Net Zero:
The Future of Agriculture

How Technology Can Cut Emissions and Deliver Carbon-Neutral Agriculture

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A Joint Report by Boston Consulting Group and XAG

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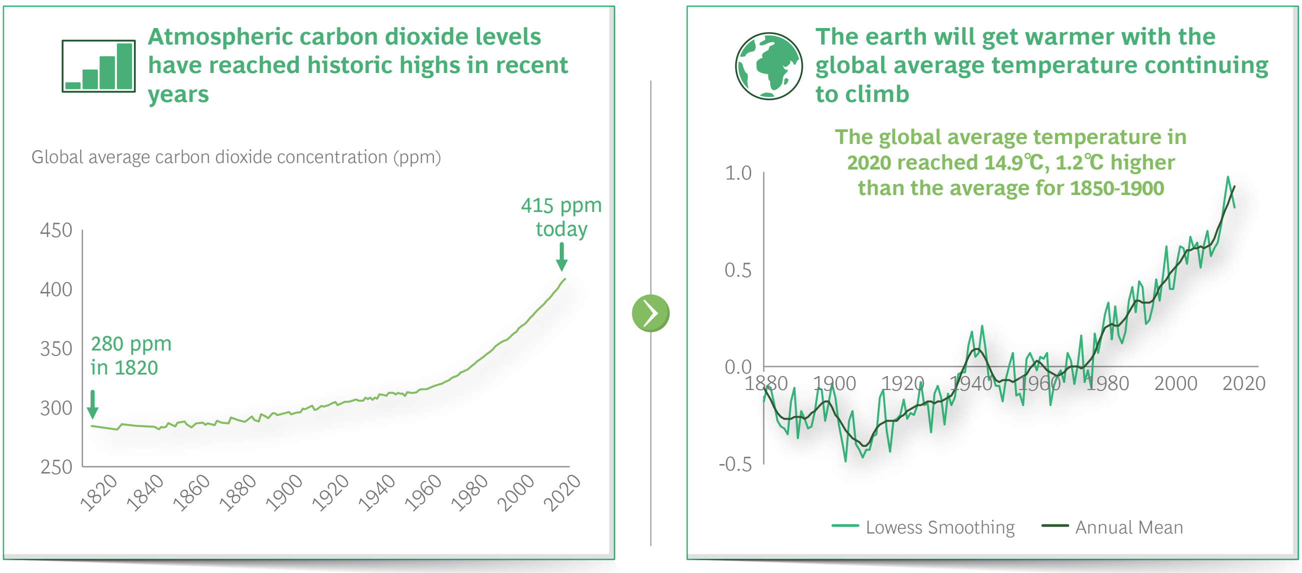
Climate change is not a future threat humans can delay a response to, but a present crisis that requires bold action. A relentless expansion in human activity over the past century has rapidly driven up global average carbon dioxide concentrations and pushed the planet's temperature to a historic high. (See Exhibit 1.)

Global warming has brought with it increasingly intense and severe extreme weather events which cause billions of dollars of damage. Between 2017 and 2020, about 3,350 extreme weather events were recorded, to the tune of 885 billion USD of damage. [1] (See Exhibit 2.)

Compared to other industries like energy, transportation and industrial goods, agriculture is more vulnerable to climate change. The sector is exposed in both direct and indirect ways. Directly, events like sudden temperature change, rainfall variation, heat waves and hurricanes are ramping up the pressure on global agricultural production systems and further threatening our food security. The Intergovernmental Panel on Climate Change (IPCC) projects a severe hit to the yields of major crops, such as wheat (by 6.0 ± 2.9%), rice (by 3.2 ± 3.7%), maize (by 7.4 ± 4.5%), and soybeans (by 3.1%) for each degree Celsius increase in global mean temperature.[2] An often-overlooked impact of elevated CO_2 concentrations lies in the detriment to nutritional quality of crops. Studies have shown that elevated CO_2 concentrations of 568–590 ppm alone will diminish the protein, micronutrient, and B vitamin content of the 18 rice cultivars grown most widely in Southeast Asia, where it is a staple food source, by enough to endanger the nutritional health of 600 million people.[3] Indirectly, the spread of pests and diseases will also have detrimental effects on agricultural production systems.

