regional differences in productivity, and the gap to Northwest Europe, through investment in technologies and infrastructure to create value.

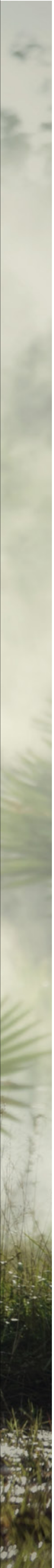
## Looking ahead

For governments, farmers, companies within the food system, and financiers, Asia's food system should be a priority in realising their decarbonisation ambitions.

The agri-food system is a high emitter of GHG in most Asian countries. At the same time, its under-development means that it has ample opportunities to restructure and adapt to the new paradigm of net-zero food production.

Revolutionising Asia's agricultural sector should aim to increase smallholder farmers' income, secure sufficient domestic production, improve the sustainability of farming in general, as well as reduce GHG emissions. Advances in technology, politics, economy and ecology are the drivers that can help bridge the gap between Asia and mature markets. Farmers in Asia must be provided with the ability to invest in technologies that can increase productivity while decreasing their environmental footprint at the same time.

This report aims to provide insights into these opportunities and contribute to the dialogue with all relevant stakeholders.



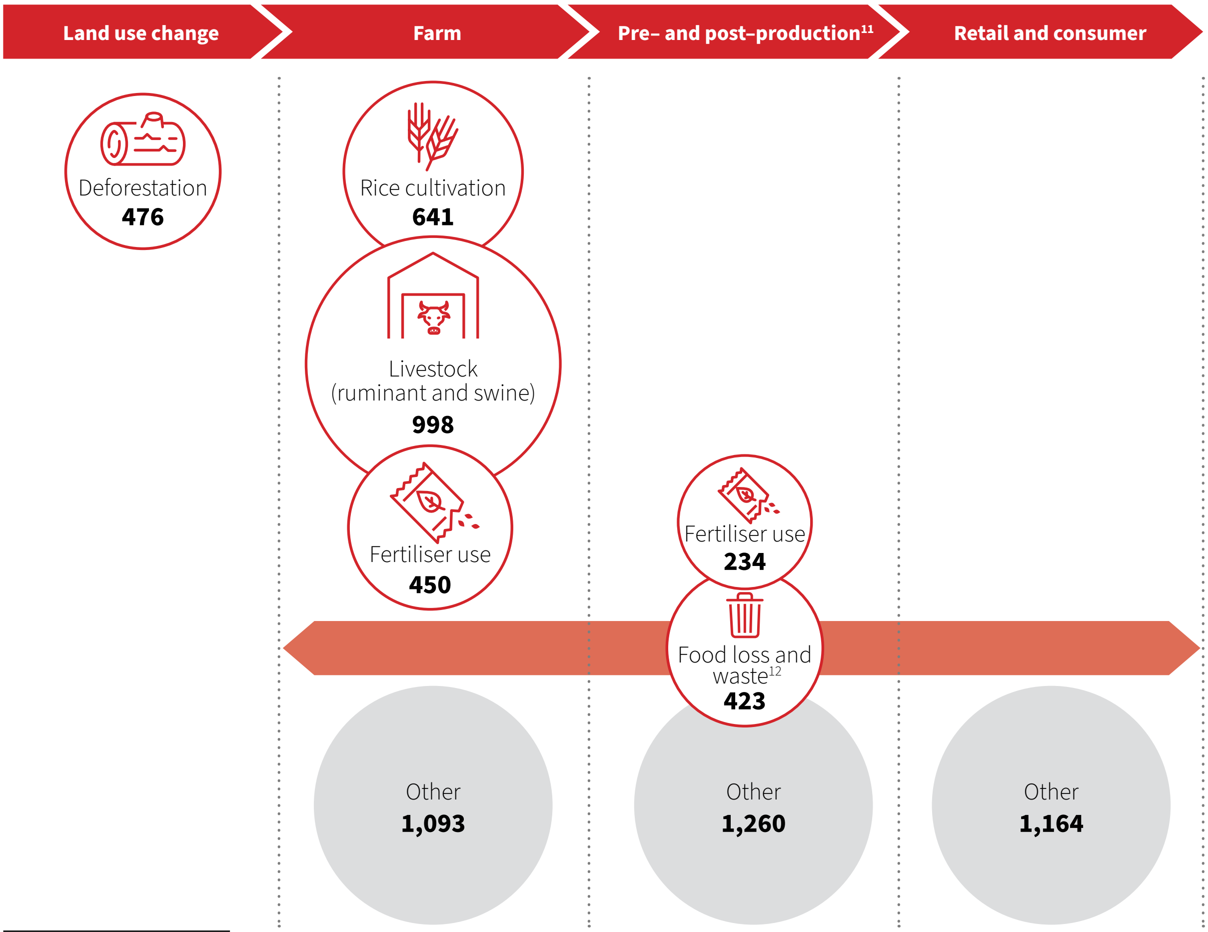
# 2 Upstream emissions in focus

## Upstream emissions

At least two thirds of emissions in Asia's agri-food value chain occur before the produce has left the farm. These upstream agricultural activities are space and resource intensive, and typically less efficient than many of the industrial processes further down the value chain, leading to higher emissions.

Carbon dioxide equivalent emissions from agri-food in Asia along the value chain

Mt $CO_2e$



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[11] Part of the emissions in pre-production occur prior to the farm stage

[12] Food loss occurs from the point at which food is ready for harvest down to the retail stage. Food waste occurs at the 'Retail and consumer' stage

# The agri-food value chain

*Illustrative and non-exhaustive list of activities at each stage of the value chain*

## Upstream

### Inputs

Seeds
Fertiliser
Pesticides
Farm equipment
Livestock feed

### Farming

Growing
Harvesting
Drying
On-site storage
Initial processing on site

### Food loss

Loss from the point at which food is ready for harvest down to the retail stage

### Land use change

Emissions due to land use change – e.g. deforestation, peatland clearance

## Downstream

### Trading & Distribution

Collection
Trading
Distribution

### Processing

Drying
Milling
Grading
Polishing
Dehydrating
Storage

### Production

Production of consumer products

### Wholesaling

Wholesale of processed produce

### Retail

Retail

### Consumption

Consumption

### Food waste

Food wasted at the retail and consumer stage

Source: FAO

Key reasons for these upstream 'hot spots' include the potency of methane and nitrous oxide as greenhouse gases, and the lower efficiency of smallholder farms compared with larger farms.

## Methane and nitrous oxide as greenhouse gases

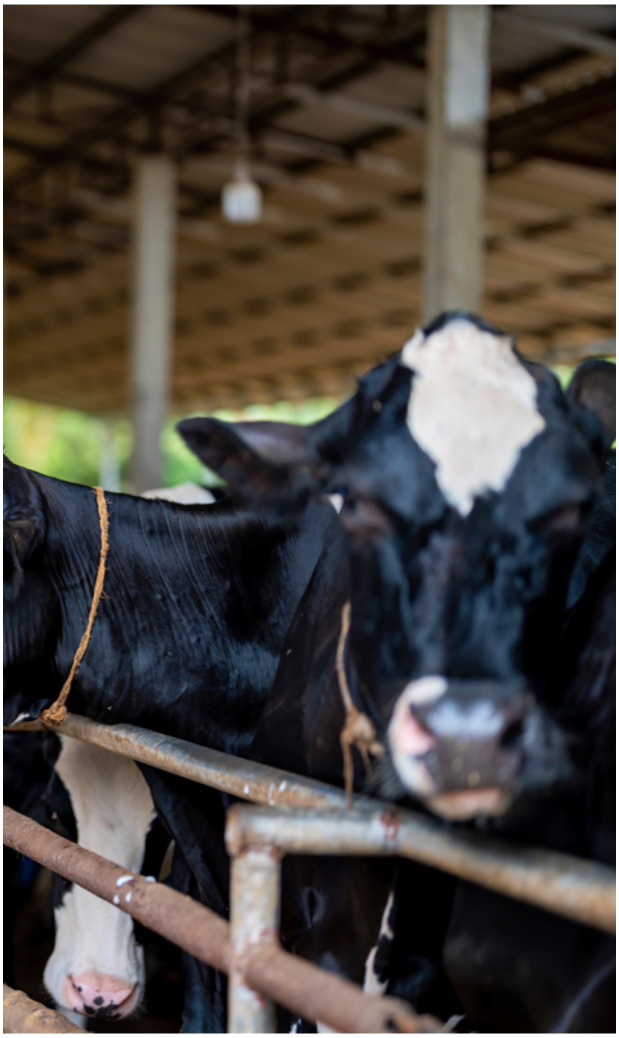
Methane has 28 times the global warming potential (GWP) of carbon dioxide and nitrous oxide has a GWP 273 times greater than carbon dioxide.

The cultivation of rice and rearing of ruminant livestock are significant sources of methane emissions. Flooding rice paddies is the traditional method of rice cultivation in Asia, which allows methane-producing anaerobic bacteria and archaea to thrive. Ruminant livestock have unique digestive physiology compared with other livestock. They ferment hard-to-digest plant material in a rumen or foregut, which allows them to extract nutrients. Digestion is supported by the microbiota in the rumen, some of which produce methane.

Untreated animal effluent and the overapplication of fertiliser are both notable sources of nitrous oxide emissions. Fertiliser overapplication is a particular challenge in Asia, partly in response to degraded soil quality, creating a continuous cycle of soil degradation as fertiliser overapplication can then further contribute to this cycle. Additionally, if fertiliser is overapplied at a point in time, fertiliser run-off, leaching and denitrification means some of the nitrogen applied will not be available for crop uptake, requiring further application at a later date to meet the needs of the crop throughout the growing cycle.

## Efficiency of smallholders compared to large farms

Rice and dairy are largely produced by smallholders in Asia. Smallholders often produce food for their own family's consumption (greater than 70% of the production on a smallholder farm is often for the farmer's household use). These smallholder farms are typically less efficient than large farms as they have less access to machinery, technologies and food storage and transportation infrastructure, which may be expensive and not designed for small farms. They are also less likely to be educated on the best agronomic practices than those farmers operating larger farms. This results in the less efficient use of inputs and lower yields than more efficient farms, as well as higher food loss. Approximately 17% of all food produced in Asia is lost before it leaves the farm, in the process of harvesting or immediately after harvest, due to inadequate storage or supply chains. This compares to approximately 15% globally.



## Upstream actions offer the most readily addressable impact

Acting on these upstream 'hot spots' can potentially yield the greatest positive impact on decarbonising the agri-food value chain. Many of the most readily addressable regenerative practices, technologies to improve yields, and technologies to directly reduce emissions can be applied to these areas (as we highlight in the tables of technologies and practices in Chapter 3).

This is in part due to the increased prevalence of larger, more mature, corporates in the downstream segments of the value chain. These larger corporates are more likely to have taken the equivalent readily addressable actions in their own operations, for several reasons:

- Reducing emissions can be associated with removing cost, e.g. overuse of fertiliser increases emissions and adds cost. Larger corporates are more able to identify and act on cost-out actions that have tangible impact on their profitability.
- Many larger corporates have committed to reducing their emissions, which has led to action on their Scope 1 and 2 emissions already as they are simpler to measure than Scope 3 (although there are also challenges with measuring Scope 1 and 2 emissions).
- Larger corporates have access to reliable financing and insurance that allows them to invest in their operations, including the latest and most efficient technologies, which smaller companies and smallholder farmers can struggle to access.

### Case Study

## Thai Wah

Thai Wah is a plant based ingredients producer with 16 operations across South East Asia, China and India and customers globally. The company works with over 50,000 smallholder farmers across Thailand, Vietnam and Cambodia.

Thai Wah is currently focused on supporting these smallholder farmers through three key areas to reduce its upstream and food loss and waste emissions:

1. **Biofertilisers** - Thai Wah is able to reduce its fertiliser spend by fermenting 500 kt of tapioca waste from its SEA factories, creating a high yield fertiliser, while reducing its emissions from food loss.
2. **Food loss and waste valorisation**[13] - In addition to valorisation through biofertilisers, Thai Wah is able to upcycle its remaining waste into animal feed and biogas, creating additional revenue streams.
3. **Bioplastic mulch film and sustainable farming practices** - Thai Wah is developing bioplastic mulch films to protect soil moisture and avoid degradation, leading to less fertiliser run-off, resulting in cost savings and emissions reduction from fertiliser overuse.

Together, these three technologies can be applied to 50% of the farm area it sources from. They are intended to have positive impacts on the farm level, reducing input costs, while improving Thai Wah's profitability through additional revenue streams from its side streams.

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[13] Valorisation is the process of adding value to the waste

Remaining downstream emissions are now focused on energy, water, transport, refrigerant gases, and food loss and waste. Some of these areas are more challenging to decarbonise – energy in particular is challenging to act upon without grid reinforcement, which is often not easily addressable at the level of the individual company.

## There are supporting factors for upstream action

Downstream value chain participants, such as processors and producers, food and beverage retailers, and hospitality providers, are increasingly focused on achieving their emissions reduction targets, which are often set to a 2030 or 2050 timeline. Many larger downstream corporates have made progress in reducing their Scope 1 and 2 emissions, and are now focusing on Scope 3 emissions, a significant proportion of which are upstream.

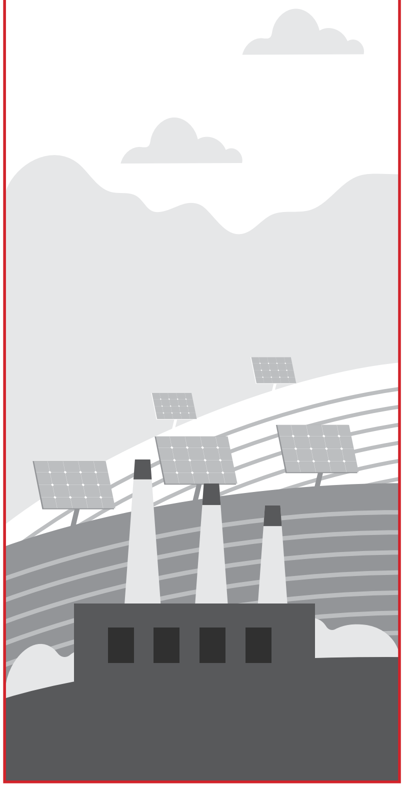
*Examples of emissions given are illustrative and non-exhaustive*

### Scope 1

Emissions are ‘direct emissions’ – those an organisation generates by undertaking its own operations. For example, a retailer may have Scope 1 emissions from transport, warehousing, refrigeration, and other sources; whereas a processor may have Scope 1 emissions from transport, warehousing, waste water, and side streams, amongst other sources of emissions.

### Scope 2

Emissions are ‘indirect emissions’ created during the generation and supply of energy that an organisation uses. However, using energy off-grid from local generation controlled by the organisation would result in energy generation emissions being part of Scope 1.



### Scope 3

Emissions are 'indirect emissions' associated with suppliers to the organisation, and users of the organisation's products – up-stream and down-stream emissions in the value chain. For retailers or processors, these may be emissions from growing the produce they sell or process, such as rice, or emissions from restaurants cooking with their products. For farmers, these may be emissions from producing and delivering the fertiliser they use on their fields, or emissions from processors or retailers using or selling their products.

Quantifying Scope 3 emissions from upstream partners is particularly challenging for several reasons. Emissions factors are often not available at a country or regional level (many are based on EU / US cases), which can be misleading when used in an Asian supply chain. These emissions factors can also lack detail that would allow corporates to make them sufficiently accurate to their own operations. Downstream corporates can also struggle to get access to upstream data when middlemen, such as traders, are involved, who may not have collected the data themselves. Middlemen can also charge an increased price if the buyer wants Scope 3 emissions data collected by offering it as a service.

Most downstream organisations we spoke with are in the process of defining Scope 3 emissions. Some had quantified Scope 3 for parts of their operations that were the most significant to their business, or where they had vertically integrated operations, allowing easy access to data. Some have completed Scope 3 quantification but felt there was more to do as the global emissions factors they were using did not reflect the reality in the countries they were growing in. Few had completed the process to a good degree of accuracy, and some had not yet started.

Quantifying Scope 3 emissions is therefore a recent development, but one that organisations across the agri-food industry acknowledge as essential. Organisations that had quantified their emissions were able to take meaningful actions to meet their emissions reduction targets. These actions typically include a significant focus on supporting their upstream partners' efforts to decarbonise, and they are often well balanced with initiatives to drive positive impacts on farmer livelihoods and food security.

“

About

95%

of our emissions are Scope 3, and we are already taking concrete actions to meet our targets."

*- Olam Agri*

“

A key problem is that **the emissions factors are EU and US based but the reality can be very different in India.** When we first looked at our emissions, we found that this **led to overestimations in some areas.** For example, the soya in India is a quarter of the emissions of elsewhere as it’s not driving any deforestation in India. There is a danger that, **without localised emissions standards and data,** we may spend a lot of time and money solving the wrong problems. **Local emissions factors are key to highly accurate Scope 3 emissions quantification**”

*- Godrej Agrovet Limited*

## Case Study

# PepsiCo

PepsiCo is one of the world's largest food and beverage companies, with customers in over 200 countries and territories around the world. PepsiCo's supply chain is highly complex and involves sourcing from 30 countries and over 1,000 manufacturing facilities, both owned and third party.

PepsiCo has significant ambitions to decarbonise its business and is aiming to achieve net-zero emissions across its supply chain by 2040 - a decade earlier than called for in the Paris Agreement. Within this, it is also looking to reduce Scope 1 and 2 emissions by 75% by 2030, with a 40% reduction in Scope 3 emissions. These ambitions are driven by a number of factors, including the need to mitigate climate change risk to PepsiCo's business and the communities in which it operates, the impact on the quantity and quality of its products, and the broader global need to safeguard the planet for future generations. The tangible impact of climate change on the company's supply chain also accentuates this urgency. PepsiCo also recognises the long-term cost benefits of green energy and adoption of regenerative agriculture, positioning it favourably for future market dynamics.

PepsiCo’s pep+ (PepsiCo Positive) transformative strategy emphasizes its dedication to sustainability, organized around three primary pillars:

### Positive Agriculture

PepsiCo is especially dedicated to scaling sustainable agriculture and regenerative practices. Recognising the critical nature of Scope 3 emissions, PepsiCo is working specifically with farmers with smaller land holdings to promote sustainable farming techniques. Regenerative farming is a primary focus, aiming to improve soil health, manage carbon emissions, and bolster biodiversity. In-market examples of these efforts include AI and drones deployed in Thailand to monitor potato crops and the use of precision tools in China to optimise fertiliser use.

### Positive Value Chain

To minimise its carbon footprint, PepsiCo is prioritising sustainable manufacturing, warehousing, and distribution strategies. This includes a transition to renewable electricity and fuels throughout its supply chain. Examples include the development of biomass boilers at manufacturing sites and the deployment of alternative fuel delivery trucks.

### Positive Choices

PepsiCo is earnestly working to reduce the environmental impact of its packaging. By emphasising the use of recycled materials, the company strives for packaging solutions that are more sustainable and eco-friendly.

Broadening its reach beyond direct operations, PepsiCo has launched its innovative S-LoCT program, providing suppliers with climate-centric skills through an online school. The pep+ Renew initiative steers suppliers towards adoption of renewable electricity, reflecting PepsiCo's ambition to run its operations on 100% renewable energy by 2040. The company has also set up its Sustainability Action Center in 2022 to further support its goals, serving stakeholders with multiple sustainability resources and tools.