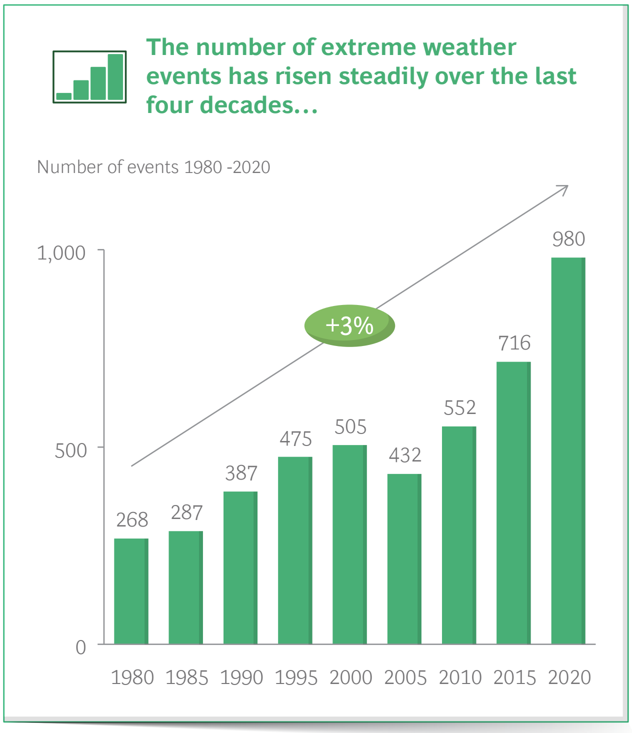
Exhibit 1. Both Global Average CO_2 Concentration and Mean Temperature Have Reached Historic Highs, Driven by Relentless Expansion in Human Activity

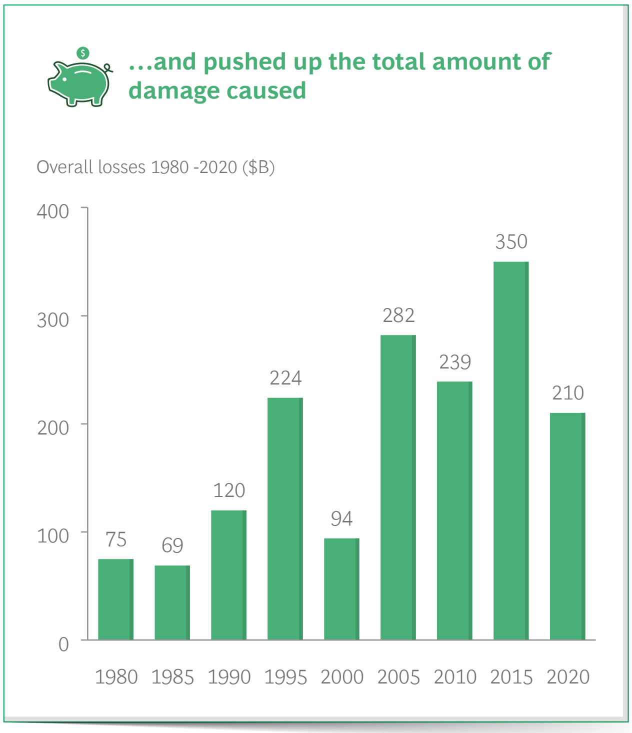


Source: Hadley Center–CO_2 and Greenhouse Gas Emissions; Hannah Ritchie and Max Roser, Our World in Data (2019).

1 Munich Reassurance, NatCatSERVICE natural disaster database.
2 IPCC, *Impacts of 1.5ºC global warming on natural and human systems*, Chapter 3.
3 United Nations Food and Agriculture Organization, CAIT Climate Data Explorer.

Exhibit 2. Frequency and Cost of Natural Disasters are Climbing, with Increasing Economic Damage





Source: Munich Re – NatCatSERVICE – Accessed 2021; BCG analysis.

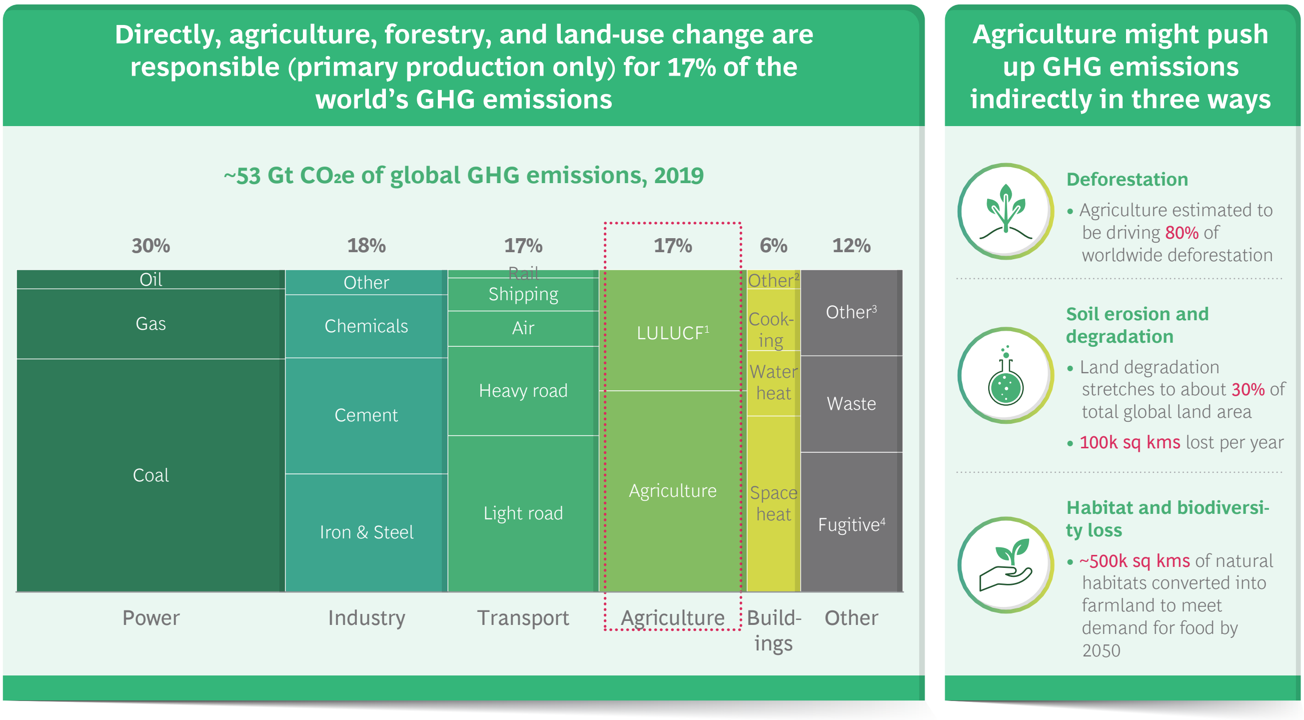
However, the agriculture sector's role in greenhouse gas (GHG) emissions is less well understood. The agricultural sector is thus both a victim of global warming and one of the greatest GHG emitters. Agriculture, forestry, and land-use change account for about 17% of the world's GHG emissions.[4] That figure rises to 21%-37% once every step of the journey from farm to table is considered. In addition, many agricultural practices place significant stress on the environment, exacerbating global warming. For instance, agricultural activities are estimated to be driving 80% of deforestation worldwide.[5] Soil eroded or degraded due to agricultural activities is less good at sequestering carbon, leading to more being released into the air. (See Exhibit 3.)

In addition, the bulk of agriculture sector GHG emissions comes mainly from non-CO_2 sources, namely methane and nitrous oxide. Agriculture accounts for an estimated 45% of all methane, and 77% of all nitrous oxide, emissions.[6] These gases are significantly more powerful drivers of global warming than carbon dioxide. Methane is 20 times more effective than CO_2 at trapping heat while nitrous oxide is about 300 times as potent as CO_2.[7]

Unless actively mitigated, GHG emissions from the agriculture sector are expected to continue to rise, due to increasing food demand driven by global population growth, which is expected to grow by over 30% to 9.7 billion people.[8] Given the current food system, the UN Food and Agriculture Organization (FAO) estimates that there is a need to produce about 50% more food by 2050.[9] This would engen-

4 United Nations Food and Agriculture Organization, CAIT Climate Data Explorer.
5 Kissinger, Herold, Veronique De Sy, *Drivers of Deforestation and Forest Degradation*.
6 World Bank, Climate Watch database, EDGAR greenhouse emission database.
7 3rd Assessment Report of the United Nations Intergovernmental Panel on Climate Change.
8 United Nations, *World Population Prospects 2019*.
9 United Nations Food and Agriculture Organization, *How to Feed the World in 2050*.

Exhibit 3. Current Agricultural Practices Drive up Greenhouse Gas Emissions, Both Directly and Indirectly



Source: CAIT; IEA; World Energy Outlook; GHG Protocol; BCG analysis.

I LULUCF: Land use, land-use change, and forestry.

II Other building emissions, e.g., appliances, lighting, space cooling.

III Other industries, e.g., aluminum, pulp and paper.

IV Fugitive gases split between power and industry, but exact split not available.

der significant increases in GHG emissions and other environmental impacts, including loss of biodiversity. (See Exhibit 4.) Finding ways to increase food production efficiency while curbing the growth of GHG emissions will be critical for agriculture sector players.