While these ambitions are admirable, PepsiCo is fully committed to stay on track to achieve all its sustainability commitments, factoring in an increase in its emissions in 2022, which were mostly driven by business growth and enhanced complexity across its supply chain. Looking ahead, PepsiCo also continues to heavily invest in decarbonisation initiatives, which are bound to result in further significant improvements over the longer term. This includes both direct investments, and more innovative initiatives such as the Pepsico Greenhouse Accelerator Program, providing grants and support to promising startups developing innovative solutions to mitigate climate impact.

# Overcoming barriers to upstream action

The key barrier to decarbonisation progress, after the quantification of Scope 3 emissions, is the challenge in extending regenerative practices and technologies to improve yields, and technologies to directly reduce carbon dioxide equivalent emissions to many smallholder farms. Smallholders represent a significant proportion of Asian agriculture (c. 55% of food production across South Asia, South East Asia and Industrialised Asia).

We have identified two approaches that have a strong chance of success in increasing the use of addressable practices and technologies on smallholder farms between now and 2030.

### 1. Smallholder engagement platforms

Examples of digital platforms to engage smallholders range from a simple database of key agronomic metrics, such as prices and weather, to fully-loaded 360-degree super-apps, typically offering five key features: agronomic advice; insurance; financing; high quality or low cost inputs; and offtake agreements (either directly through the app or through a third party partner). These apps can be commercially independent or they can be linked to a third party, such as a crop aggregator or a farming input producer.

Smallholder engagement platforms allow the farmer to immediately invest in the 'low hanging fruit' of suitable inputs, such as fertiliser and pest control chemicals, as well as agronomic advice to reduce input costs and improve yields.

This investment is often made possible through an offtake scheme, which de-risks the investment from a smallholder perspective as they will not struggle to sell their produce, and a combination of insurance and financing. Offtake schemes can also disintermediate some complex supply chains, resulting in better prices and improved profitability for farmers.

Smallholder engagement platforms can lay the foundation for farmers to access carbon markets, by aggregating the impact and collecting the data to demonstrate reduced emissions and / or carbon sequestration. Access to these carbon markets would otherwise be challenging.

The most successful platforms to date combine a digital app that provides real-time updates on market and environmental conditions, with local human touchpoints. The touchpoints can be from their existing distribution network and supported by specialist agronomists; or they can be local champions, hired and trained to support farmers in their community. Importantly this touchpoint can serve multiple functions, removing the need for financing and insurance partners to have their own touchpoint on the ground.

This blended approach of digital technologies and human touchpoints is key to help scale these platforms. The hope is that this approach can help overcome hurdles such as some farmers' lower technological literacy, as well as their reluctance to risk their livelihoods by trying new things, particularly new approaches based on what they see on their phone alone. However, this does present challenges to scaling these platforms as they are ultimately dependent on growing a network of people.

## 2. Functional consolidation

Large, mechanised farms in the likes of the US and Europe are typically more productive than smallholder farms, with lower emissions per unit of produce. Consolidating smallholder farms where the environmental conditions support a larger farm would likely lead to improved efficiency and profitability, and reduced carbon dioxide equivalent emissions per unit of produce. It would also support the use of more machinery on the farm as economies of scale justify the capex and operational cost, enabling the roll-out of further technologies across the Asian agri-food sector. This may work for certain segments, e.g. the dairy industry in India, in conjunction with the upskilling of the existing farm workers.

However, a substantial proportion of Asian farming is unlikely to consolidate in the foreseeable future, as the Asian agri-food sector is highly fragmented due to many social, political and geographical reasons.

One possible solution is functional consolidation. There are several routes this could take.

Collectives of smallholder farms, such as farm clusters or cooperatives, can be organised via the government or the private sector. These collectives can offer the potential for a wider pool of food producers to realise better prices for their product through collective selling, as well as benefit from the latest technologies in a more cost-effective manner by purchasing equipment together.

Another means of functional consolidation is through equipment rental businesses, which can be conducted either on a small local scale or using a large regional model. These can serve as a cost-effective way of facilitating access for smallholder farmers to technologies that improve yield and profitability, while reducing emissions. For example, a direct seeding drilling machine can be hired for US$40 per use, whereas buying the same machine costs US$7,000. Additionally, these rental businesses can be government-backed, reducing the cost of rental.

Another route to functional consolidation is the operation of groups of farms by large third party farming organisations. This model is common in China, where it is typically overseen by the government. The smallholders retain ownership of the land but allow a large organisation to operate it as part of a larger farm.

Functional consolidation provides access to technologies that may be unaffordable to a single smallholder farm. Access to machinery will potentially become increasingly important in the Asian agri-food sector as economic development drives further urbanisation. As more farmers move to factory and urban jobs, those that remain are typically older. This may lead to increasing labour shortages in the Asian agri-food sector. Mechanisation, alongside other efficiency improvements, may therefore become essential to maintain or increase food production.

The most viable option to mechanise Asian farms is through the use of equipment that is designed for use in the Asian agri-food sector – such as smaller, simpler, lower-cost machinery compared with that used in US and European mega-farms – and made available through a rental model. This approach to mechanising part of the Asian agri-food sector can potentially reduce carbon dioxide equivalent emissions by facilitating transformed agricultural practices, such as no-till farming.

**Case Study**

## Smallholder engagement platforms and their benefits: Jiva

Jiva is a 360-degree smallholder farmer services platform, with a mission to improve the livelihoods of smallholder farmers at scale. Starting with corn operations in 2021, Jiva now has physical operations in three crops (corn, chilli, and cassava) in Indonesia, and provides advisory and market pricing across dozens of other crops in India where it serves 9 million farmers. In Indonesia, Jiva supports its farmers through a digitally-supported ecosystem of 6,000 village-level entrepreneurs (Sahabat Jiva), and agri-retailers.

Jiva trains its partners to deliver critical input, harvest, and advisory services directly to farmers in their local communities, increasing the support a farmer receives throughout the growing cycle. Key to this offering is:

1. **Financing, provided in the form of inputs as an advance and paid back through an offtake arrangement** – this helps ensure that farmers use funds specifically for planting (fund diversion is a key challenge in smallholder financing), while simultaneously helping the farmer get access to fairer prices at harvest when they sell to a Jiva partner.

2. **Advisory on the most suitable agronomic solutions to their farm** – delivered digitally through the Jiva farmer app, which has an AI-driven pest and disease diagnosis feature. Agronomy is also supported physically through Jiva's partner network, and their agronomy and customer experience teams.

3. **Access to high quality inputs, delivered to the door** – Jiva's inputs marketplace helps farmers get access to the right inputs, at the right time, even during peak demand periods when farmers would usually have to substitute for lower quality products due to scarcity.

4. **A microinsurance product** – Jiva is developing climate-change focused microinsurance that provides smallholders with a safety net. This is becoming increasingly important in the context of more regular environmental disasters, driven by climate change. The safety net will improve their ability to invest for the long-term in their farm. To do this Jiva is using its connections to multiple smallholders to aggregate risk and remove administrative tasks, for example by conducting know your client checks once rather than multiple times with multiple touchpoints from different financers and insurers, to reduce the costs the insurers would otherwise take on directly.

# 3

# The opportunity for decarbonisation in action

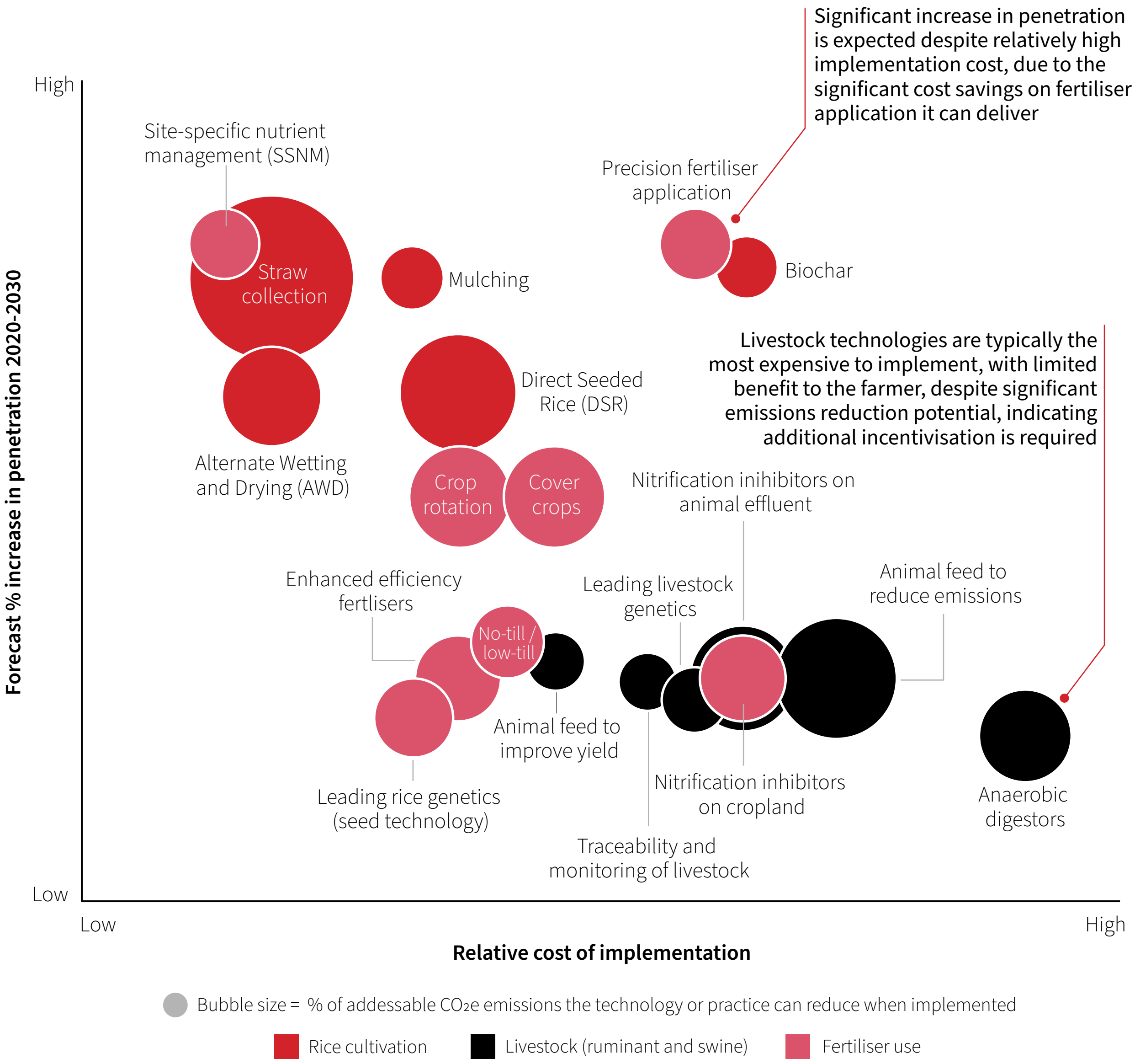
A wide variety of agri-food technologies and practices are in use globally, with significant variation by crop, local climate, infrastructure, geographical constraints, and cultural practices. The optimal selection of technologies and practices can help reduce carbon dioxide equivalent emissions, whilst also providing commercial benefits to the farmer, such as decreased costs, increased yield, higher profitability, and a higher quality of life.

Some of these technologies and practices are not suitable for use in parts of Asia under the existing farming paradigm. This is partly due to the existing farm organisation, including the prevalence of smallholder farms, and supply chain structures, including the role of intermediaries in the supply chain reducing the price farmers achieve for their produce, meaning there is less revenue for farmers to invest in expensive technologies. Some technologies and practices are only suitable to parts of Asia. For example, the implementation of Alternate Wetting and Drying practices in rice paddies is only applicable to flood-irrigated paddies, which represent between 20% and 80% of paddies, depending on the country and region.

However, there is still significant scope for technologies to be applied to large parts of Asia today. Based on discussions with agri-food value chain participants and a review of published literature, we have identified 23 significant technologies and practices that offer the potential to reduce emissions in four of the five key problem areas in agri-food emissions in Asia that we have focused on. Deforestation is an area of success in Asia, as we will discuss below, and further action will be principally driven by restoration and afforestation, incentivised by the carbon markets.

Forecast penetration increase of addressable agri-food technologies and practices vs. relative cost of implementation

% increase in penetration 2020-2030, relative cost of implementation,
% of addressable $CO_2e$ emissions reduced by the technology or practice



Significant increase in penetration is expected despite relatively high implementation cost, due to the significant cost savings on fertiliser application it can deliver

Livestock technologies are typically the most expensive to implement, with limited benefit to the farmer, despite significant emissions reduction potential, indicating additional incentivisation is required

Source: PwC analysis

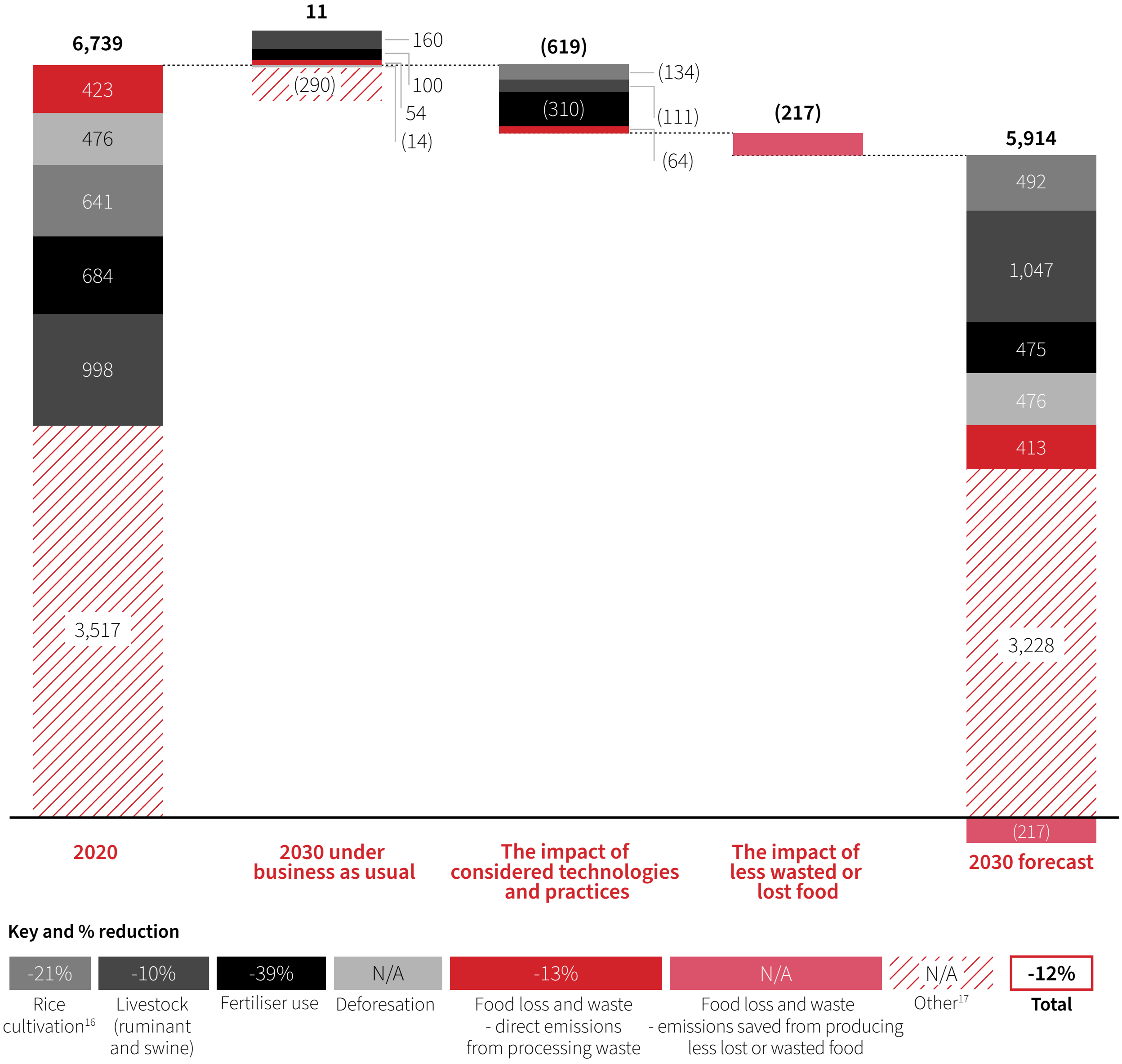
These 23 technologies and practices have the potential to create an immediate and positive impact on farm profitability by improving efficiency and yields. These technologies and practices can be applied individually or in combination – not all will be relevant to each farm or organisation. There are also social benefits that can be achieved by implementing these technologies and practices, by boosting food production, reducing food loss and waste, as well as facilitating improved access to food in the region.

If these technologies and practices are applied at the rate we forecast, based on the current demand in the market, there is potential for a 12% reduction in carbon dioxide equivalent emissions compared to forecast business-as-usual emissions from the Asian agri-food sector by 2030. This represents a reduction of approximately 840 Mt $CO_2e$ emissions, equivalent to that of the entire global aviation industry in 2022. This reduction in emissions would require around US$125bn of investment in physical farm-level technologies and assets on rice and cattle farms, in addition to further investment on other farms and infrastructure and technology along the supply chain.

Forecast impact of technologies and practices on carbon dioxide equivalent emissions of Asian agri-food

**Quantification of decarbonisation impact from the application of assessed technologies / practices under the current trajectory**

Mt $CO_2e$[14], 2020[15]-2030



Source: FAO, PwC analysis

While considering the impact of the 23 technologies and practices, we modelled their emissions reduction potential by considering the baseline emissions they can target, the potential increase in use on a small farm and large farm level (the penetration increase), as well as the emissions reduction potential of the technology or practice.

The forecast reduction in emissions is most notable in fertiliser use, with a potential decrease of 39% of $CO_2e$ emissions forecast compared to a business-as-usual scenario in 2030. The lowest impact will be in livestock (ruminant and swine), where only a 10% reduction in $CO_2e$ emissions is forecast, due to the relative costs and challenges of technology implementation and the expected impact on the farmer's business, in terms of costs, revenue and profitability.

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[14] $CO_2e$ emissions calculated using a 100 year global warming potential (GWP) under AR6 guidance

[15] 2020 data is the latest available from the FAO

[16] Rice cultivation excludes emissions from fertiliser use, deforestation and food loss and waste

[17] Other emissions are those not included in the problem areas, such as emissions from downstream operations, agri-food electricity use and wastewater, transport, and crop / livestock management beyond rice, ruminants and swine, other than fertiliser, which is fully included

# Fertiliser use

| Technology / practice | Description | Stage of the value chain | Technology / practice impact type |
|---|---|---|---|
| **Crop rotation** | A practice of planting different crops sequentially on the same plot of land to improve soil health. | Upstream | Farming practice |
| **Cover crops** | Using a plant that has limited economic value in itself but adds value through covering otherwise empty post-harvested beds to improve soil health when cash crops are not growing. | Upstream | Farming practice |
| **Site-specific nutrient management (SSNM)** | A practice of planning the application of fertilisers as and when needed, dynamically adjusted to location and season | Upstream | Farming practice |
| **Precision fertiliser application** | Using sensors, software and application hardware to monitor and analyse real time conditions of crops, soil, and other relevant targets to more accurately understand the limiting factor of growth in a crop. Then using these automated systems to adjust the rate of application and / or type of fertiliser in response to this information. | Upstream | Software / sensors / input application |
| **Enhanced efficiency fertilisers** | Types of fertiliser designed to reduce nutrient losses into the environment, either via slowing the release of nutrients for uptake or inhibiting the conversion of nutrients to other forms less susceptible to losses. | Upstream | Inputs |
| **Nitrification inhibitors on cropland** | Chemical compounds that reduce nitrous oxide emissions and nitrate leaching by inhibiting the process of nitrification. | Upstream | Inputs / farming practice |

## Fertiliser is often overused in the Asian agri-food sector.

Partly as a response to highly degraded soil, and partly because farmers realise the importance of nutrient supplementation and can lean on the side of caution when applying it, but also due to heavy government subsidies in the region in the past. However, most governments are scaling back on fertiliser subsidies currently, as fiscal and environmental costs are influencing their approach.