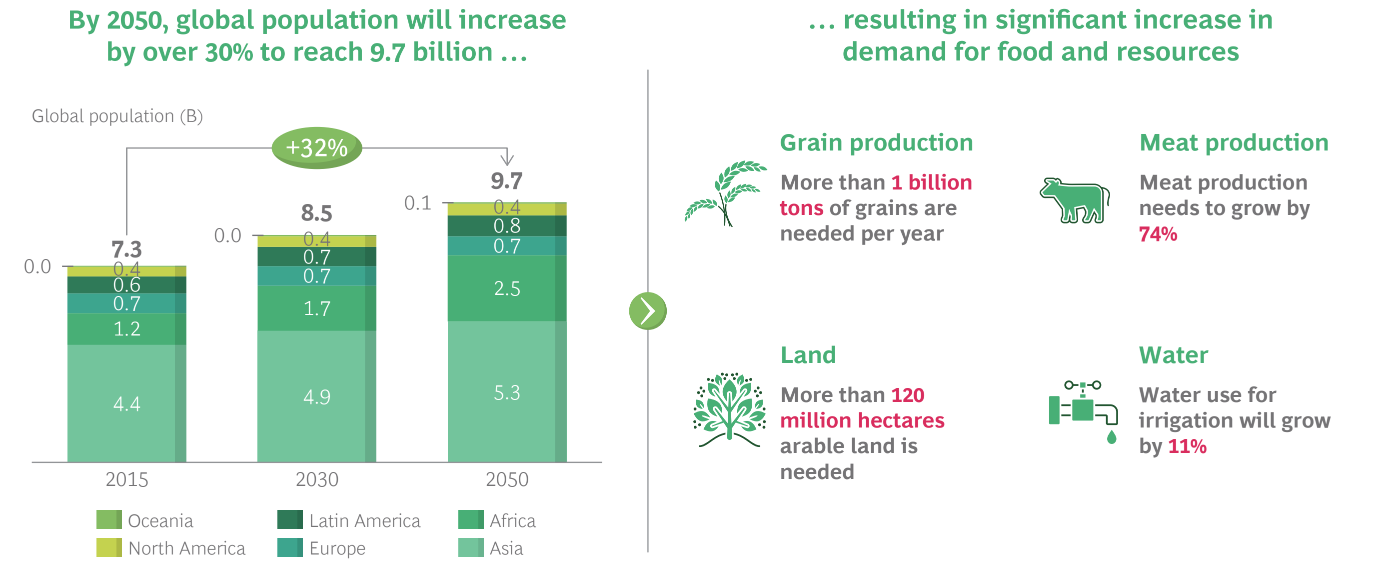
The Global Race to Net Zero

In the face of increasing climate uncertainty, the international community has joined forces under the leadership of the United Nations. It was in this context that the United Nations Framework Convention on Climate Change (UNFCCC) was founded, to facilitate cooperation between various parties. Since 1995, the UNFCCC has held the Conference of Parties (COP) annually, enabling intergovernmental conversations and promoting agreements on actions to combat climate change.

A key pillar of the global net zero transition is the "Paris Agreement" reached at the 21st Conference of Parties (COP21) in December 2015. The Agreement is a legally-binding international treaty which commits all signatories to reducing their emissions and working together to adapt to the impacts of climate change. The Agreement sets out three long-term goals:

- Substantially reduce global greenhouse gas emissions to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees Celsius.

Exhibit 4. Significant Increase in Food Production Required to Meet Global Demand



Source: UN Department of Economic and Social Affairs (2019), The World Population Prospects; FAO, Global Agriculture Towards 2050; literature search; BCG analysis.

Npte: Due to rounded number, the sum may not equal to total amount.

- Review countries' commitment every five years.
- Provide financing to developing countries to mitigate climate change, strengthen resilience and enhance their ability to adapt to climate impacts.

The Agreement has provided a durable framework to guide the global effort towards a net zero world and was signed by 195 parties and joined by 192 parties till 2021.

In November 2021, China and the US issued a joint statement at the COP26 summit, vowing to ramp up cooperation tackling climate change, including reducing methane emissions, protecting forests, and phasing down coal. The two countries also announced that they will increase their efforts this decade to hold the increase in global average temperature to "well below" 2 degrees Celsius and to "pursue efforts" to limit it to 1.5 degrees Celsius. The two countries' joint statement recognizes that the 1.5°C goal is at the heart of any credible climate plan and serves as a call for closer international collaboration and solidarity on climate issues. (See the sidebar, "Countries' Race to Net Zero Emission Target".)

Currently, governments have been mainly focused on reducing GHG emissions in the energy, transportation and industrial sectors. Those industries constitute a larger proportion of total emissions and have relatively straight-forward GHG emission reduction mechanisms. Therefore, although reducing emissions in the agriculture sector is listed as one of the key levers in many countries' carbon neutrality strategies, no agriculture-specific legislation/policies have been issued by the major economies. Nevertheless, as the challenges of climate change become more pressing, more countries are starting to pay more attention to reducing agricultural emissions. Most leading countries' national guidelines on carbon neutrality have highlighted the importance of leveraging technology to upgrade the agriculture production system, and increase productivity while cutting down GHG emissions, for instance:

The United Kingdom: UK was one of the first countries to put forward both agriculture GHG emission target and action plans. In 2019, the National Farmers' Union (NFU) set the goal of reaching net zero GHG emissions across the whole of agriculture in England and Wales by 2040. The

NFU plans to achieve this goal through three key levers. The first lever is to improve farming's production efficiency, enabling the same quantity of food, or more, to be produced with less input in smarter ways. The second lever is to improve land management and vegetation to allow more carbon to be captured and stored in the soil. The final lever is to boost the use of renewable energy and bioenergy to displace fossil fuels. These three pillars cannot be realized without a higher adoption of technology across the whole agriculture value chain.

Japan: The Ministry of Agriculture, Forestry, and Fisheries (MAFF) has announced that Japan's agriculture sector will reach zero carbon emissions in 2050, mainly through two approaches. Firstly, leveraging biotechnology to reduce GHG emissions from production activities, such as improving the biological nitrification inhibition of crops. Secondly, promoting the use of hydrogen power and increasing electrification for agricultural machinery.

China: As one of the world's largest agricultural countries, China has been exploring ways to lower GHG emissions in the agriculture sector for years. The Ministry of Agriculture and Rural Affairs has issued guidelines on energy saving and reduction of GHG emissions in rural areas, in 2007 and 2011 respectively. These two guidelines mainly focused on encouraging scientific agronomic practices and promoting the use of energy saving agricultural machinery.