The potential for emissions reduction from fertiliser use is high, especially since it makes strong business sense to farmers: plant nutrition is one of their more significant costs, and applying fertiliser past the point at which the supplemented nutrient is no longer the limiting factor in growth is wasted expenditure. Therefore, minimal incentivisation is required to drive behavioural change amongst farmers in this area.

The limitation in increasing the uptake of these technologies and practices is mainly a lack of education in best practice techniques and the ability to accurately measure the level of soil nutrients. Technologies to enable the accurate sensing of soil nutrients are an area of active innovation and range from in-field soil sensors and testing kits, to digital leaf colour charts specific to the plant variety.

However, in-field sensors require capital expenditure at the level of the farmer. At the same time, digital leaf colour charts only identify a deficiency or an overapplication of a nutrient after the event, at which point yield might already have been impacted.

One area of highly scalable, near real-time soil nutrient tracking is through the aggregation of multiple data sources, using existing climate and weather data, supported by some in-field measurements to calibrate these data sources on a small number of fields in the local area.

**Case Study**

## Laconic

Laconic is a global provider of integrated Environmental Intelligence Services, using data aggregation and analysis to facilitate environmental management and natural capital monetisation. They recently announced a $357m USD engagement with Perusda Bali, a Balinese government-owned enterprise, to provide comprehensive Environmental Intelligence, Natural Capital Monetization, and Regenerative Ecoculture services across Bali.

Laconic uses its platform, SADAR, to aggregate data from multiple sources to enable decisions that best support the upstream agri-food sector. One notable use of this is in precision application of fertiliser. SADAR is able to fuse remote sensing technologies, observations from people on the ground, informatics and AI predictive modelling to produce a map of the soil organic carbon in Balinese farms at a 10m squared pixel level with 80%+ fidelity (approaching 90%). A key input here is satellite data to measure soil organic carbon and other nutrient levels through spectroscopy, calibrated by on-the-ground testing (known as 'ground-truthing'). The advantage is that only 500 soil samples from 7 locations across the island of Bali are required on a monthly basis to maintain this level of accuracy, effectively removing the requirement for farmers to procure expensive sensors themselves.

It can then work directly with smallholder farmers to apply the most relevant technologies and practices, driven by its data aggregation and analysis, or with implementation partners.

# Rice cultivation

| Technology / practice | Description | Stage of the value chain | Technology / practice impact type |
|---|---|---|---|
| **Alternate Wetting and Drying (AWD)** | A method of controlled and intermittent irrigation, with more prolonged dry periods vs. traditional continuous flooding. | Upstream | Farming practice |
| **Direct Seeded Rice (DSR)** | A crop establishment practice, in which rice seeds are sown directly into the field, as opposed to the conventional practice of transplanting seedlings into the paddy. | Upstream | Farming practice |
| **Biochar** | The creation of a charcoal-like substance by partially burning (pyrolysing) rice straw and other organic agricultural waste in a controlled process, emitting less carbon than complete combustion. The product can then be applied to fields to increase soil organic carbon, which can in turn help retain more nitrogen from applied fertiliser. | Upstream | Inputs / waste management |
| **Mulching** | A process of using residues of the previous crop to cover soil surface, and allowing the residues to naturally compost. | Upstream | Inputs / waste management |
| **Straw collection** | The practice of gathering and storing rice straw in a bale for use in an economically valuable process, such as biofuel production, animal / human food production, or the production of materials for construction. | Upstream | Inputs / waste management |
| **No-till / low-till** | A method of directly planting crops into a field with minimal soil disturbance vs. traditional tilling. | Upstream | Farming practice |
| **Leading rice genetics (seed technology)** | The use of artificially selected seeds in rice paddies to select for beneficial characteristics, e.g. yield and resilience. Does not include genetic modification technologies. | Upstream | Inputs |

## Rice is a staple crop in Asia.

It is also a crop grown by smallholder farmers using traditional methods that have been passed down through generations. There is scope to improve farmers' livelihoods and reduce emissions by making simple changes to growing methods and implementing readily available technologies.

There are two key areas in rice cultivation where new practices and technologies can be applied to reduce emissions:

### i) Flooding of rice paddies during the growing season

Traditionally, rice paddies are flooded periodically throughout the growing season. Flooding leads to methane emissions from anaerobic bacteria and archaea that thrive in the flooded paddies. Flooding is also a highly water-intensive practice, and often takes place in areas that are already water-stressed.

Regenerative agricultural practices such as Alternate Wetting and Drying (AWD) and Direct Seeding Rice (DSR) can significantly reduce – or even totally remove – the need for flooding. This reduces emissions and water use, while maintaining yield. In some cases yield can improve by up to 20% above that achieved by using traditional flooding practices when using hybridised rice varieties adapted to these methods of cultivation. These practices can also be significantly cheaper for the farmer than transplanting seedlings grown in controlled environments into a flooded paddy, improving farmer profitability and reducing labour requirements.

> “No area has more potential to impact agri-food emissions than rice right now, in particular the conversion from the traditional method of transplanting rice to direct seeding."
>
> *- Bayer*

### ii) Burning of rice straw following harvest

The burning of rice straw and stubble following harvest releases significant carbon. It can also lead to haze, which is a social issue. This has made rice straw burning a current focus of many local and national governments.

This issue can be addressed through various crop residue management solutions.

For example, using rice straw for biochar production reduces the carbon dioxide equivalent emissions compared with burning the rice straw completely. The biochar product can then be applied to the field, increasing soil organic carbon content. Higher organic carbon in the soil leads to better nitrogen retention, which reduces the amount of fertiliser needed. This further reduces emissions from fertiliser application and generates higher returns for the farmers as less fertiliser is needed. Another solution is mulching to increase soil organic content.

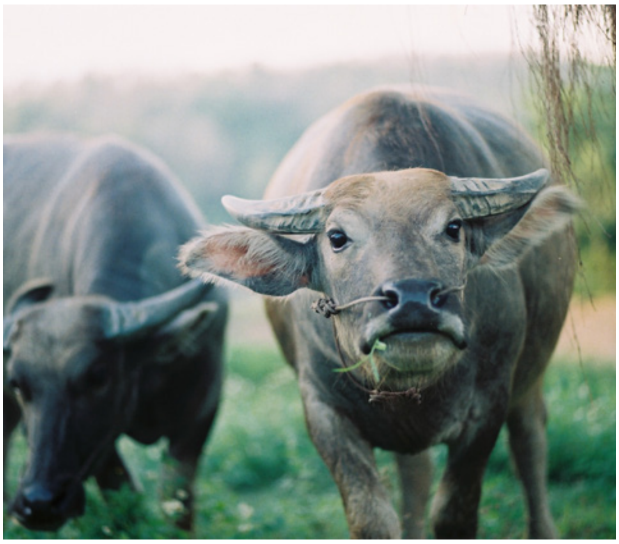
Rice straw can also be collected for use in an anaerobic digestor to generate energy, for processing into an animal or human food source, or for use in fibre boards in construction and packaging, amongst other uses.

## Livestock (ruminant and swine)

| Technology / practice | Description | Stage of the value chain | Technology / practice impact type |
|---|---|---|---|
| **Animal feed to improve yield** | Increasing the quantity of feed given to livestock or including supplementary additives to improve yield (e.g. quantity of milk, size of livestock) and reduce the number of animals needed to produce the same or greater produce. | Upstream | Inputs |
| **Animal feed to reduce emissions** | Using feed additives and supplements that inihibit the formation of methane in the animal's digestive system. | Upstream | Inputs |
| **Nitrification inihibitors on animal effluent** | Chemical compounds that reduce nitrous oxide emissions and nitrate leaching by inhibiting the process of nitrification. | Upstream | Inputs / farming practice / animal health |
| **Leading livestock genetics** | The use of artificially selected animals to select for beneficial characteristics, e.g. yield, gender, resilience. For example, this could be done via artificial insemination, and include the use of sexed semen (selecting the gender) or beef-on-dairy (improving the beef yield from male calves on dairy farms). Does not include genetic modification technologies. | Upstream | Inputs |
| **Anaerobic digestors** | Machinery in which microorganisms break down biodegradable material in the absence of oxygen, producing biogas. This biogas is captured for use or sale, rather than released into the atmosphere. | Upstream | Waste management |
| **Traceability and monitoring of livestock** | Monitoring livestock activity, health and other biometric data points to ensure the animal is kept productive. This can involve hardware, software and the adaptation of practices. | Upstream | Inputs / farming practice |

Ruminant livestock emit methane as part of their digestive process and animal effluent has high levels of ammonia and nitrous oxide.

In some cases, particularly smallholder herds, yield improvements can be made by using larger quantities of better-quality feed, higher-yielding livestock genetics, and genetic approaches, such as sexed semen (selecting male or female cattle as required) or beef-on-dairy (optimising male dairy calves for beef production). Direct actions to target emissions are also possible using chemical solutions, such as emission-reducing feed additives, nitrification inhibitors and anaerobic digestors, although the suitability of these will depend on whether the herd is in an open pasture or housed.



**Case Study**

## Asparagopsis

Asparagopsis is a type of red seaweed, which contains several active compounds (the principle one is thought to be bromoform) that are able to disrupt the methane-producing pathways in the gut of ruminant livestock.

The exact mechanism through which methane production is inhibited remains an area of scientific inquiry, but it is likely through the disruption of the metabolism of methane-producing microorganisms that naturally exist in the rumen microbiota.

Supplementation of feed with Asparagopsis has the potential to significantly reduce methane emissions from ruminant livestock – up to 80-90% in laboratory conditions, although likely much less than this in the field.

There are still regulatory processes to pass before its widescale uptake in Asia, some of which can take multiple years, although it is approved for use in Australia, with promising methane reductions in trials (c. 30%).

The main barrier to uptake after regulatory approval is the additional cost it represents for farmers, without a current revenue stream from its decarbonisation potential. Incentivisation is an area for government consideration, the carbon markets, and consumer product pricing, but it will likely take time before this technology becomes a workable option for most Asian farms.

Livestock is a particularly challenging area of agri-food to decarbonise – our forecast is for only a 10% reduction in carbon dioxide equivalent emissions in Asia – in part because of the following three factors:

**i) Higher costs of some technologies**

Many of the significant decarbonisation opportunities in livestock involve additional cost and labour, without an existing way to increase revenue, for example nitrification inhibitors applied to animal effluent, using feed additives specifically to reduce emissions from methane producing microorganisms in a ruminant's digestive system, and anaerobic digestors to capture emissions from waste add costs with limited or no increases in revenue.

Many smallholder dairy farms also face challenges in providing their cattle with adequate feed, let alone sourcing specific high cost feed supplements, such as *Asparagopsis*, to reduce emissions.

**ii) Variation in the ruminant livestock landscape across Asia**

The ruminant landscape varies significantly across Asia. In India – whose dairy herds are amongst the world's largest – there is a highly fragmented dairy production landscape, and up to 60% of dairy farmers have a herd of less than five cows that roams free on pasture. In contrast, there are Chinese dairy and beef farms with housed herds on the scale of those in the US (the average dairy herd size in the US is c. 340 heads of cattle), alongside smallholder dairy and beef farms.

**iii) Cultural importance of cattle**

The significance of cattle in parts of South Asian culture means many farmers are reluctant to change their practices to undertake what they view as 'experiments' on their herds, for example by using higher-yielding genetics through technologies such as artificial insemination.

The combined impact of these three factors could mean that the penetration of livestock decarbonisation technologies is lower than that of rice and fertiliser use by 2030. There are three key factors to increase the uptake of these technologies in livestock:

### i) Introduce a degree of functional consolidation

Emissions from livestock in parts of Asia would likely benefit from livestock herd intensification to increase the efficiency of smallholder farms, which is contrary to the approach being taken in EU countries, where herd size reduction is being pursued to reduce the total emissions from livestock.

Increasing the purchasing power of smallholders through cooperative procurement (e.g. of a shared anaerobic digestor for livestock waste) would also be part of this consolidation.

### ii) Streamline regulatory processes

There are promising technologies available, such as nitrification inhibitors, feed additives, methane vaccines, and selection of genetic variants with the intention of reducing emissions, which have the potential to create a step-change reduction in carbon dioxide equivalent emissions.

However, these technologies may face long regulatory approval processes, meaning they will take time to come to market. Streamlining regulations and identifying high-priority, low-risk innovations which could receive expedited approval would accelerate their impact, which is of critical importance given the time value of carbon dioxide equivalent emissions.

### iii) A suitable carbon market or higher consumer prices

Farmers need to be incentivised to adopt lower-emissions practices that are otherwise economically infeasible. Additional incentives, in the form of the carbon markets or tax relief for implementing these technologies and practices are needed to increase uptake by farmers.

This is particularly important given consumers are typically unwilling to pay more for lower emissions products, although there are examples at the premium end of the market, and this may change going forwards.

# Food loss and waste

| Technology / practice | Description | Stage of the value chain | Technology / practice impact type |
|---|---|---|---|
| **Improved valorisation of loss and waste (e.g. energy, feed, new products)** | Converting food loss and waste in the supply chain into alternative products with useful economic value, the preference being for alternative human foodstuffs. | Upstream / Downstream | Waste management |
| **Improved packaging** | Using packaging technologies to reduce food loss, be it through an improved primary protective layer on the produce, or more rigid secondary and tertiary packaging to prevent impact damage. | Upstream / Downstream | Production practices / R&D |
| **Better supply chain management and traceability (e.g. RFID, digital twins, software)** | Improved matching between the retail distribution centre and the store to prevent the movement of excess produce to a store where it will not be sold, or insufficient movement of produce to a store, increasing the likelihood of food waste in the distribution centre. | Upstream / Downstream | Logistics / software |
| **Improved infrastructure (e.g. cold chain, storage)** | Improved infrastructure along the supply chain to reduce food loss and wastage. | Upstream / Downstream | Infrastructure |

Food loss and waste are significant issues in agri-food globally. Food loss is defined as food that was fit for consumption at the point that it was ready for harvest but was then lost before it reached retail channels. Food waste refers to food lost at the retail or consumer level.

Up to a third of all food produced in Asia is ultimately lost or wasted, although there is significant variation across regions. Regions with high food loss typically have lower food waste, and vice versa. This is because food loss can be associated with less developed supply chain infrastructure (such as storage, processing and cold chain infrastructure), while food waste is partly a product of wealth.

This loss and waste leads to much higher emissions and costs than what is required to produce the amount of food currently consumed. It is also a social challenge as many people across Asia still do not have enough to eat.

Food loss and waste has therefore consistently been a top priority of the United Nations (UN) and the Food and Agriculture Organisation (FAO). One of the first steps to take is to improve the data quality of where food is lost and wasted. The FAO is leading an effort to develop new datasets to supplement the FAO's existing food waste data. This will hopefully drive action across the supply chain.

## Drivers of food loss and waste

Food loss and waste occur for multiple reasons, some of the key problem areas are below:

### Food loss

**Food not harvested** – food left in the field and not harvested, or harvested at the wrong time. This is often caused by labour shortages, extreme weather and lack of visibility on the best time to harvest. The use of simple machinery to support existing harvesters and pickers, for example small trailers and harvesting chisels, can increase the productivity of the workers who currently do not always have access to these basic machines. Better weather forecasting and improved farmer access to this data can help optimise harvesting time. Data platforms and Artificial Intelligence (AI), which are increasingly becoming available to smallholders, can support the farmer in selecting the best time to harvest.

**Storage and transportation loss** – loss due to inadequate storage and transportation, for example the lack of cold storage across the supply chain, or inadequate controls over other variables, such as humidity, can lead to significant food loss. Cold chain and storage infrastructure represents a potentially significant investment opportunity in the Asian agri-food sector, which would also have a positive impact on emissions.

## Food loss (cont.)

**Machine and processing damage** – old or inefficient machinery can lead to loss, for example from broken rice. Replacement of this machinery often makes business sense to increase revenue, but can require investment or financing.

**Damage during handling** – delicate produce, such as eggs and fruit, are prone to breakage, and some crops are prone to overripening when transported together (e.g. bananas). Better or more protective packaging can reduce food loss, but must be evaluated against the cost and emissions of the packaging. Plastic returnable transit packaging can be adopted to reduce single use plastic while offering additional protection in closed-loop supply chains.

**Rejection for aesthetic reasons** – in some wealthier markets edible food can be rejected as it does not meet aesthetic standards determined by the buyer.

**Downstream supply chain bottlenecks** – a lack of processing capacity during harvesting can result in food loss as pre-processed produce is kept in storage for too long. Digitisation can help to better manage logistics.

## Food waste

**Ineffective supply** – misalignments in demand and supply between distribution centres and stores can lead to food being kept in the wrong place, contributing to food waste. An oversupply to stores can lead to unsold product going to waste, or food that is wanted in a store may be kept in a distribution centre too long and go to waste before reaching stores. This can be addressed with supply chain management technology, tags such as RFIDs, digital twins. In the future, blockchain technology may be applied if it is beneficial.

**Ineffective packaging** – packaging is essential to maintain a barrier between the food and the air, which extends the lifespan of the food. In some cases where minimal packaging is used, this can increase food waste, making it a delicate trade-off between packaging and plastic use, and food waste.

**Consumer behaviour –** overbuying or overpreparing food leads to significant waste in wealthier parts of Asia. This is sometimes intentional as people might prioritise their time over taking multiple trips to the grocery store, or cooking multiple times, even if it carries additional expenditure on wasted food. However, this problem is less notable in many parts of South and South East Asia, compared with some wealthier global regions.

In addition to food loss and waste, there are significant losses in crop production before the produce is ready for harvest, due largely to pests and inclement weather. These are not normally included in the definition of food loss. However, there are significant amounts of carbon dioxide equivalent emissions from partially growing crops that go to waste before harvest. Pests are a particularly significant challenge in Asia, and inclement weather will damage crops more regularly as a result of climate change. General regenerative agriculture processes, including crop rotation and diversification, and better advice to farmers on the best chemicals to use and the best times to apply them may help reduce these losses and improve productivity.

## Valorisation of waste

The focus should be ensuring food produced for human consumption is consumed by people through action on supply chain management, infrastructure, packaging technologies and consumer behaviour. However, where this is not possible, extracting additional value from waste – valorising the waste – is the next best option. Currently there is a lack of valorisation options in many value chains across Asia.

Valorisation can be carried out in various ways, such as by developing new products, repurposing waste as animal feed or fuel, all of which result in more value per kilogram of carbon dioxide equivalent emissions released as part of producing the food than the existing disposal routes.

**Case Study**

### Dole

Dole launched its Dole Specialty Ingredients business in 2021 to transform side streams into high-value specialty ingredients, with an aim to reduce food loss and increase the value of some waste that was diverted to animal feed. This has led to the creation of enzymes, extracts, oils, fibres and other ingredients for use in human food, for example its green banana powder, a source of dietary starch usable in baked goods, pasta and yoghurt, which is upcycled from underripe bananas.

**Case Study**

## DFI Retail Group

DFI Retail Group have focused on emissions from food loss and waste and refrigerant gases (which make up 40% of their Scope 1 and 2 emissions), amongst other areas:

- They have successfully reduced their upstream fresh food loss ratio in Hong Kong, Singapore, Malaysia and Indonesia in a three year period 2019-2022, driven in large part by improvements in demand planning, using data from their supply chain to make more accurate pull requests from warehouse to store based on need in the store. DFI has also successfully implemented donation schemes for near-expiry food and food waste recycling into biogas for damaged food, contributing to achieving their group-wide waste diversion target of 80% by 2030.
- They have reduced their carbon dioxide equivalent emissions from refrigerant gases by 24% from 2021-2022, driven by the use of refrigerant gases with a lower GWP, improved leak detection and better maintenance. They have built on this progress through the implementation of Water Loop refrigerant systems in their sites, which use significantly less refrigerant gas and less energy than traditional cooling systems - this reduces their emissions from refrigeration. This technology has been installed in nine sites and all new-build stores since 2023.

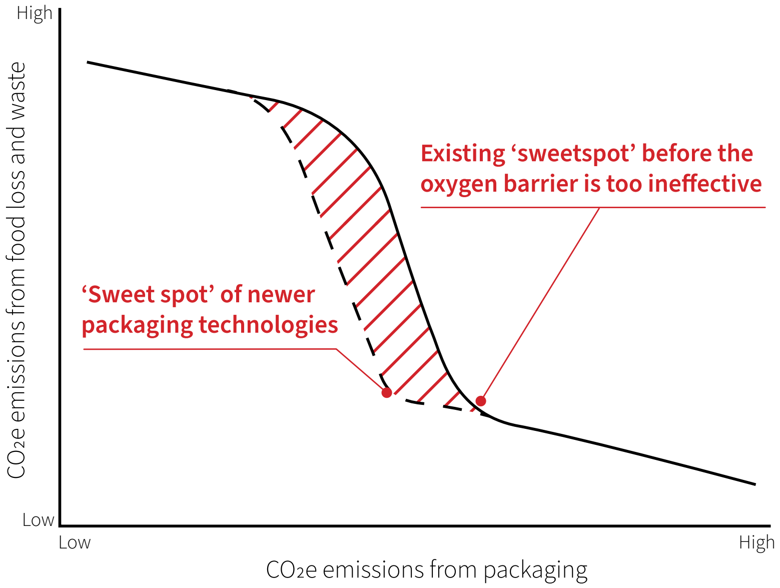
# Emissions from packaging vs. emissions from food loss and waste

Some solutions, such as packaging technology, are a trade-off between reducing emissions from food loss and waste, and the emissions from producing the packaging itself.

The trade-off in this case will shift as better packaging technologies offer more effective oxygen barriers with less associated emissions – the 'sweet spot' of this equilibrium varies depending on the produce being packaged, the transport and storage conditions and the time from harvest to consumption. The lower penetration of cold chain and suitable storage facilities in parts of Asia compared with the penetration in the US and Europe means packaging is unlikely to be a key area of emissions reduction ahead of 2030 in many parts of South and South East Asia, as packaging advancements are better suited to be trialled in Industrialised Asia, the US and Europe.

Trade-off between packaging emissions and emissions from food loss and waste

*Illustrative example*



*Carbon dioxide equivalent emissions from packaging generally go up with more packaging, which in turn reduces carbon dioxide emissions from food loss and waste. However, this is not linear, there is a 'sweet spot' in the trade- off between the two. New packaging technologies can reduce carbon dioxide equivalent emissions from packaging food by using alternatives to plastic, smaller quantities of packaging material and more efficient methods of application.*

**Case Study**

## Apeel

Apeel is a thin covering that can be applied to the outside of fresh produce (fruits and vegetables) to offer an additional protective layer, keeping moisture in and oxygen out. It is made of monoglycerides and diglycerides, edible and approved by regulators globally. The advantage of this additional barrier is it extends the shelf-life of fresh produce, without requiring high emissions-packaging, such as plastic shrink-wrapping. As Apeel-covered products last longer, they can spend additional time in the supply chain, which gives produce a higher chance of being consumed by a person. This reduces food loss and waste along the supply chain – trials in Europe have reduced food waste at the retail stage by 50%. Additionally, it offers smallholders the opportunity to sell fresh produce in higher value markets, that may not previously have been accessible due to the logistical challenge of moving produce that spoils quickly. Apeel is also low cost compared to alternative packaging and does not require significant capex spend on equipment to apply it, meaning it is potentially applicable at the smallholder level in Asia in the future.

# Deforestation

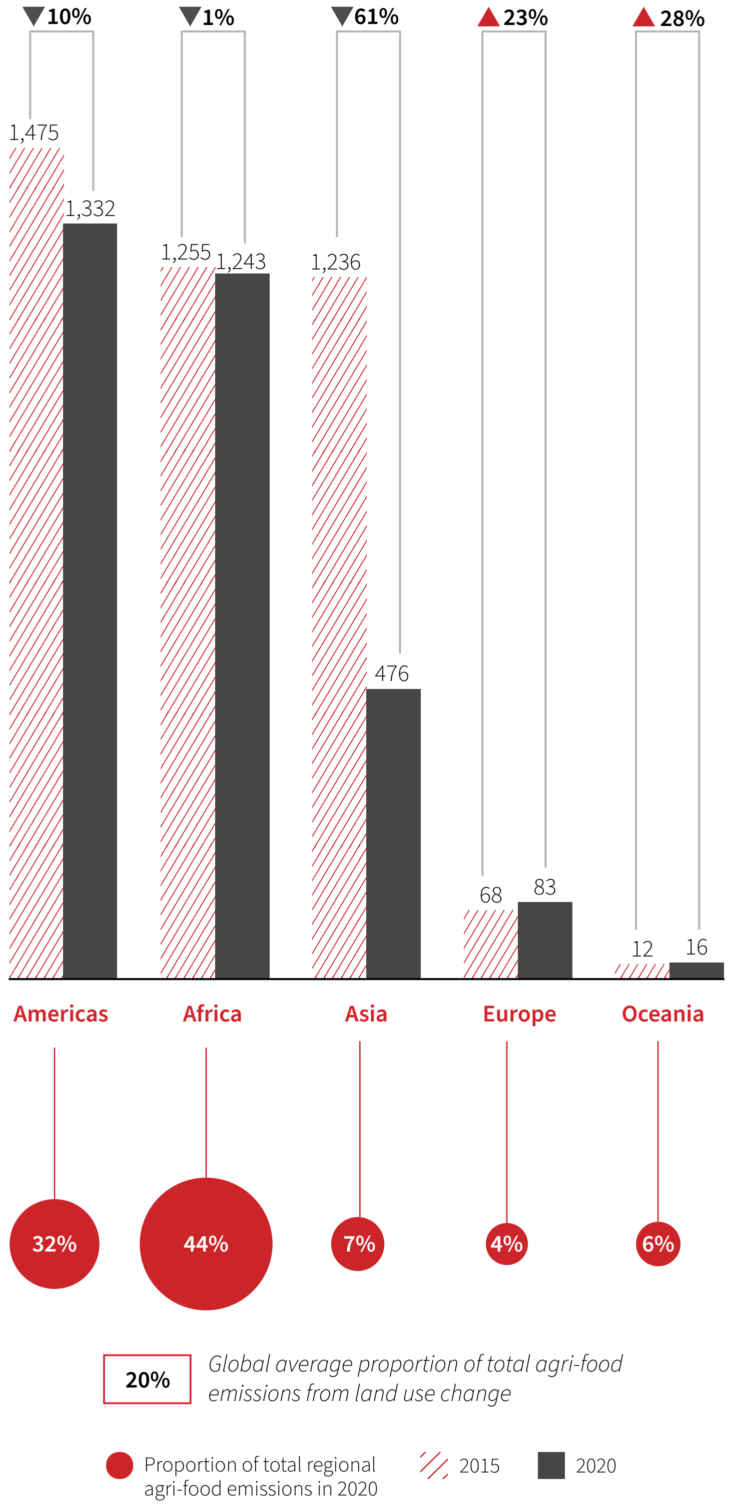
Deforestation for agricultural purposes has historically been a problem area in Asia. The demand for palm oil from Indonesia and Malaysia led to the destruction of primary rainforest and peatlands, to be replaced by palm oil plantations.

However, significant progress in managing land use change has been made, in particular since 2015-16. In 2015, emissions from land use change represented approximately 17% of all agri-food emissions in Asia. In 2020, there were approximately 480 Mt of emissions from land use change, which is around 7% of emissions from the Asian agri-food sector. This is considerably lower than the 32% level in the Americas and 44% in Africa. It is more comparable to Europe's 4% level and Oceania's 6%.

Asia's significant emissions reduction in this area since 2015-16 is largely due to the positive progress made on sustainable palm oil, which now serves as a positive example for other sources of deforestation in the region, such as Nickel mining, which has increased forest clearance in Indonesia, as well as across the globe.

Carbon dioxide equivalent emissions from land use change

Mt CO$_2$e emissions / % of total agri-food emissions, 2020



**Case Study**

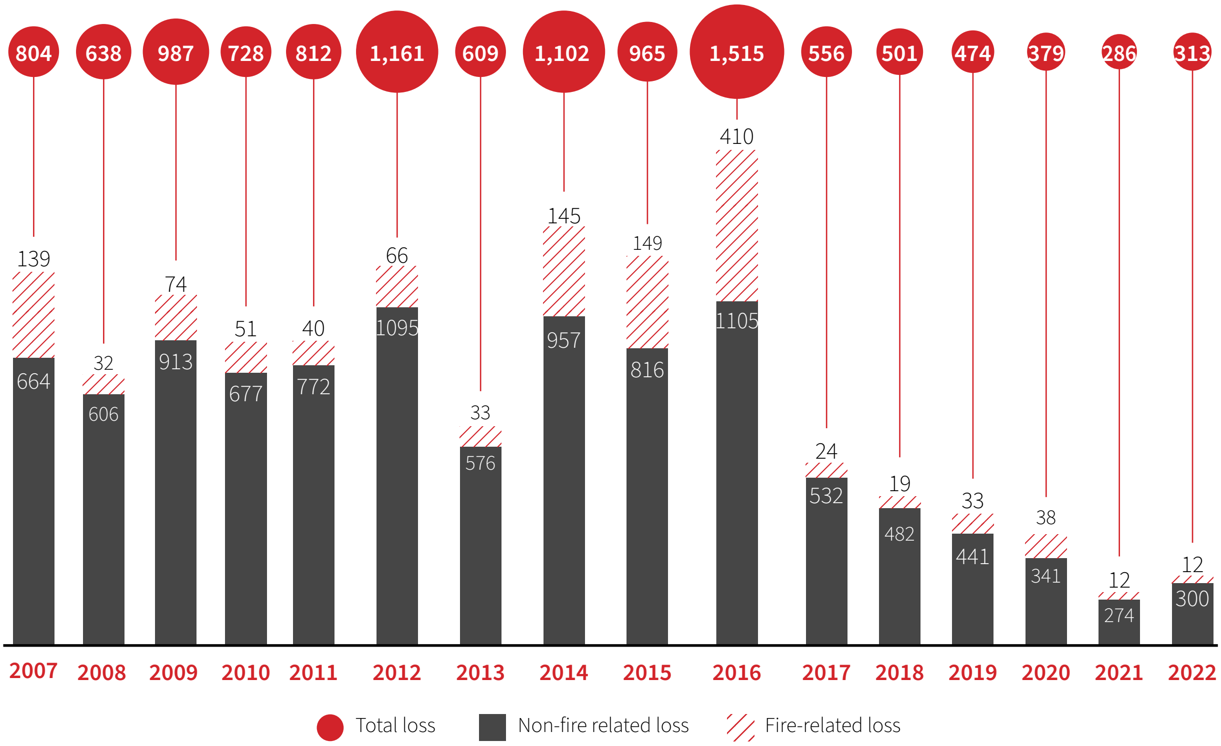
## The Roundtable on Sustainable Palm Oil

The Roundtable on Sustainable Palm Oil was established in 2004, bringing together palm oil farmers, palm oil producers, consumer goods manufacturer, governments of palm oil producing countries, retailers, financial institutions, and NGOs. This led the way on sustainable palm oil commitments, but significant reduction in deforestation in Indonesia and Malaysia came in 2016 – emissions from Land use change in 2016-2020 were c. 45% lower than 2011-2015. A combination of key factors contributed to this, including:

- A moratorium on new palm oil licenses in Indonesia in 2016, preventing further greenfield expansion, although smallholders continue to expand in certain areas.
- The establishment of the Indonesian peatland restoration agency in 2016 following significant forest fires in 2015, with the remit to prevent further damage to peatlands, and ultimately restore peatlands.
- A series of large producers committed to zero deforestation between 2013 and 2016, including Cargill, Golden Agri Resources, IOI Group, Musim Mas and Wilmar.

Deforestation in Indonesia and Malaysia

m ha tropical primary forest lost in the year[18]



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18 Fire-related loss and non-fire related loss may not sum to total loss due to rounding

# Future technologies

Technologies that are currently at a lower Technology Readiness Level and less suitable for widespread use ahead of 2030, such as biologicals (e.g. fertilisers and stimulants), biological manufacturing, future genetic modification of staple crops and livestock, and green ammonia are likely to play a future role in reducing emissions.

Some of these technologies are in use at a small scale today, but they face regulatory or commercial barriers to widespread adoption. Despite this, we see positive movements to use these more advanced technologies in recent years. For example, China is undertaking large scale trials of Genetically Modified Organism (GMO) corn and soy beans in its domestic agriculture for the first time in 2023, a key step to commercial approval.

However, the higher time value of carbon produced now means we believe investment to increase uptake of existing, effective technologies offers the most impactful path to decarbonising the Asian agri-food sector.

# Alternative foods

Alternative foods have the potential to significantly decarbonise agri-food – today a plant-based burger emits up to 90% fewer emissions than a beef burger.

However, the key consumer criteria when buying alternative food products are, i) good taste, ii) a competitive price compared to meat, and iii) health benefits in-line with or better than meat.

The alternative food products on the market have generally not performed in-line with consumer expectations in these areas. Ultraprocessed plant-based products seeking to mask low quality ingredients with high levels of salt, sugar, and other additives were rushed to market, often at a price premium to meat.

The consequence of this is that uptake has stuttered in recent years and valuations of alternative foods producers have often declined as a result.

The long-term potential for alternative foods remains high as they are a powerful option in the drive towards decarbonisation. New technologies in alternative foods, including precision fermentation of animal proteins, fats and other molecules, are close to economic feasibility.

These technologies, in combination with existing technologies, such as biomass fermentation and existing plant products, have the potential to significantly advance the penetration of these products in a short space of time by improving the taste and health characteristics at a competitive price.

Longer-term technologies, such as cell culturing, represent a potential further step-change in carbon dioxide equivalent emissions, but they remain quite far from commercial feasibility at scale.

This report focuses on immediate, implementable actions. As a result, while alternative foods represent a huge potential decarbonisation and investment opportunity, we have not considered them as a lever in this analysis.

Additionally, improvements in alternative food technologies and increased uptake by consumers should be seen as complementary to meat consumption. Decarbonising livestock using available technologies must remain a key focus as consumers are unlikely to completely transition away from regular meat consumption, but a good quality alternative food, with positive taste, price, and health features, can allow consumers to eat higher quality meat, less often. This can improve emissions from livestock and farmer livelihoods as the economics of meat transition to a more sustainable model.

# Benefits to the farmers

To incentivise farmers to adopt new emissions-reducing technologies and practices, the benefits must be clear.

Benefits to the farmer of these technologies and practices include lower input costs, higher yield, better prices for their produce, assurance of offtake, lower taxes, or additional revenue streams. All of these ultimately drive improved profitability and a positive impact on their livelihoods.

However, some technologies and practices do not make sense to implement at the farm level without a method of carbon pricing, allowing the farmer to either avoid a 'carbon tax', or to receive additional income from the carbon markets. These are typically technologies that add operational costs with limited yield or quality improvements that can lead to more revenue from their produce.

Overall though, the majority of the technologies and practices that we have considered have a positive impact on a farm level.

We have quantified the impact on profitability from transforming two typical Asian farms, using the available technologies and practices. In these two examples, we have not considered the impact of carbon pricing.

# Illustrative rice farm example

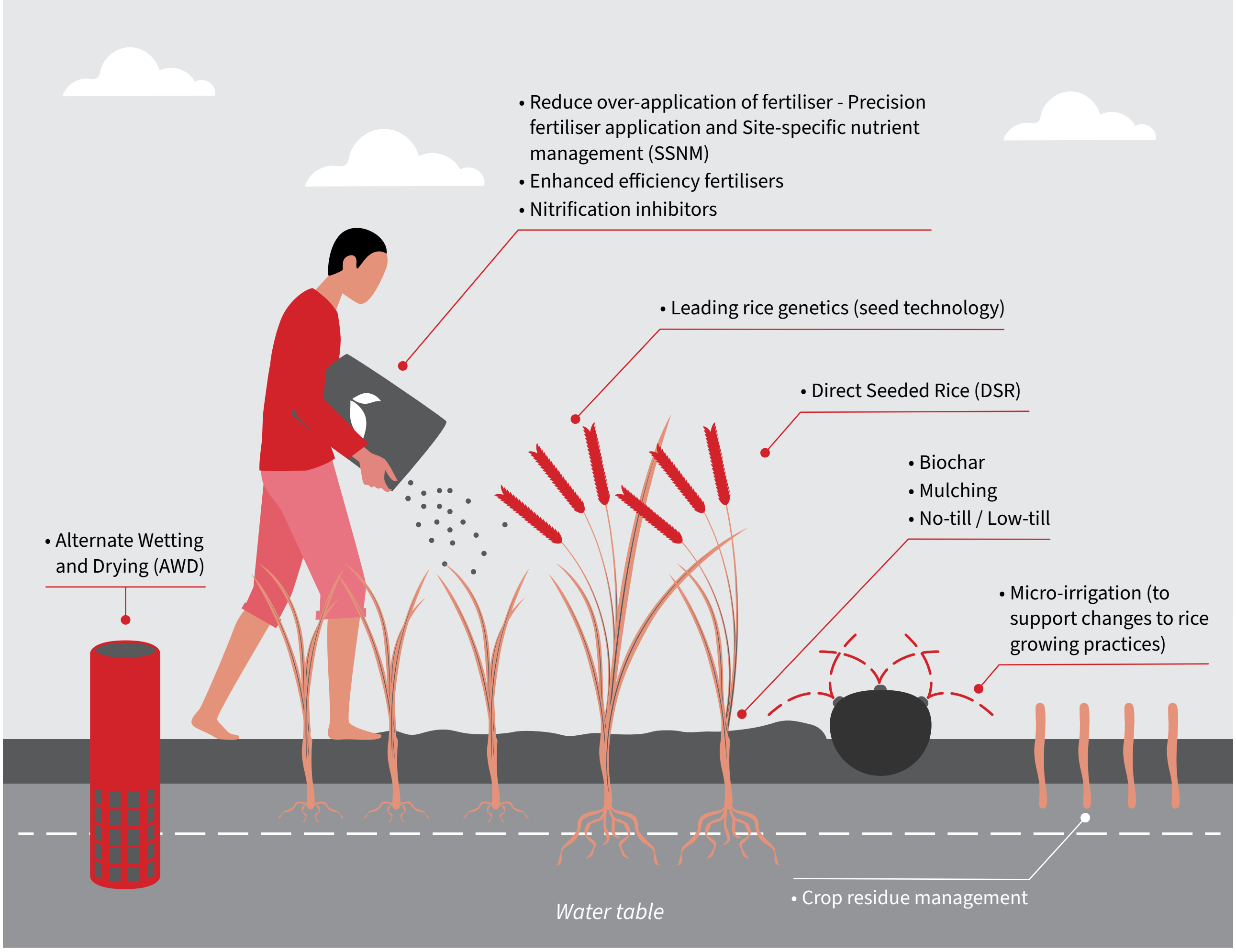
To implement these technologies and practices on a typical two-hectare rice farm would decrease annual operating costs by about 20% and improve revenue by around 55%, resulting in an approximately 16 ppt increase in gross margin. A key assumption is that new seeding and crop residue management machinery is available to rent.