After President Xi announced China's ambitious goal of achieving carbon neutrality before 2060, the country has been accelerating the transition towards carbon neutrality and agriculture has come under the spotlight. The general action plan issued by the State Council has highlighted the importance of promoting use of agricultural machinery powered by renewable energies, such as solar and biomass energy. In addition, the Chinese government is currently drafting an agriculture specific carbon neutral transition action plan. More detailed measures will be introduced gradually.

The United States: In Feb 2020, the U.S. Secretary of Agriculture unveiled a plan to reduce 50% of emissions in the agricultural sector while maintaining a goal to increase agricultural production by 40% by 2050. Also stated in its net zero transition strategy, the US plans to keep investing in agricultural technologies and drive innovation across the industry value chain. Four technology clusters were identified as the main innovation focus, including genome design, digital and automation, prescriptive intervention, and system-based farm management. The US government also plans to encourage large farm owners to adapt climate-smart practices like rotational cattle grazing systems by offering financial aid and incentives.

Countries' Race to Net Zero Emission Target

To reach the joint GHG emission reduction target, governments have issued their own laws or policy documents regarding net zero transition. Depending on the stage of climate actions they have reached*, those countries can be mainly divided into four groups**: 1. Countries that have enacted legislation; 2. Countries that have proposed legislation; 3. Countries that have issued policy documents; 4. Countries that are still discussing their reduction targets.

1 Countries that have enacted legislation: thirteen countries, including the United Kingdom, New Zealand, France, Canada, Denmark, Sweden, South Korea, Japan, etc.

- **The United Kingdom:** In 2008, the United Kingdom passed the "Climate Change Act 2008", which committed to an 80% reduction in carbon emissions by 2050, compared to 1990 level. In 2019, UK passed an amendment to the Climate Change Act, updating the target from at least 80% lower than the 1990 baseline to at least 100% lower by 2050 (the 2050 Target Amendment)

- **Japan:** In October 2020, then Prime Minister Yoshihide Suga declared that Japan will aim for net zero GHG emissions by 2050. In April 2021, the country further announced a new 2030 domestic emissions reduction target of a 46% reduction by 2030 from 2013 level, with

* The Energy and Climate Intelligence Unit, Net zero transition scorecard, statistics in different countries and categories as of November 2021.

** Suriname and Bhutan have declared carbon neutrality due to higher forest cover and lower energy demand, and are thus not included in the classification.

the possibility of additional measures to achieve a 50% reduction. In June 2021, the country codified this commitment by passing the revised "Act on Promotion of Global Warming Countermeasures", which also requires local Japanese governments to draw up renewable energy targets with concrete implementation plans.

2 Countries that have proposed legislation: three countries, including Ireland, Chile, and Fiji.

- **Ireland:** In March 2021, Ireland's coalition government approved the "Climate Action and Low Carbon Development (Amendment) Act 2021" bill, which commits the country to cutting its emissions by 51% below 2018 level by 2030 and to reaching net zero no later than 2050. Government is pushing the bill through parliament as priority legislation.

3 Countries that have issued policy documents: Fifty-three countries, including China, the United States, Finland, India, Switzerland, Norway, Brazil, Indonesia, etc.

- **China:** President Xi made a historic announcement at the 75th session of the UN General Assembly in September 2020: China aims to peak its CO_2 emissions before 2030 and achieve carbon neutrality before 2060. The country's 14th Five-Year Plan has further laid out the guidelines for bending the GHG emissions curve in the next 10 years, mainly focus on controlling both the amount and intensity of energy consumption and promoting use of clean energies.

  Prior to COP26, China's State Council issued the "Action Plan for Carbon Dioxide Peaking Before 2030" on 26th October 2021. The action plan will guide China's carbon neutral transition and lays out a framework for detailed transition roadmaps across different industries. According to the plan, the nation will step up the replacement and upgrade of coal consumption, develop new energies, tap the potential of hydroelectricity and nuclear power, control consumption of fuel and gas and accelerate construction of a new electricity system. By 2030, non-fossil fuels will account for 25% of China's total energy consumption and its CO_2 emissions per unit of GDP will be reduced by more than 65% compared with 2005.

- **The United States:** The United States re-joined the Paris Agreement on President Joe Biden's first day in office. In Nov 2021, US government refined its long-term strategy towards net zero GHG emissions and reaffirmed the country's goal of achieving net zero emissions no later than 2050. The country also set an economy-wide target of reducing its net GHG emissions by 50%-52% below 2005 levels by 2030. The US net zero transition mainly relies on integration of five technological transformations: decarbonize electricity, switch to clean energies, cut energy waste, reduce methane and other non-CO_2 emissions, and scale up CO_2 removal.

4 Countries still discussing their reduction targets: Over ninety countries have begun national policy discussions. Countries in Africa and the Middle East are expected to catch up on the net zero race and propose legislation or policy documents concerning net zero emissions in the coming years, bringing approximately 75% of global emissions under strict reduction regulations.