A significant proportion of these increased costs comes from micro-irrigation, which can be expensive. However, many local governments are already subsidising the installation of irrigation systems due to stress on local water supplies, reducing the up-front capital expenditure required. These subsidies are as much as 70% in India.

The investment on a farm level, either directly or into the rental businesses that would supply the farms, would be approximately US$3,100 per typical two hectare smallholder rice farm. We believe a c. US$53bn investment would be sufficient to implement these farmlevel technologies and practices on addressable rice farms across the region – a comparatively small cost given the potential decarbonisation and economic benefits.

| Total capex required for considered on-farm equipment per typical 2 ha farm (USD) | Change in operating expenses (%) | Change in revenue (%) | Change in gross margin (%) |
|---|---|---|---|
| **+ c. 3,100** | **- c. 20%** | **+ c. 55%** | **+ c. 16 ppt** |

*Illustrative example*



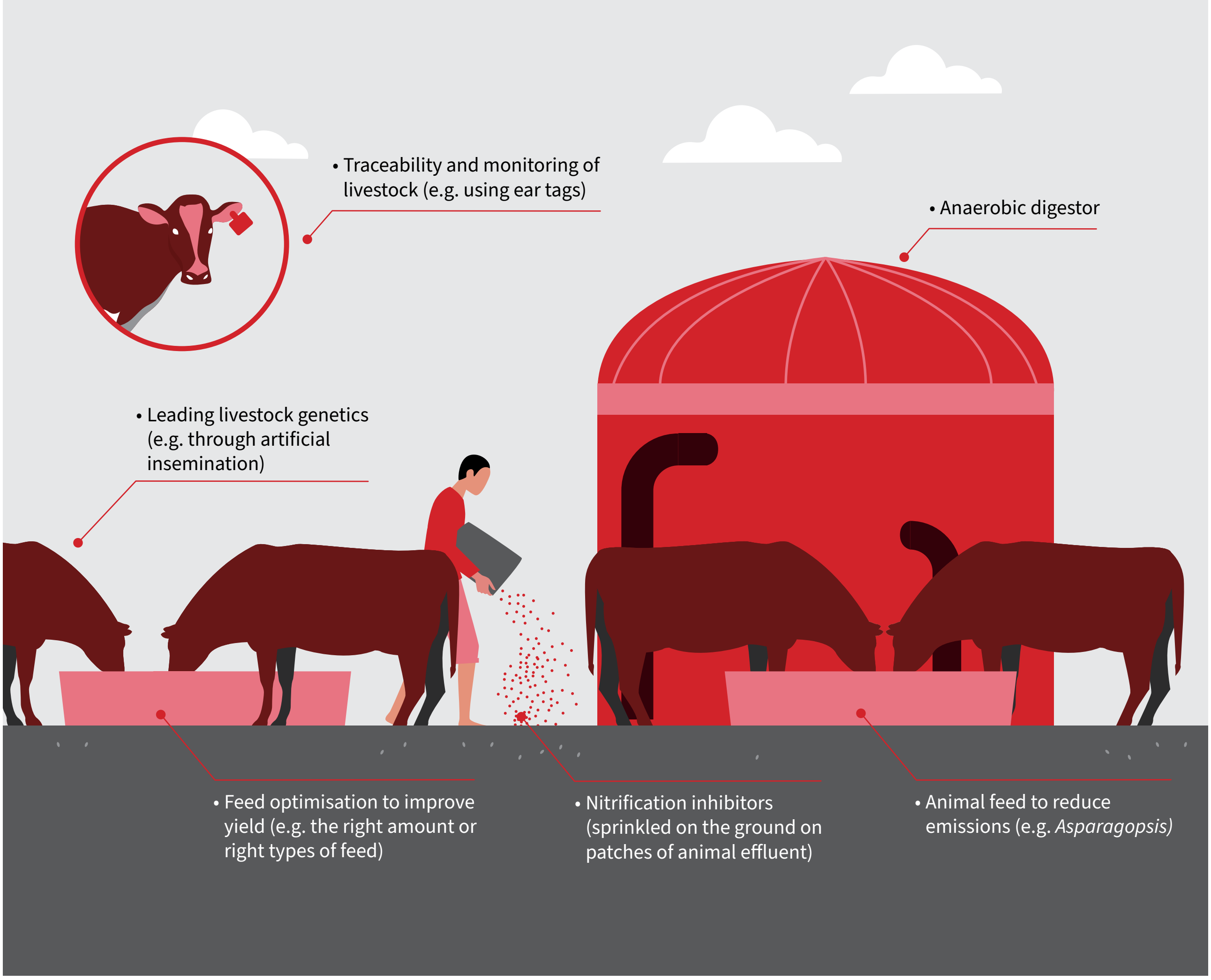
## Illustrative livestock farm example

To transition a 20-cow dairy farm, which is relatively large in many parts of Asia's dairy farming landscape, to new practices and technologies would increase annual operating costs by approximately 20%, but also increase revenue by around 25%. Again, a key assumption is that significant machinery (such as anaerobic digestors) is available to use on a rental or community basis. While this results in c. 2 ppt improvement in gross margin overall, it would require a blend of technologies with both positive and negative profitability impacts to achieve sufficient levels of decarbonisation.

The investment on a farm level required is c. US$21,000, which a typical Asian smallholder farmer is unlikely to be able to afford. To reach the forecast emissions reduction would require approximately US$72bn investment in farm-level technologies across addressable dairy and cattle farms in Asia.

| Total capex required for considered on-farm equipment per typical 20 cow dairy farm | Change in operating expenses (%) | Change in revenue (%) | Change in gross margin (%) |
|---|---|---|---|
| **+ c. 21,000** | **+ c. 20%** | **+ c. 25%** | **+ c. 2 ppt** |

*Illustrative example*



# Remaining barriers to uptake

Many of these technologies and solutions make good business sense to farmers and reduce emissions. However, barriers to uptake do still apply:

i. **Lack of adequate awareness, knowledge and training:** Smallholder farmers often follow farming practices that have been handed down for generations, without a detailed understanding of why a practice works well. With the adequate training and support, they would be better equipped to adapt to newer technologies and practices.

ii. **Cultural significance:** Some existing practices are deeply ingrained in Asian culture and livelihoods, such as farming rice in flooded paddies, which are often also used to breed fish and crawfish. Education will be required to help communities adapt to these changes.

iii. **Up-front investment and access to equipment:** Smallholder farmers may not have the resources or financing to afford the up-front investment required for many of the technologies and practices, be it for different seed varieties or new equipment. For example, many smallholders currently do not have access to anaerobic digestors and biochar furnaces under the existing financing structures.

iv. **Inability to measure a parameter or assess a need for an input accurately:** Simple technologies such as leaf colour charts can help determine whether more fertiliser use is needed. However, smallholders typically do not have access to these. More sophisticated in-field sensors are expensive and therefore not available to most smallholders.

v. **The insecurity of smallholder farming:** Many farmers may still feel insecure about the risks of changing their practices without a guaranteed return, even if they are educated about the potential benefits. Insurance and offtake agreements may help to address this.

vi. **Transition period of lower productivity:** Some practices and technologies may take time to implement. This period of lower profitability, sometimes lasting several years before the long-term benefit of higher yield or lower costs are realised, is not something the smallholder farmer can commit to without support from other parties, such as their downstream partners and governments.

vii. **Lack of clear land tenure rights:** Land tenure rights can be unclear or poorly suited to the local needs of farmers. Without clear land tenure rights, smallholders may not see sufficient benefit in investing in the long-term health and productivity of the farm, or in some cases they may not be allowed to change practices.

viii. **Labour intensity:** Some new practices are more labour-intense than existing ones, others are labour saving. Where additional labour is required, this can be challenging to properly account for in an economy where the labour is often informal. However, many farmers rely on multiple sources of income, so they may not be willing to spend more time on a new practice that may offer a less secure return on their time than their other jobs.

ix. **Lack of alternative monetisation:** Emissions-reducing practices and technologies have value from reducing emissions and sequestering carbon. Theoretically, this should provide an additional revenue stream from the carbon markets. However, it is challenging for smallholders to access these currently and voluntary carbon markets are struggling to drive action. Regulated carbon markets in agri-food with a suitable carbon price would accelerate this.

x. **Consumers unwilling to pay more:** Consumers are generally not willing to pay a premium for lower-carbon produce, which reduces the incentive to change practices or invest in technologies.

There is scope to address these barriers through co-ordinated, targeted actions to drive uptake of practices and technologies that are beneficial to society and beneficial to farmers once established.

# 4

# Targeted actions to support sustainable change

## Action is needed now

Fast, coordinated action on emissions has never been more important than it is today. The time value of carbon produced now means emissions reductions today have an outsized impact compared to emissions reductions in the future as the world looks to manage the impact of climate change on the environment. Delaying action may lead to runaway warming caused by passing climate tipping points, such as changes to ocean circulation, ice loss, and permafrost loss.

Multiple environmental disasters in 2022 and 2023 highlight the need to accelerate action, particularly in the agri-food sector, which is exposed to drought, flooding, fires and disease. These climate-linked disasters put crops and livestock production at risk, threatening food security, lives and livelihoods in many parts of the world.

Meanwhile, geopolitical tensions can impact agri-food systems at short notice, as seen with Russia's invasion of Ukraine and India's ban on rice exports, both of which had significant impacts on food security.

These disasters and geopolitical actions have put agri-food front of mind and high on the international community's agenda. However, action cannot come soon enough. El Nino is expected in 2023-2024 based on observations from the National Oceanic and Atmospheric Administration (NOAA). The previous El Nino in 2015-16 drove a 16% spike in the global price of rice, as a result of climate-driven disruption to rice cultivation.

## International and country-level roadmaps must coordinate actions

Reducing emissions in the Asian agri-food sector is highly complex and requires actions from all stakeholders. These actions cannot be taken by the various parties in isolation; they must be coordinated if agri-food is to become more sustainable and profitable for all those involved.

A roadmap to coordinate actions across stakeholders is therefore essential. This roadmap must prioritise areas for action and set ambitious, but achievable, targets. Considerations for the roadmap include:

- The establishment of global standards and methodologies to measure, report and audit emissions from agri-food.
- The verification and validation of the carbon markets.
- Frameworks to streamline and expedite approval for new technologies for use in global markets while retaining rigour in key safety tests.
- Incentivisation of different stakeholders to act (e.g. smallholders, large MNCs, financial institutions, etc.).

The phasing of the roadmap will be vitally important – for example, government incentives and disincentives must be applied to nudge behaviour at the optimum point in time, when the solution offers sufficient reward to those involved to continue once the incentives are removed.

# Actions required by stakeholders

| Action group | Action | Government | Regulators | Financial institutions | Investors |
|---|---|---|---|---|---|
| **Public policy, regulation and engagement** | Establish a roadmap to prioritise actions and support this with stable long-term actions to support these priorities. | △ | △ | | |
| | Create clear, efficient regulatory standards and pathways to measure carbon dioxide equivalent emissions along the value chain, including the use of local emissions factors. Draw on collaboration across the value chain to ensure the measurement methodologies are simple and implementable. | △ | △ | | |
| | Improve the reliability and validity of the carbon markets (both voluntary and regulated), and incentivise actions using a time-based system, recognising both reduction and sequestration of carbon dioxide equivalent emissions, to better direct support to the most effective technologies and practices. Apply a regulated carbon market to agri-food with a suitable carbon price to drive action. | △ | △ | △ | |
| | Raise awareness of the benefits of new practices and technologies for all parties involved. | △ | | | |
| | Clarify and simplify land ownership rights with a view to increasing the security of smallholders to invest in their farms, to the extent possible. | △ | △ | | |
| | Test and prove the efficacy of new technologies to reduce emissions. | | △ | | |
| | Create a low carbon verification programme for consumer goods (similar to Fairtrade), and include this on packaging visible to consumers. | | | | |
| **Incentivisation** | Offer initial subsidies to nudge behavioural changes, or support the purchase of key equipment. | △ | | | |
| | Offer targeted ongoing subsidies to incentivise decarbonisation behaviours in economically important industries that are challenging to decarbonise profitably (e.g. dairy). | △ | | | |
| **Financing and investing** | Invest in technologies that have the potential to reduce emissions. | | | | △ |
| | Finance and invest in large-scale infrastructure programmes, including those that improve the infrastructure of the agri-food supply chain. | △ | | △ | △ |
| | Finance the smallholder transition period (the period between technology implementation or practice change and the positive yield and / or profitability impact). | △ | | △ | |
| **Retail** | Remove incentives that encourage consumers to overbuy (e.g. remove multi-buy discounts and prioritise lower single unit prices). | | | | |
| | Take actions to prioritise food being consumed rather than other less efficient waste valorisation routes, such as biofuel. | △ | △ | | |
| **End user / consumer** | Be willing to engage with both on-the-ground support and digital solutions, and adapt practices according to the new knowledge shared with you. | | | | |
| | Be willing to make a purchasing or stocking decision based on carbon emissions, and potentially pay more for verified low carbon products. | | | | |
| | Reduce overbuying and food waste. | | | | |
| **Collaboration** | Facilitate good data sharing to enable Scope 3 emissions tracking without inhibitory additional charges for partners looking to understand emissions in their supply chain or customer base. | | △ | | |
| **Measurement** | Measure end-to-end carbon dioxied equivalent emissions (Scope 1, 2 and 3) | | | | |

△ Action required

| NGOs | Academic institutions | Farming input suppliers | Traders | Large downstream MNCs | Large farms | Small-holders | Retailers | Consumers |
|---|---|---|---|---|---|---|---|---|
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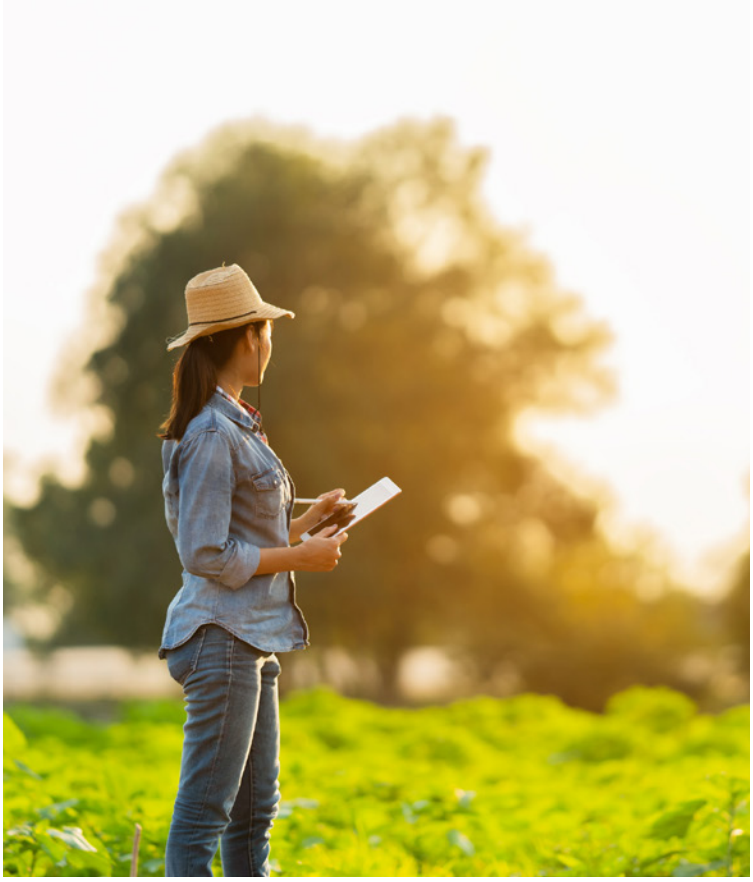
△ Action required

## Engagement of smallholders

Reducing Scope 3 emissions (up to 90% of agri-food emissions in some value chains) will not be possible without the solutions working at an individual farm level. Engaging smallholder farmers is key when introducing and phasing support measures and incentives.

If the roadmap does not work for the smallholders, it will have limited impact on emissions as a whole. Agriculture is a livelihood for many of these smallholders, particularly in rural Asia, and actions that do not adequately consider the effect on them are likely to have social and political impacts. One area of further consideration regards land ownership rights. Any actions governments can take to clarify and simplify these often complex or unclear arrangements, with a view to increasing smallholder security, would increase their ability to invest in more efficient farms.



## Consumers must drive change

Consumers consistently indicate a preference for lower emissions food. They must drive change in emissions from agri- food through their purchasing decisions and actions. Other stakeholders must support them by creating environments to enable consumers to make these decisions. Three examples of actions consumers can take, and the support needed from other stakeholders, are below:

- **Make purchasing decisions based on the emissions profile of foods** – prioritise lower emissions foods when choosing between similar brands or interchangeable food types. To do this, other stakeholders must drive action to create a low emissions verification programme, and make this information accessible to the consumer, for example by including it on the food packaging. Some consumers may also be willing to pay more for lower emissions food to drive change faster.

- **Avoid overbuying to reduce food waste** – consumers often overbuy to increase convenience and reduce the price of food. Consumers should look to buy only what they need, and retailers must look to support this by removing unnecessary multi-buy discounts and applying the savings to the individual items.

- **Reduce consumption of high emissions foods and focus on quality** – consumers can look to reduce their consumption of high emissions foods, such as beef, and look to focus on eating high-quality beef less regularly. There is therefore a need for a tasty, healthy, price competitive alternative.

## Carbon markets are key to driving significant change

Carbon markets are key to driving the increased adoption of technologies and practices to decarbonise agri-food in Asia. They represent an additional potential revenue stream for stakeholders that may not otherwise take actions to decarbonise their operations.

**Case Study**

### The carbon markets

The Asian agri-food sector is well suited to generate revenue from the carbon markets as the low cost of implementation of highly effective technologies and practices means it is easier to act here than in many other, hard to decarbonise industries. There is also potential for carbon sequestration through soil carbon retention, forest and peatland restoration, and afforestation, including approaches such as agroforestry, in which trees are integrated into functional farming land (for example, in strips or as windbreaks). Many of the barriers to action when looking to reduce carbon equivalent emissions in agri-food are social or financial, rather than technological. This is not the case in some other sectors, such as the energy sector, which faces more significant technological barriers to decarbonisation in the short-term. Carbon markets can play a role in addressing these social and financial barriers.

**Carbon credits and offsets:**

- Regulatory carbon pricing applies a cap on the amount of carbon that can be produced by an organisation – anything above that must be abated or offset, anything below that can be traded as a ‘credit’. This cap may then decrease to drive emissions down. This creates a trade in carbon credits and offsets to meet regulatory demands and regulatory carbon markets are often referred to as ‘cap-and-trade’. Only the largest companies in the most emissions intense sectors are currently subject to this, although this may change in the future.

- Voluntary carbon pricing facilitates an organisation’s voluntary commitment to reduce emissions. Abatement should be the first action taken, but for hard to abate emissions offsets can be purchased on the market. The Science Based Target initiative’s (SBTi’s) corporate net-zero standard for setting corporate net-zero targets in line with 1.5°C requires residual emissions that cannot be abated to be offset with permanent carbon removals. The demand for these offsets will likely increase as more companies look to sign-up to rigorous decarbonisation targets, such as the SBTi.

# The carbon markets (cont.)

**There is therefore the opportunity for best-in-class organisations to:**

i. Reduce emissions beyond any carbon dioxide equivalent emissions caps, which may generate carbon credits or offsets to trade. Take a rigorours approach to measuring and validating these reductions, to support a high-quality carbon credit or offset. The technologies and practices considered in this report would help facilitate this.

ii. Sequester carbon to generate carbon offsets through the integration of afforestation, restoration and reforestation approaches, many of which can be combined with forms of farming (e.g. silvopasture, agroforestry).

**However, the carbon market has faced challenges, namely:**

- Challenges measuring carbon dioxide equivalent emissions have led to uncertainty around the actual emissions reduction of some credits and offsets.
- There has been limited progress to create a global set of standards to certify the validity of carbon credits and offsets.
- The resulting low validity of carbon credits and offsets traded has reduced corporate trust in the voluntary carbon market, as corporates seek to avoid 'greenwashing' labels.
- The carbon price, particularly in the voluntary carbon market, is too low to enforce meaningful change in some areas that offer the highest potential for reduction, in large part due to the prevalence of low-quality, low-price carbon credits and offsets in the market. These typically support carbon emission avoidance from forested areas, which have almost zero cost to implement. The cost of removing carbon from the air is multiple times higher than the current carbon price.
- Not all sectors or companies are included in the regulated carbon markets in Asia.

In order to address these challenges, an agreed set of regulatory frameworks, including measurement standards that take into account the duration and reliability of emissions reduction and sequestration, and accurate local emissions factors will be required. This should lead to higher carbon prices that reflect the true value of carbon, which in turn will act as more attractive incentives. This would support further investment into the areas that can best contribute to decarbonisation, including many in the Asian agri-food sector. The Asian Development Bank estimates a carbon price of at least US$70 per tonne in Asia is required by 2030 to drive action. Additionally, if Asia does not act to price carbon properly across industries, it may also impact its trade competitiveness as other regions apply carbon border adjustment tariffs.

Applying these technologies and practices to drive an 840 Mt $CO_2e$ reduction in emissions in the agri-food sector in Asia could potentially generate additional revenue streams from the carbon markets. However, these vary widely based on the price of carbon and the penetration of the carbon markets into smallholder farming. These revenue streams could be between US$2 billion – the potential revenue from the voluntary carbon markets (using an optimistic assumption of US $10 per tonne and 20% penetration of the 840 Mt $CO_2e$ carbon emissions reduction) – and US$59 billion – assuming regulated carbon markets encompass the agri-food sector in Asia (facilitated by technology and alignment of emissions measurements), with a carbon price of US$70 per tonne.[19]

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[19] Asian Development Bank

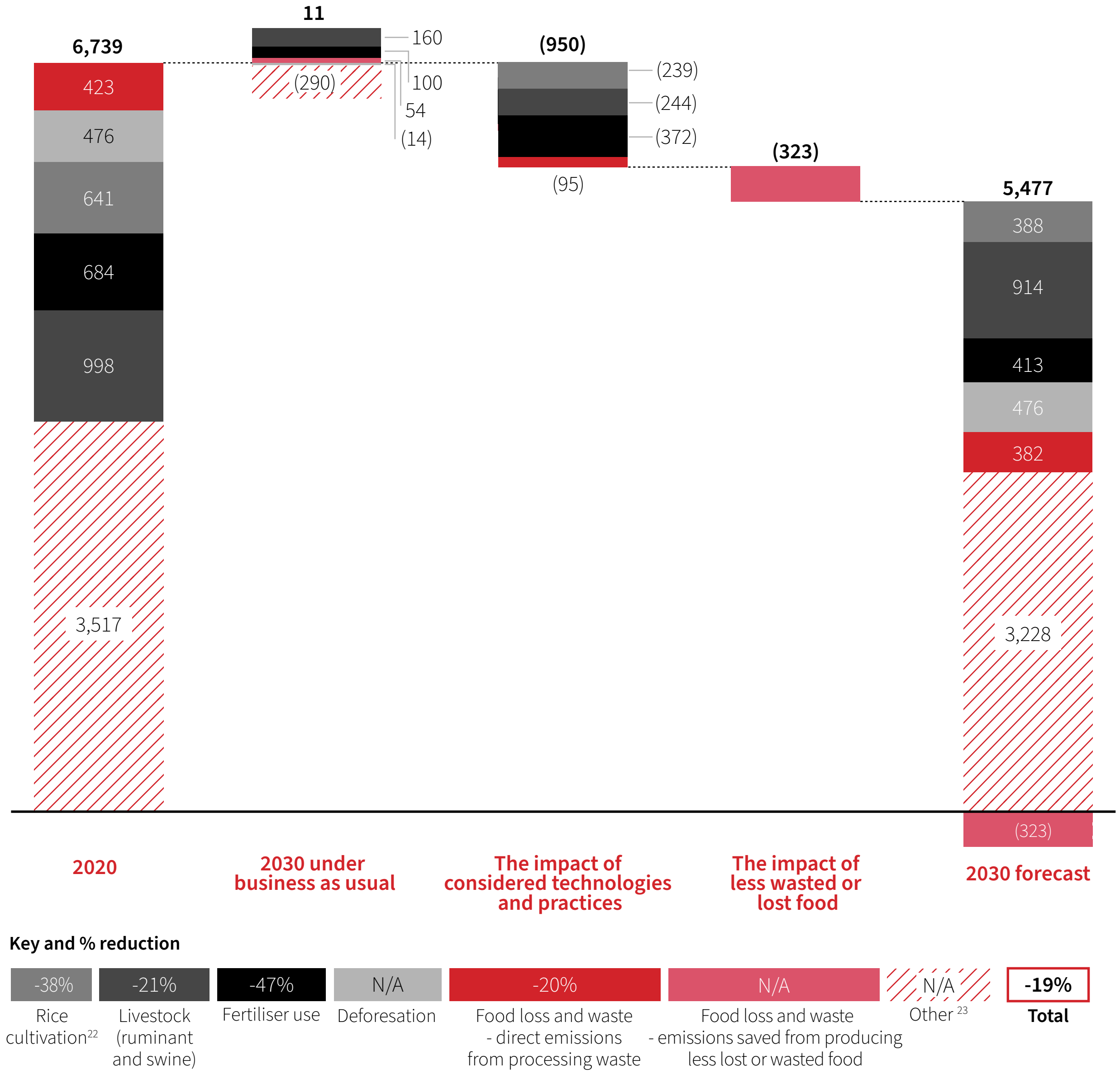
# There is the potential to accelerate the uptake of these technologies

In an upside scenario, additional incentives and highly functional carbon markets could be applied to further drive penetration of the practices and technologies that we have considered. In this scenario the carbon dioxide equivalent emissions from the Asian agri-food sector could be reduced by up to 1,260 Mt $CO_2e$ emissions in 2030 (c. 19% of the 2030 business-as-usual value), equivalent to 1.6 times the emissions from the global aviation industry in 2022, and greater than 840 Mt $CO_2e$ emissions in 2030 that we highlight as possible under the current incentivisation landscape.

Forecast impact of technologies and practices on carbon dioxide quivalent emissions of Asian agri-food - upside scenario

**Quantification of decarbonisation impact from the application of assessed technologies / practices under an accelerated support trajectory**

Mt $CO_2e$[20], 2020[21]-2030



Source: FAO, PwC analysis

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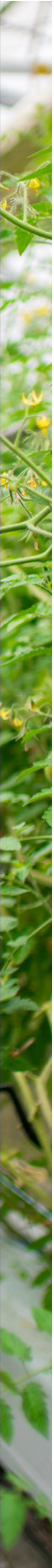
20 $CO_2e$ emissions calculated using a 100 year global warming potential (GWP) under AR6 guidance

21 2020 data is the latest available from the FAO

22 Rice cultivation excludes emissions from fertiliser use, deforestation and food loss and waste

23 Other emissions are those not included in the problem areas, such as emissions from downstream operations, agri-food electricity use and wastewater, transport, and crop / livestock management beyond rice, ruminants and swine, other than fertiliser, which is fully included



# 5 The current investment landscape

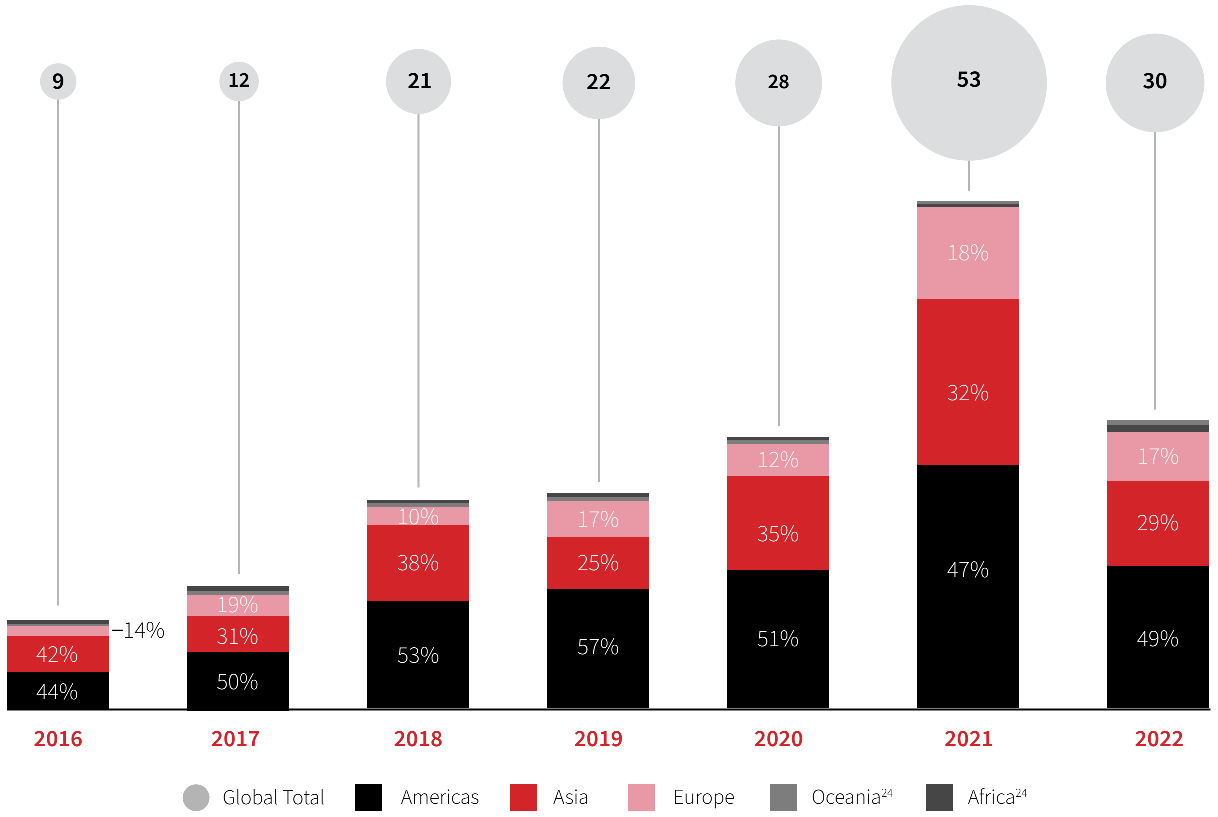
## Early stage investment in agri-food technology globally

Early stage agri-food technology deals activity to date has been focused largely on Western assets – approximately two thirds of this global investment between 2019 and 2022 was in Europe and the Amercias (most of which is from the US, c. $12.4 bn of the $14.7bn invested in the Americas in 2022). While this investment in agri-food technology has dropped in 2022, it remains above 2019 levels, indicating continued focus on the sector from investors.

Early stage agri-food technology deals activity to date has been focused largely on Western assets – approximately two thirds of this global investment between 2019 and 2022 was in Europe and the Amercias (most of which is from the US, c. $12.4 bn of the $14.7bn invested in the Americas in 2022). Most agri-food technologies are currently designed for larger scale US and European mechanised farms and are therefore less suitable for smallholder farms in Asia, without adjustments and localisation to account for different farm sizes, farming practices and environmental conditions (such as soil health and water scarcity). The development of this machinery in the US and Europe has also led to a larger pool of high value targets to invest in, while many targets in Asia are earlier stage. The investment in Asia tends to be driven by relatively underdeveloped production systems, logistics solutions and supporting infrastructure compared with those in Western agri-food value chains.

## Early stage investment in agri-food technology by region

USD Bn, 2016-2022



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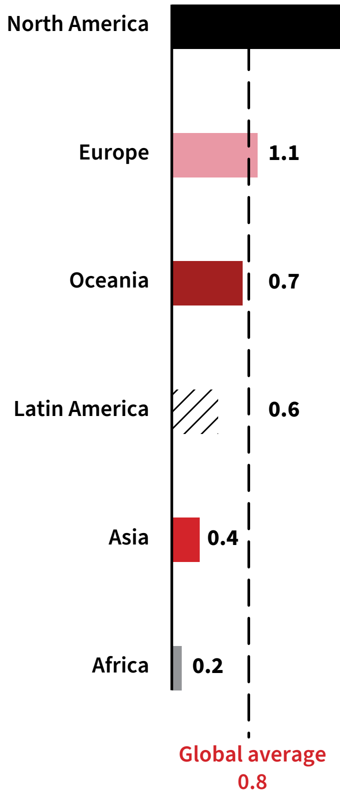
[24] Graph numbers not shown for Oceania or Africa, they are less than 2% each in all years

This difference is particularly notable when considered in the context of production values – the early stage investment in agri-food per dollar of produce in the US is approximately 11 times greater than in Asia.

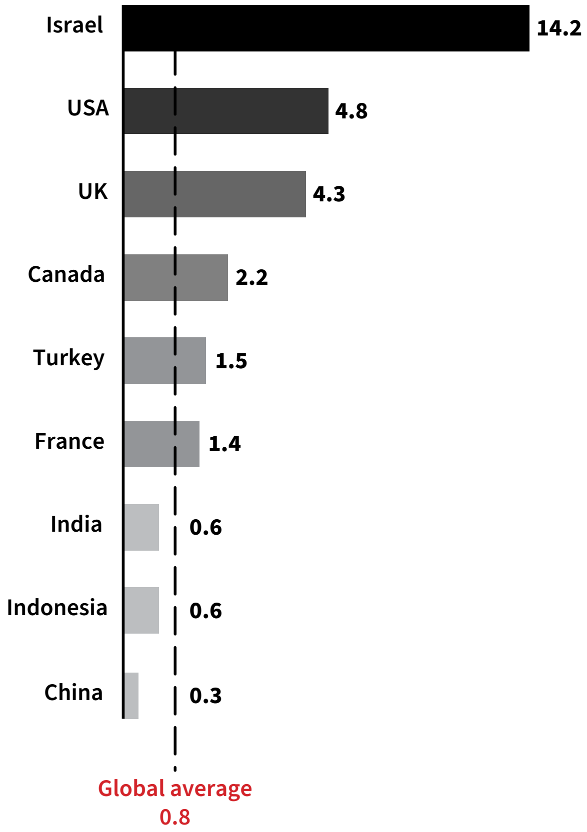
Early stage investment in agri-food technology relative to production value by region

USD cents of early stage investment in agri-food technology per dollar of agricultural production, 2020-2022 average[25]



Early stage investment in agri-food technology relative to production value by country - selected countries only

USD cents of early stage investment in agri-food technology per dollar of agricultural production, 2020-2022 average[26]



Source: AgFunder, FAO

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[25,26] 2020-2022 average early stage investment in agri-food technology per 2020-2021 average agircultural production value as 2022 value not available from the FAO

# Sources of investment

Investment in agri-food technology is typically from private capital, mainly Private Equity (PE), Sovereign Wealth Funds and Venture Capital (VC) funds, as well as some corporate investment, which typically invest in assets at different stages of maturity. Sovereign Wealth Funds are particularly active given the significance of agri-food to national food security.

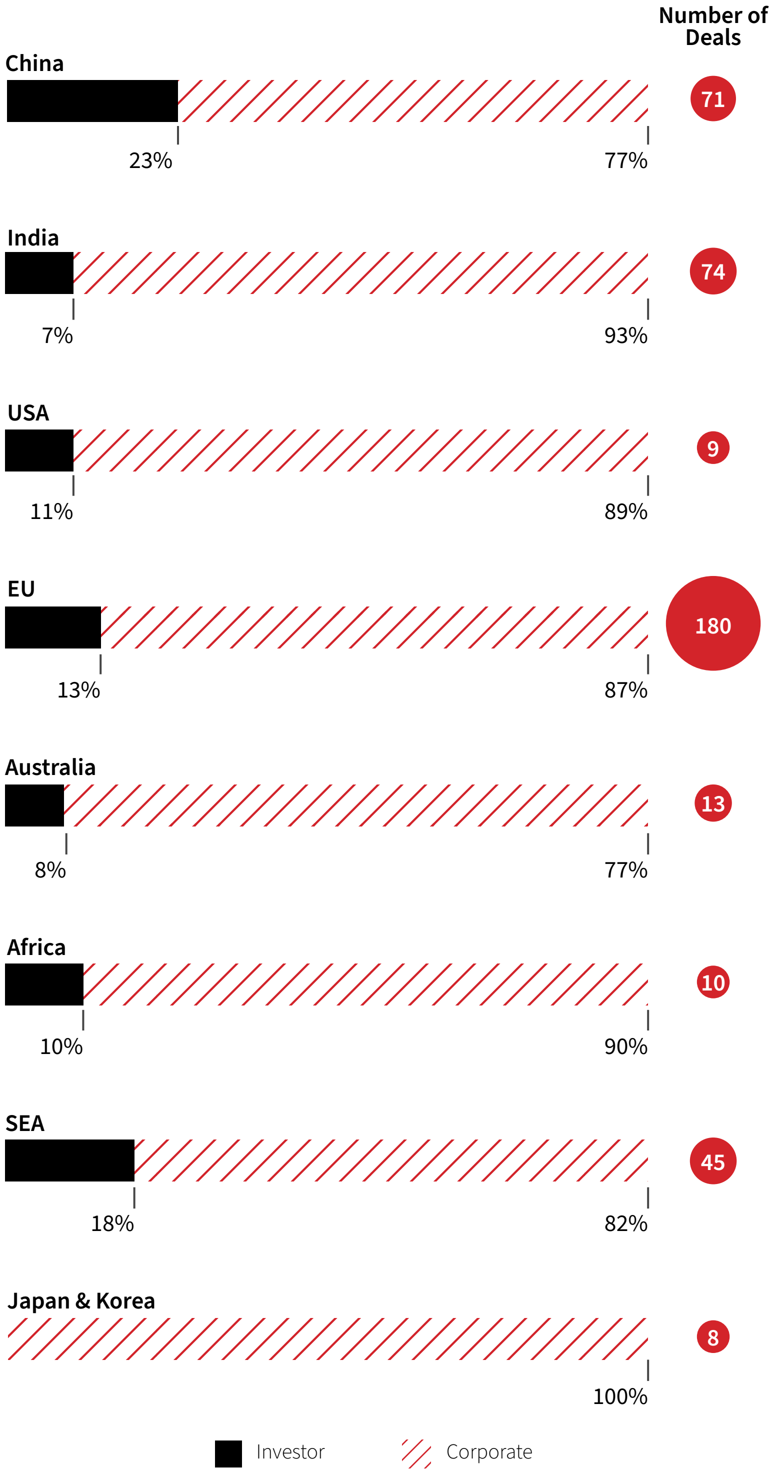
Specialist agtech-focused VC funds and sustainability / climate-focused PE funds are increasingly active investors in agri- food, driven by the disruptive potential of many technologies, for example marketplaces to disintermediate complex supply chains, as well as the positive decarnbonisation and social impact potential in the sector.