Decoding Greenhouse Emissions in Agriculture

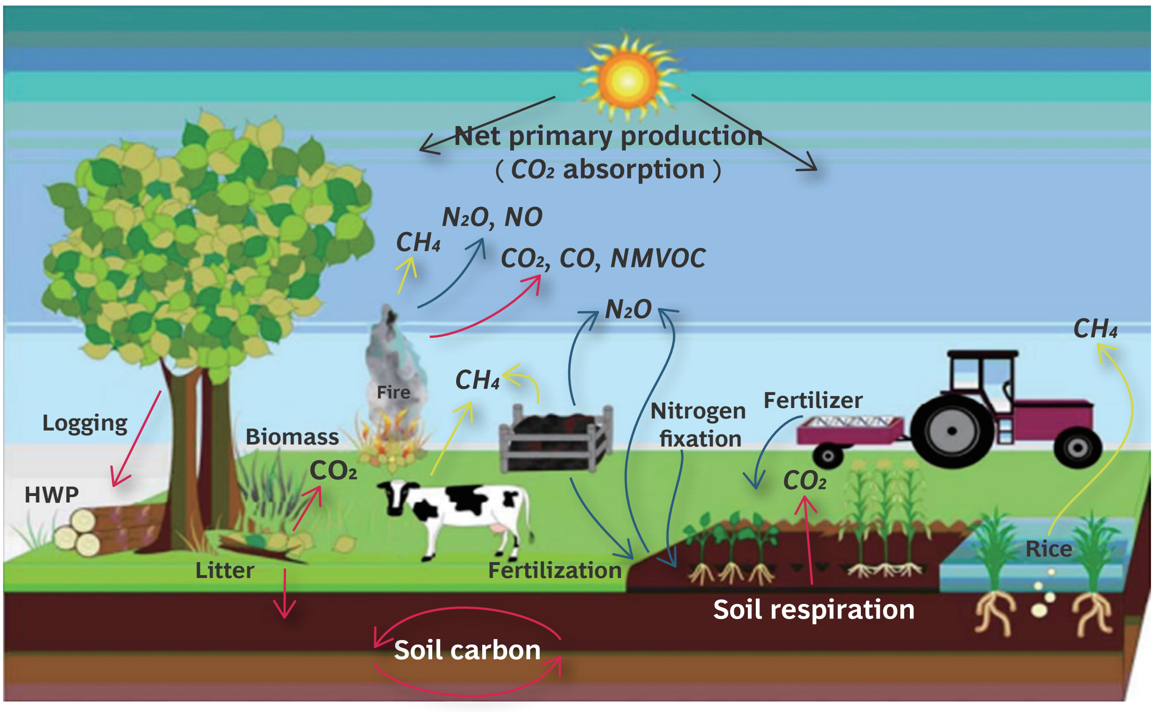
The diffuse nature of agricultural activities makes it challenging to address agricultural emissions. Before being brought to our table, agricultural products go through R&D, farming, harvesting, processing, distributing, retailing and storage processes. All these stages and activities generate greenhouse emissions. In addition, tracking, measuring, and auditing greenhouse emissions in agriculture might be more challenging than in other sectors, due to two main factors. Unlike in other sectors, activities in the agriculture ecosystem would result in both emissions and removals of greenhouse gas. For instance, as wastelands or sand lands are cultivated for crops, these lands' ability to absorb and store carbon improves, turning them into a "sink", rather than a source, of carbon dioxide. The emissions in agriculture ecosystems are also subject to weather, location, species on the farm, land types, and the way the soil is managed; these factors all impact GHG emission or sequestration. Moreover, certain aboveground or belowground emissions accumulated gradually, making it more difficult to track and quantify the agriculture sector's carbon footprint.

Overview of Agricultural Emission Sources

Basically, every agricultural practice within the farm gate, such as manure management, soil cultivation, and farm machinery energy consumption, produces GHG emissions. The main agriculture GHGs of concern are CO_2, N_2O and CH_4, each emitted at different points along the agriculture value chain. (See Exhibit 5.)

According to the GHG Protocol developed by the World Business Council for Sustainable Development (WBCSD), within the farm gate, emission sources are either mechanical or non-mechanical. Non-mechanical emissions generally occur through complex biological processes such as decomposition, fermentation, or the burning of crop residues. Mechanical emissions come from combusting sources or industrial processes that consume fuels, chemical feedstock, or electricity. Typical mechanical sources are farm equipment or machinery, including harvesters, vehicles, and air-conditioning equipment. In addition, although both mechanical and non-mechanical sources emit carbon dioxide, non-carbon GHGs account for a much greater proportion of agriculture emissions. Non-mechanical sources emit CH_4 and N_2O mostly through biological processes such as enteric fermentation and fertilizer nitrification. Beside CO_2, CH_4, and NO_2, mechanical sources also emit other greenhouse gases like HFCs and PFCs and these emissions depend on the individual equipment or materials involved.

Exhibit 5. Major GHG Emissions Sources on Farms



Source: IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 1.

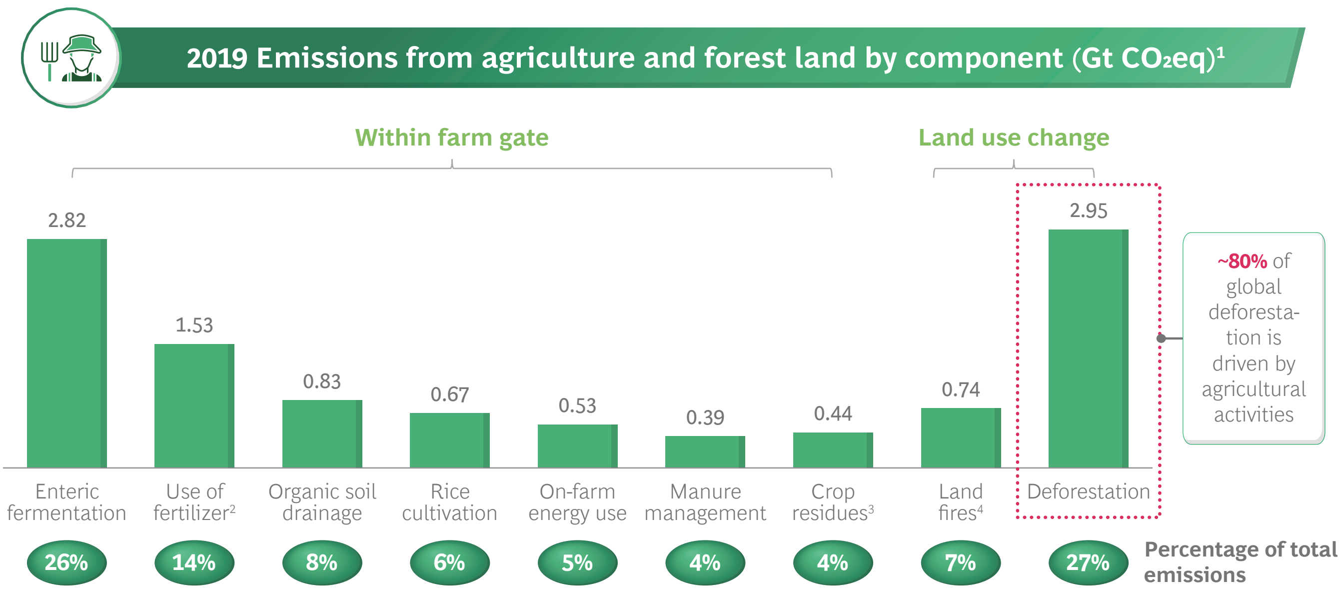
However, the exact mix of emission sources and GHGs varies widely depending on the type of farm, management practices and natural factors at play. These factors include original land cover; farm topography and hydrology; soil microbial density and ecology; soil temperature, moisture, organic content and composition; crop or livestock type; and land and waste management practices. Few studies offer a consistent comparison of how emission source share differs across farming systems, making it difficult to accurately predict the emission mix for a given farm. Nonetheless, based on FAO data, there are seven major GHG emission sources within the farm gate. (See Exhibit 6.)

Of the 7.2 Gt Co_2eq GHG emissions generated within the farm gate in 2019, enteric fermentation in digestive systems of livestock was the largest contributor, accounting for 26% of total emissions. Enteric fermentation mainly emits methane (CH_4) as carbohydrates are broken down by bacteria in the digestive tract of herbivores. The amount of CH_4 emitted is decided by the species, age, and size of livestock, as well as the quantity and type of feed. Ruminant livestock such as cattle and dairy cows release much more methane than non-ruminants.

Fertilizers, including both livestock manure (either left on pasture or used as organic fertilizer) and synthetic fertilizers, are responsible for about 14% of total agricultural emissions, mainly in the form of nitrous oxide (N_2O) emissions. The N_2O is emitted when the increased nitrogen content in the soil from these fertilizers stimulates denitrification by soil microbes. N_2O emissions can also occur indirectly via leaching or volatilization.

The third largest CO_2 emission source within the farm gate is drainage of organic soils to prepare land for agriculture. In undrained organic soils, the inputs of organic matter can exceed decomposition losses under anaerobic conditions and help to sequester more carbon. However, soil drainage easily leads to decomposition of carbon stored in organic soil, which becomes aerobic. The degree of CO_2 loss is influenced by many factors including drainage depth, temperature, and soil fertility.

Exhibit 6. Among Seven Major Sources of Agriculture GHG Emissions Within the Farm Gate, Enteric Fermentation and Use of Fertilizers are the Two Largest



Source: FAO, Emission Database FAOSTAT 2021; BCG analysis.

I Emissions/removals from forest land not included.

II Including synthetic fertilizers, manure applied to soils and manure left on pasture.

III Including management and burning of crop residues as well as savanna fires.

IV Land fires including fires in humid tropic forest and fires on organic soil.