However, investments from large, more traditional agri-food corporates remain a significant part of the picture. Approximately 23% of early stage funding deals in China between 2020 and 2022 involved corporates, in particular large state-backed Chinese agribusinesses. This analysis does not include investment into more mature businesses, which can also be significant across regions. We address this in more detail in our previous report, ‘The Asia Food Challenge: Harvesting the Future’.

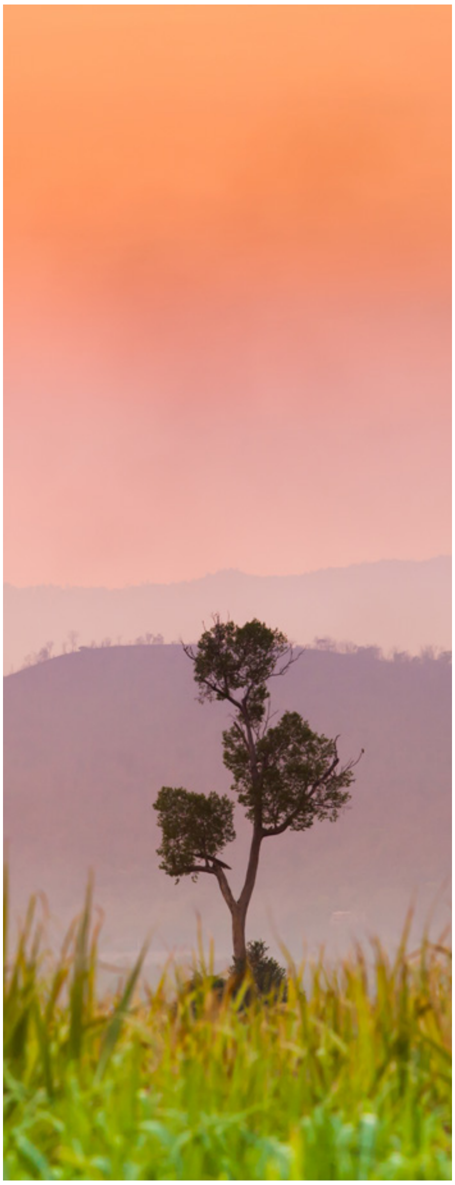
## Early stage agri-food technology investment by source of capital

**Non-exhaustive early stage investments in selected geographies**

% of deals / number of deals analysed, 2020-2022



Source: AgFunder



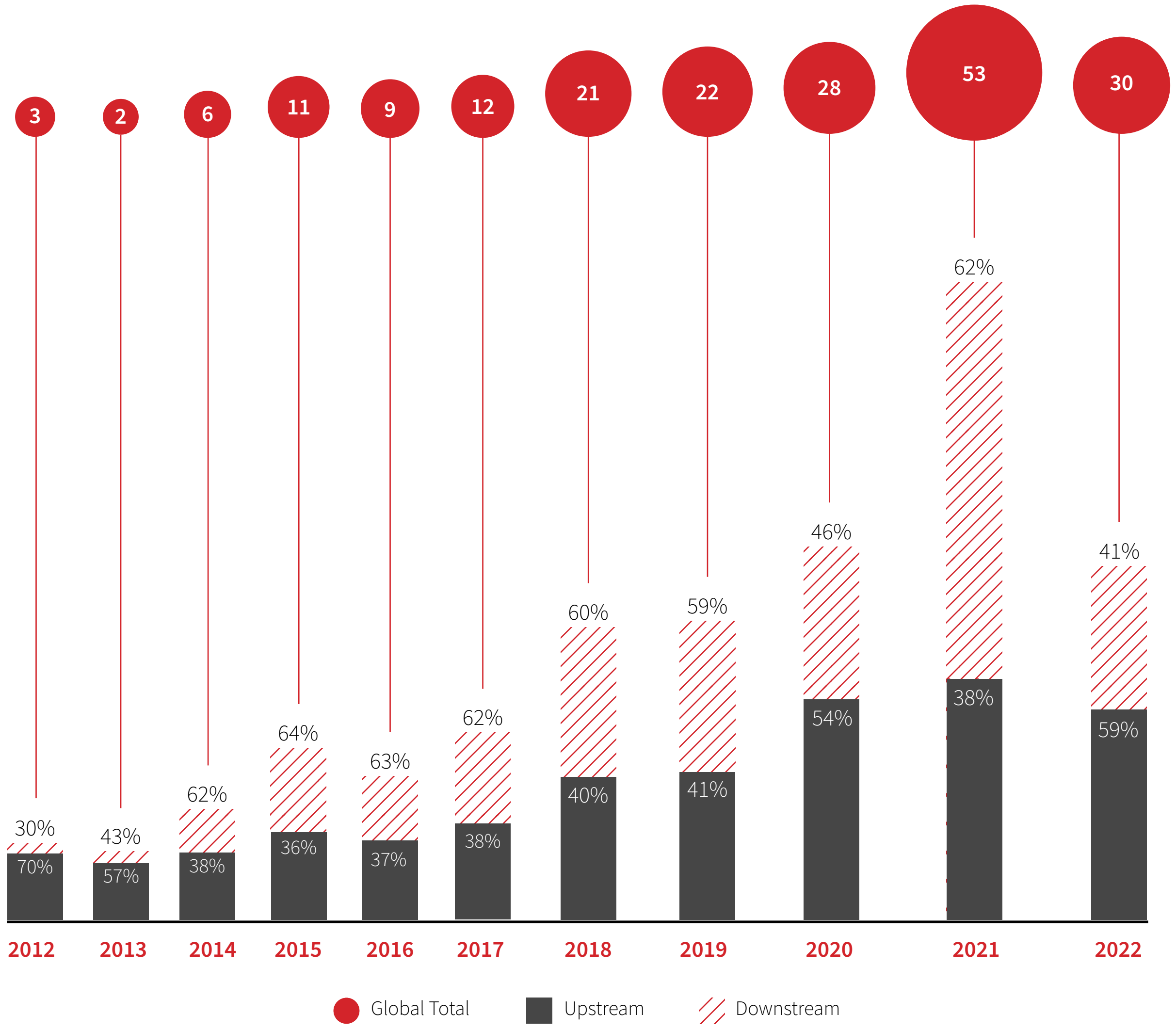
## Upstream in focus

There is an increasing focus on upstream investment, driven in part by greater access to the upstream through smallholder engagement platforms, and an increasing focus on sustainable and regenerative practices, linking closely to the potential for decarbonisation. These simple practices and technologies have significant yield improvements and a clear value proposition. They also serve a social need, improving potential access to government support and favourable regulation.

Global early stage agri-food technology investment by stage of the supply chain

**Non-exhaustive early stage investments**

USD Bn of early stage investment / % of total early stage investment, 2012-2022



Source: AgFunder

To-date, upstream investment in China and India has principally been focused on biotechnology, including biological stimulants and other chemicals to reduce emissions and improve results compared to using traditional chemicals, as well as platforms and marketplaces to improve access to smallholders and disintermediate complex supply chains, which add significant cost and make emissions measurements complicated. Asia-specific farm robotics and machinery is also an area of active investment, particularly drones for measurements and application of chemicals, which are increasingly common in China in particular. There is the potential to increase the use of this Asia-specific machinery across South and South East Asia, but funding is more complex given smallholder farms are run independently. In China many smallholders lease their land to large third-party farming organisations, which facilitates investments in capital-heavy machinery.

# Agri-food technology by stage of the value chain

## Upstream

**Agriculture Biotechnology**

On-farm inputs for crop & animal agriculture including genetics, microbiome technology, breeding technology, animal health

**Agribusiness Marketplaces & Fintech.**

Commodities trading platforms, online input procurement, equipment leasing, farmer fintech

**Bioenergy & Biomaterials**

Novel materials, non-food extraction & processing, feedstock technology

**Farm Management Software, Sensing & IoT**

Agriculture data capturing devices, decision support software, big data analytics

**Farm Robotics, Mechanisation & Equipment**

On-farm machinery, automation, drone manufacturers, growing equipment

**Novel Farming Systems**

Indoor farms, aquaculture, insect & algae production

**Supply Chain Technologies**

Food safety & traceability tech, logistics & transport, processing tech

**Innovative Foods**

Cultured meat, novel ingredients, plant-based proteins

**Miscellaneous**

All other agri-food-related technology

## Downstream

**In-Store Retail & Restaurant Tech**

Shelf-stacking robots, 3D food printers, payment systems, food waste monitoring IoT

**Home & Cooking Tech**

Smart kitchen appliances, nutrition technologies, food testing devices & home grow kits

**Cloud Retail Infrastructure**

On-demand enabling tech, ghost kitchens, last-mile delivery robots & services

**Online Restaurant & Meal Marketplaces**

Online tech platforms delivering prepared food and meal kits from a wide range of vendors

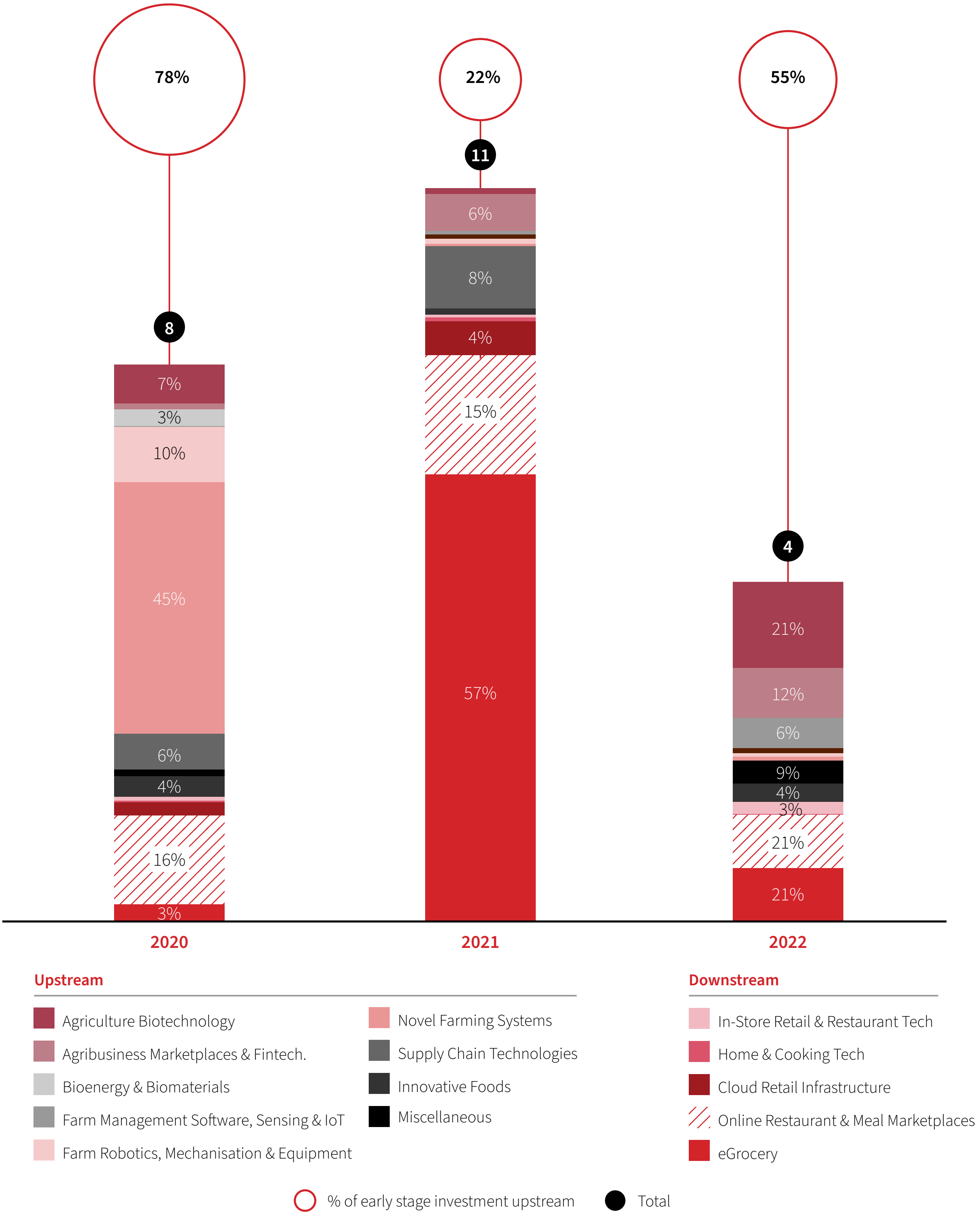
**eGrocery**

Online stores & marketplaces for sale and delivery of processed and unprocessed food products to consumers

Source: : Agfunder, PwC analysis

## Early stage agri-food technology investment in China and India[27] by type of agri-food technology

USD Bn of early stage investment / % of early stage investment by agri-food technology area, 2020-2022[28]



Source: AgFunder, FAO

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[27] China and India shown due to the scale of early stage agri-food technology investment in these countries in Asia

[28] Chart segments with 1% or 2% have not been labelled

# Selected early stage investments in agri-food technology

*Illustrative and non-exhaustive - highlighting various technologies*

## Examples of Agribusiness Marketplaces & Fintech businesses

| Company Name | Description | Geography |
|---|---|---|
| **Dehaat** | Plsatform providing agricultural inputs, agronomic advice, financial services, etc. | 🇮🇳 |
| **Agrostar** | Platform providing agronomic advice personalised to the plots of smallholders and a marketplace for agri. inputs, physical tools, etc. | 🇮🇳 |
| **Vegrow** | Platform providing agronomic advice, supply chain services, and a marketplace for agricultural inputs | 🇮🇳 |
| **Bighaat** | E-commerce platform for agricultural inputs with additional agronomic advice | 🇮🇳 |
| **Moofarm** | Developer of dairy farm management software | 🇮🇳 |
| **Jai Kisan** | Fintech platform that provides sustainable financing to rural smallholders in emerging markets | 🇮🇳 |
| **Aye Kart** | Supply chain and fintech management platform | 🇮🇳 |
| **Bijak** | B2B platform for agricultural commodities for SME buyers and sellers | 🇮🇳 |
| **Animall** | Dairy and cattle marketplace | 🇮🇳 |
| **Captain Fresh** | Seafood marketplace and supply chain services | 🇮🇳 |
| **Gramophone** | Platform providing agronomic advice and data to optimise farming output | 🇮🇳 |

## Examples of Agriculture Biotechnology businesses

| Company Name | Description | Geography |
|---|---|---|
| **ZhongXin Breeding** | Provider of pig breeding technology to sustainably breed high quality, healthy pork | 🇨🇳 |
| **Absolute Foods (Inera CropScience)** | Producer of sustainable biofertilisers | 🇮🇳 |
| **Desert Control** | Technology provider focused on converting arid land to farm land | 🇪🇺 |
| **Derit seeds** | Seed breeding and R&D company | 🇨🇳 |
| **CapitalBio Technology** | Analytical instruments for use in biological and chemical R&D and quality control | 🇨🇳 |
| **Cwbio IT Group** | Biological reagents producer | 🇨🇳 |
| **Jinse Nong Hua** | Seed breeding and R&D company | 🇨🇳 |
| **Bota Biosciences** | Developer of an AI-based platform for enzyme and microorganism strain engineering | 🇨🇳 |
| **Qihe Biotech** | Producer of grow-at-home fungi logs | 🇨🇳 |
| **Readline** | Developer of immobilized enzyme catalysis technology | 🇨🇳 |
| **Lead Biotechnology** | Drug developer leveraging AI technology | 🇨🇳 |
| **Igenesis** | Manufacturer of molecular diagnostic technology and products | 🇨🇳 |
| **Enzymaster** | Developer of novel enzymes and enzymatic catalysis technology | 🇨🇳 |

### Examples of Farm Robotics, Mechanisation & Equipment businesses

| Company Name | Description | Geography |
|---|---|---|
| **XAG** | Drone service provider | 🇨🇳 |
| **i-KINGTEC** | Developer of intelligent industrial drone and UAV systems | 🇨🇳 |
| **Quadtalent** | Provider of digital transformation and enterprise AI solutions | 🇨🇳 |
| **FJ Dynamics** | Developer of intelligent logistics robots | 🇨🇳 |
| **Clobotics** | Provider of a cloud-based industrial data analytics platform | 🇨🇳 |
| **Yetiantieniu** | Agricultural equipment manufacturer | 🇨🇳 |

### Examples of Farm Management Software, Sensing & IoT businesses

| Company Name | Description | Geography |
|---|---|---|
| **Agnext** | Agricultural sensing platform focusing on precision and digital agri-technologies | 🇮🇳 |
| **Cropin** | Farm management software facilitating data-driven farming | 🇮🇳 |

### Examples of Novel Farming Systems businesses

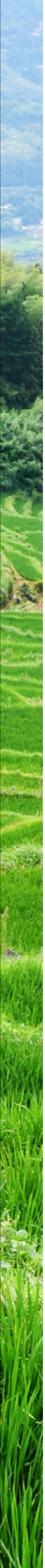
| Company Name | Description | Geography |
|---|---|---|
| **Xiaozao Tech** | Biofuel producer from micro-algae | 🇨🇳 |
| **Aqgromalin** | Platform offering IoT monitoring systems and blockchain-enabled tech solutions to smallholder farms | 🇮🇳 |

## Investment outlook

The Asian agri-food sector represents a continued investment opportunity. Near-term areas of investment include machinery and robotics, as well as other simple technologies, such as irrigation, while mid-term there are opportunities in biologicals and advanced plant nutrition, and genetics. Packaging is another area of potential innovation and investment, as it remains an area of Scope 1 emissions for large downstream corporates. There is also a significant requirement for infrastructure investment, in processing, storage, cold chain and effective waste valorisation.

Drivers of investment in agri-food also include factors such as:

- **Population growth** – the increasing demands of a growing population.
- **Growing middle class** – the demand for more, higher quality food, typically with a higher profitability for sellers, increases the availability of funds for investment.
- **Urbanisation** – the growing population of cities drives the need for novel ways of meeting their food demands, such as eGrocery and delivery platforms.
- **Technological adoption in the upstream** – the uptake of technology to improve efficiency and yields upstream, and facilitating platforms to enable this.
- **Sustainability** – an area of increasing focus by impact funds.
- **Food security** – governments in the region are focused on food security, leading to investments to secure their food supply chains.



# 6

# The Asian agri-food company's playbook

## We have sought to highlight key technologies and practices that present actionable opportunities for decarbonisation in the Asian agri-food sector.

Technology is a key enabler of the decarbonisation journey. However, not all technologies will be immediately applicable to every farm and company, and technologies not mentioned in this report will also play important roles. The optimal technologies for an individual business' operations are affected by multiple factors, including their position in the value chain; crop, livestock or product types; geography; local behaviours and customs; company size; and infrastructure.

The first step every company must make when embarking on the decarbonisation journey is to measure emissions accurately across their value chain. This will provide insight into which technologies and practices are the optimal solution for them. Emissions are challenging to measure accurately, particularly Scope 3 emissions. It is also an area that is expected to evolve rapidly as governments, regulators and other stakeholders increasingly standardise methodologies and research into geography-specific emissions factors, which will improve the accuracy of measurements.

Organisations can therefore acknowledge that their current view of emissions is likely imperfect and limited, and balance this with the need to take action immediately by prioritising 'no regret' areas, which target known emissions 'hot spots' and generate positive business impacts.

**Case Study**

**Terrascope**

## Challenges in emissions measurement

Measuring Scope 3 emissions in agri-food presents significant challenges given the multi-layered agri-food value chains.

Traceability is a major challenge since agri-food supply chains encompass food processors, farmers, fertiliser producers, and varied transportation modes, with each node contributing unique emissions at different stages. The fragmentation of the value chain increases the number of entities from which emission data needs to be collected.

Data maturity is also a challenge since a significant number of entities in the value chain typically lack sophisticated mechanisms for capturing and submitting data. As a result, companies resort to using proxy data or industry averages. This then leads to a loss of data granularity and a reduction of accuracy, making it harder to identify opportunities for abatement. The issue of data accuracy is also compounded by the fact that data is often manually captured or estimated, and may not represent the actual processes on the ground. Additionally, proxy data, such as emissions factors, are often not specific to the region and practices being used, which can lead to inaccuracies.

The absence of standardised reporting adds to the complexity of data assimilation. While established guidelines like the GRI Standards exist, the lack of a universally adopted format results in a variety of methodologies, each with its own degree of reliability. Additionally, non-climate-centric policies in areas such as macroeconomics and the environment often overshadow dedicated climate policies, necessitating a more concerted global response.

Lastly, the constraints in resources are a significant barrier. The extensive nature of agri-food value chains makes measuring emissions both resource-intensive and costly. To navigate these multifaceted challenges, collaborative efforts, enhanced global cooperation, and advancements in carbon measurement technology are paramount.

## Emissions in the rice value chain

In the rice value chain in India, for instance, emissions are markedly skewed towards the production end of the value chain, with between 50% and 65% of the emissions generated during the Supply / Production stage, involving processes such as seed supply, fertiliser use, and flooding of rice paddies. Post-Harvest Processing accounts for a further 10% to 25%. The remaining emissions, of between 20% and 25%, come from Distribution and Consumption, covering transportation and end-user practices.

**Carbon dioxide equivalent emissions along an example rice value chain in India**

| **Stage** | **Supply / Production** | | **Post-Harvesting Processing** | | **Distribution & Consumption** | | |
|---|---|---|---|---|---|---|---|
| **Proportion of emissions** | 50-65% of emission | | 10-25% of emissions | | 20-25% of emissions | | |
| **Step** | **Input supply** | **Production** | **Trading & Distribution** | **Dehusking & polishing** | **Wholesale distribution & export** | **Retail** | **Consumption** |
| **Key Players** | • Farmers<br>• Seed & agrochemical companies<br>• Banks<br>• Equipment suppliers<br>• Government | • Farmers | • Traders & local buying agents<br>• Government | • Processors<br>• Millers<br>• Custom mills | • Wholesalers<br>• Exporters | • Retailers | • Consumers |
| **Activities & Inputs** | • Seed collection<br>• Seed supply<br>• Fertilier supply<br>• Equipment supply<br>• Financing | • Growing<br>• Harvesting<br>• Drying<br>• Threshing | • Paddy collection<br>• Paddy selling<br>• Rice trading | • Drying<br>• Storage<br>• Dehusking<br>• Grading<br>• Milling<br>• Polishing | • Wholesale<br>• Rice export | • Selling | • Consumption |

# Challenges in Emission measurement (cont.)

### Scope 3 emissions in the rice value chain

Estimating Scope 3 emissions is an intricate task, complicated by factors like localised agricultural practices, geographical variations, supply chain fragmentation leading to data unavailability, and changing technologies. Terrascope builds confidence in emissions data and helps close data gaps through AI-powered emissions factor matching and hotspot analysis. Based on a number of rice buyers and traders that Terrascope has worked with, Scope 3 emissions in the rice value chain account for over 75% of the total emissions, emanating largely from purchased goods, cultivation practices, and logistics.

### Decarbonisation levers in focus

Once emissions have been estimated and mapped, effective levers can be identified and implemented. Based on Terrascope's experience in-field, supplemented by simulations for rice-fields in Asia, Terrascope has identified three decarbonisation levers that have had a significant impact on emissions for its customers in Asia. Below are three examples of best-in-class actions customers can take and the benefits customers have realised from applying these levers to their operations.

#### i. Alternate Wetting and Drying (AWD)

One of Terrascope's clients implemented AWD in a northern Indian state. The initiative, rolled out to 700 farmers in 2021, aimed to improve the production of quality, sustainable, traceable, and safe Basmati rice. The implementation of AWD in 217 farms reduced the water withdrawal per kilo of rice produced from approximately 3,800 litres to 3,200 litres. The project has delivered 20% reduction in costs, 12% increase in yield and 30% net income increase for farmers, while reducing methane emissions by 48%.

#### ii. Site-specific Nutrient Management (SSNM)

One of Terrascope's clients provides training to farmers with the objective of changing behaviour to reduce synthetic fertiliser use on-farm and to encourage an optimal balance of fertiliser use as part of the Sustainable Rice Platform (SRP) registered training programme.

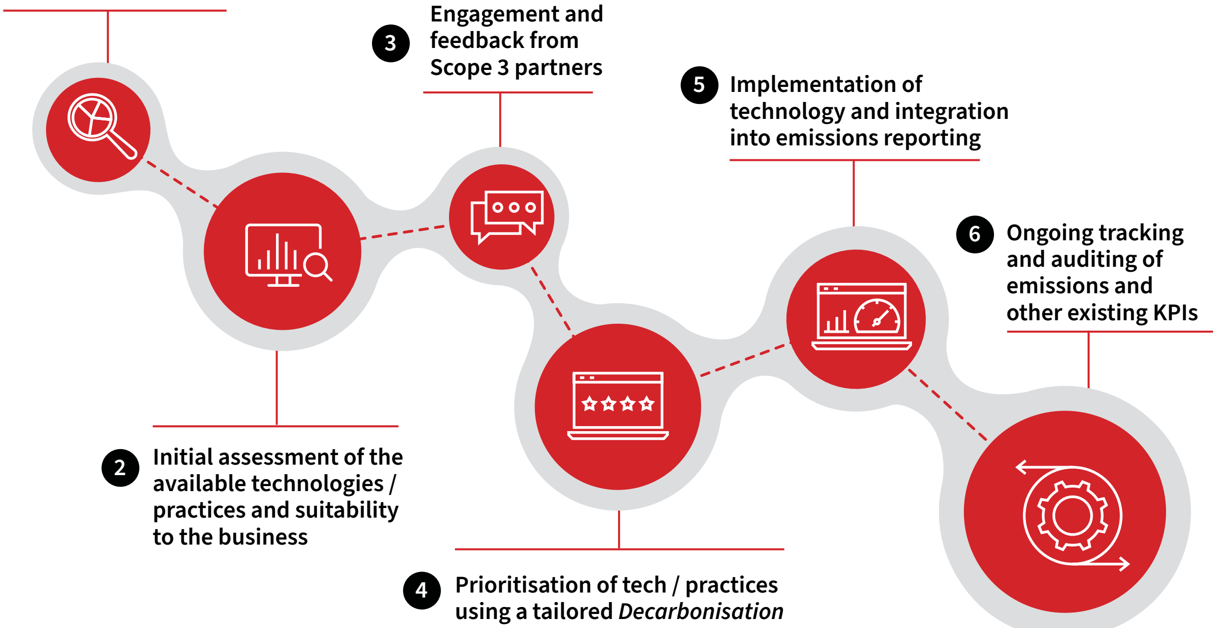
They have estimated the impact of changes in fertiliser use by comparing fertiliser use for 2,400 farmers who have received between two and three years of training to those that have received one year of training. The results were significant. For those who received between two and three years of training, on a per tonne of rice basis, the annual societal costs of water pollution and GHG emissions were estimated to be reduced by 14% and 21% respectively. Additionally, for the 2,400 farms, additional fertiliser training is estimated to have decreased fertiliser leakage into water by approximately 8,700 kg and associated GHG emissions by 270 t $CO_2e$.

#### iii. Hermetic storage bags

These bags primarily reduce emissions intensity by preventing post-harvest losses due to pest and microbial contamination, thus increasing the rice available for consumption per hectare cultivated and contributing to overall food security. We estimate that they lower GHG emissions by approximately 7% when used in rice supply chains.

# The Asian agri-food company’s playbook

We have developed a simple playbook that companies can refer to when embarking on their journey to reduce their emissions. Decarbonisation should be considered in the context of wider business initiatives, rather than in isolation as a purely social initiative; many of the technologies and practices we have considered can contribute effectively to reducing costs, increasing revenue from existing products, or creating additional revenue streams if implemented correctly.



❶ **Diagnostic of carbon emissions (Scope 1-3)**

❷ **Initial assessment of the available technologies / practices and suitability to the business**

❸ **Engagement and feedback from Scope 3 partners**

❹ **Prioritisation of tech / practices using a tailored *Decarbonisation Matrix* to identify areas to reduce emissions while improving business performance, considering:**

- Impact on emissions
- Impact on yield
- Impact on revenue
- Impact on COGS
- Impact on overhead costs
- Impact on profitability
- Cost of action
- Speed of benefit realisation

❺ **Implementation of technology and integration into emissions reporting**

❻ **Ongoing tracking and auditing of emissions and other existing KPIs**

Leads to

**Value Creation from decarbonisation**

- ✚ Cost-out from lower input costs
- ✚ Alignment of growth priorities with future market trends (fit for growth)
- ✚ Increased access to capital from sustainability-driven investors
- ✚ Access to carbon markets
- ✚ Meets consumer preferences
- ✚ Stability of supply
- ✚ Potential creation of additional revenue streams
- ✚ Improved efficiency / yield increasing revenue from existing products

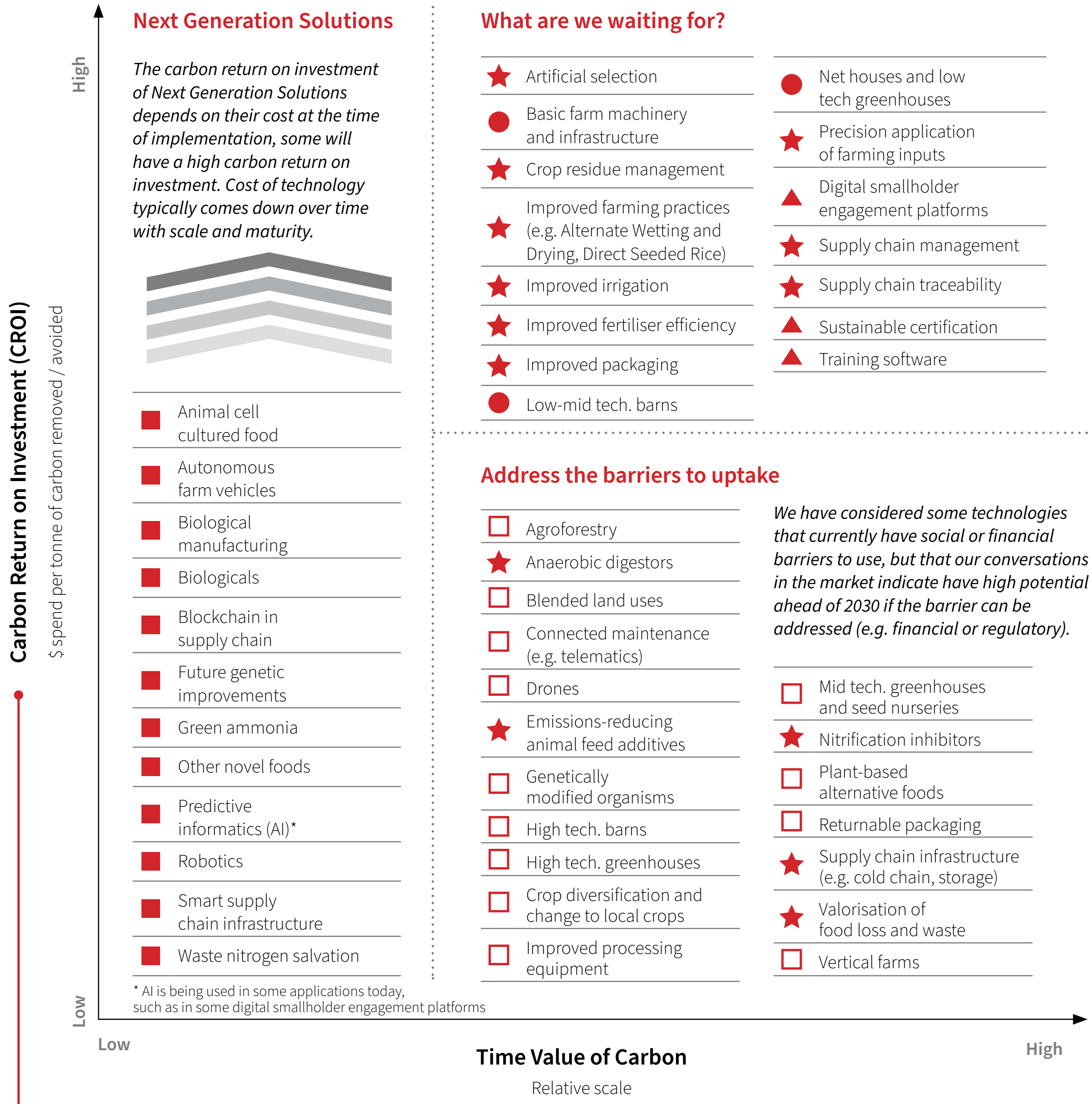
Given the urgency to act and the reality of resource constraints, we believe that the *Decarbonisation Matrix* can serve as a useful tool to inform companies' decarbonisation strategy, by allowing them to assess and prioritize decarbonisation levers specific to their business based on time to impact and relative costs and benefits, therefore delivering maximum impact as quickly as possible and in the most economically viable manner.

# The Decarbonisation Matrix

*Illustrative & non-exhaustive – intended to highlight various technologies and practices*

Key

- ■ Low Technology Readiness Level
- ☐ High financial or social barriers exist ahead of 2030
- ★ Technology considered
- ● High existing penetration
- ▲ Enabler considered as part of other technologies / practices



## Next Generation Solutions

*The carbon return on investment of Next Generation Solutions depends on their cost at the time of implementation, some will have a high carbon return on investment. Cost of technology typically comes down over time with scale and maturity.*

- ■ Animal cell cultured food
- ■ Autonomous farm vehicles
- ■ Biological manufacturing
- ■ Biologicals
- ■ Blockchain in supply chain
- ■ Future genetic improvements
- ■ Green ammonia
- ■ Other novel foods
- ■ Predictive informatics (AI)*
- ■ Robotics
- ■ Smart supply chain infrastructure
- ■ Waste nitrogen salvation

## What are we waiting for?

- ★ Artificial selection
- ● Basic farm machinery and infrastructure
- ★ Crop residue management
- ★ Improved farming practices (e.g. Alternate Wetting and Drying, Direct Seeded Rice)
- ★ Improved irrigation
- ★ Improved fertiliser efficiency
- ★ Improved packaging
- ● Low-mid tech. barns
- ● Net houses and low tech greenhouses
- ★ Precision application of farming inputs
- ▲ Digital smallholder engagement platforms
- ★ Supply chain management
- ★ Supply chain traceability
- ▲ Sustainable certification
- ▲ Training software

## Address the barriers to uptake

- ☐ Agroforestry
- ★ Anaerobic digestors
- ☐ Blended land uses
- ☐ Connected maintenance (e.g. telematics)
- ☐ Drones
- ★ Emissions-reducing animal feed additives
- ☐ Genetically modified organisms
- ☐ High tech. barns
- ☐ High tech. greenhouses
- ☐ Crop diversification and change to local crops
- ☐ Improved processing equipment

*We have considered some technologies that currently have social or financial barriers to use, but that our conversations in the market indicate have high potential ahead of 2030 if the barrier can be addressed (e.g. financial or regulatory).*

- ☐ Mid tech. greenhouses and seed nurseries
- ★ Nitrification inhibitors
- ☐ Plant-based alternative foods
- ☐ Returnable packaging
- ★ Supply chain infrastructure (e.g. cold chain, storage)
- ★ Valorisation of food loss and waste
- ☐ Vertical farms

* AI is being used in some applications today, such as in some digital smallholder engagement platforms

### The lower the unit cost of removing or avoiding a tonne of carbon dioxide emissions, the higher the CROI

- Factor in costs, potential savings and additional revenue streams from decarbonisation
- When considering the unit cost, use the life cycle $CO_2e$ emissions incurred in the implementation and usage, and avoided, reduced or removed by the technology or practice, as well as the life cycle cost

### Can it be done now? When will the decarbonization impact materialise?

- It is critical to deliver immediate impact as we approach climate tipping points - a tonne of carbon avoided, reduced or removed today is more valuable than a tonne in the future
- Assign higher time value to levers that are ready for widespread adoption given their technological maturity and commerciality
- Differentiate between constraints due to physics, chemistry and input costs vs. constraints that are a human construct (e.g., regulatory hurdles, financing arrangements and public sentiment)

# Key takeaways: the time is now

Any pathway to decarbonising Asia must focus on the agri-food sector. The sector accounts for 50% of all carbon dioxide equivalent emissions in South East Asia and 45% in South Asia.

The solutions already exist. Investing in addressable technologies that are already available today, as well as regenerative practices and infrastructure improvements could lead to a significant reduction in carbon dioxide equivalent emissions, once these investments are fully implemented.

But time is of the essence; action needs to be taken now to kickstart the decarbonisation journey. With climate action growing more urgent every day, readily available solutions must be prioritised. Agri-food offers the opportunity for rapid, significant decarbonisation.

**Action now is facilitated by four key factors:**

- Large organisations across the value chain have made decarbonisation commitments, many of which have a target in 2030.
- Scope 3 emissions are challenging to measure but organisations are making positive progress here, providing the data and direction for action to be taken to reduce emissions. Regulators must continue to standardise methodologies and develop local emissions factors to increase the integrity of these measurements.
- Platforms now exist to engage with smallholders and support them as they transition to technologies and practices that generate fewer emissions (and are often more profitable) than their current approach.
- Global social and political awareness of the quickening pace of climate change and the impact this has on agri-food is increasing, and there is broad support for action on emissions from agri-food.

The movement is growing but the momentum needs to be sustained by implementing a coherent set of actions. These are to be driven by global and country-level roadmaps, that detail focused priorities and targets. COP28, held at the end of 2023 represents a significant opportunity for alignment on action.

In particular, there needs to be alignment across the market to ensure that nudges provided by incentives can be made sustainable while supporting businesses and livelihoods of people across the value chain. Functioning carbon markets in agri-food (both regulated and voluntary) with a suitable carbon price to drive action are a key part of this.

In conclusion, the Asia Food Challenge is not only about emissions, but about feeding nearly 60% of the world's population in a sustainable fashion, one that promotes businesses, sustains people, and protects the Earth we live in.

The time for coherent action to secure food supply chains and the habitability of the planet is now.

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