Rice cultivation is also a major contributor of agricultural GHG emissions. When the soil is flooded, the oxygen in the soil is consumed by soil microorganisms, animals, and plant roots, and methanogenic bacteria begin to grow and move around, and they produce methane (CH_4) from carbon dioxide and acetic acid, etc., which is diffused and emitted into the atmosphere by means of rice plants and air bubbles.

The fifth largest emission source is emissions from on-farm energy use. Modern intensive farming requires the combustion of vast amounts of fossil energy (including coal and diesel oil) to operate equipment and machinery, and to power the farm itself.

The last two major sources of agricultural emissions are the treatment of livestock manure and crop residues. CH_4 is emitted during the storage and treatment of manure under anaerobic conditions and N_2O is emitted either directly or indirectly from stored or treated manure. In addition, burning crop residues, particularly crop straws, as a form of insect pest control accounts for much of the carbon emissions and air pollution in rural areas.

To reduce agricultural carbon emissions, the most effective way is to start from each emission source, and use technology to manage and reduce them. However, with current technology, attention shall be paid to the huge variation in potentials for GHG reductions from different emission sources. Although animal enteric fermentation is the largest source of agricultural greenhouse emissions, mitigating its impact is not straightforward. Recent scientific research has found that methane emissions from animal enteric fermentation can be greatly reduced by including additives in the feed to pasture animals. Mainstream additives include red seaweed and 3-nitrooxypropanol (3-NOP). The U.S. Environmental Protection Agency (EPA) estimates that red seaweed supplements could help reduce animal greenhouse gas emissions by up to 60%[10] by 2030 if it is made available on ranches nationwide. However, there are still large gap before red seaweed can be used on a large scale, including ways to reduce costs of growing, harvesting and handling so as to make it acceptable to farmers as an economical additive, and whether long-term consumption of the additive by livestock could lead to high tolerance or other side effects. Another way to reduce the emissions of enteric fermentation is to substantially reduce human consumption of ruminant protein (such as beef and lamb), but requires a huge change in human diet, which is difficult for most people to accept. At the same time, whether reducing the intake of animal protein will cause harm to human health is still scientifically controversial.

On the other hand, efforts to reduce emissions from other sources of agricultural GHG emissions may have more immediate and efficient results. Replacing fuel machineries with electric ones, for example, could quickly reduce greenhouse emissions while maintaining the production level. Reducing fertilizer input with smart soil monitoring tools is also considered an effective way to curb N_2O emissions. However, these measures are often overlooked. Although measures aimed at reducing emissions by enteric fermentation are currently the focus of research, the actual effect still needs extensive scientific validations. Subsequent chapters of this report will focus on introducing relatively mature and achievable technologies to reduce emissions.

Accounting for Agricultural Players' GHG Emissions

Although agricultural GHG emission sources and mechanisms might differ greatly from players in other industries, the emission auditing methodology for GHGs is generally consistent. The GHG Protocol developed by the World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI) has been recognized as the leading standard for measuring and reporting corporate GHG emissions. Under the GHG Protocol, corporates need to determine their baseline of GHG emissions by following four steps: defining emission auditing boundaries, defining GHG gases, identifying relevant activities, and calculating emissions at the individual activity level. (See Exhibit 7.)

Step 1: Defining emission auditing boundaries

Agricultural players will need to set two boundaries when calculating their GHG emissions: organizational boundary and business operational boundary. For the former, corporates may choose to calculate emissions based on their share of equity in the operation, reflecting their economic benefit (the Equity Share Approach). Alternatively, a company may only calculate emissions from those of its subsidiaries over which it exercises 100% control (the Financial Control approach) or exclude subsidiaries in which it has a stake but no power over business operations (the Operational Control Approach).

For business operational boundary-setting, companies need to identify emissions associated with their operations, categorizing them as direct or indirect emissions, and choosing the scope of accounting and reporting for indirect emissions. The GHG protocol classifies emissions into three scopes. (See Exhibit 8.)

- **Scope 1:** Direct GHG emissions from both production activities and physical or production processes under a company's direct control.
- **Scope 2:** Indirect GHG emissions from consuming purchased or acquired power, such as electricity, heat, steam, and cooling.

10 *US Long-term Transition Strategy for Net Zero Greenhouse Gas Emission*, Chapter 5.

Exhibit 7. Four Steps for Agricultural Players to Calculate GHG Emissions

1 Set emission auditing boundary

Setting organizational boundaries
- Equity share approach
- Financial control approach
- Operational control approach

Setting operational boundaries
- Scope 1: All direct sources
- Scope 2: Consumption of purchased heat, steam and electricity
- Scope 3: All other indirect sources

Companies can choose whether to report Scope 3 sources

2 Explicate GHG gases

"Kyoto basket of six"
- Carbon dioxide
- Methane
- Nitrous oxide
- Hydrofluorocarbons
- Perfluorocarbons
- Hexafluoride

Companies are free to identify and report other relevant Greenhouse gases

3 Identify relevant emission activities

Check local accounting & reporting standards first

Example: "Guidelines of GHG Emissions Accounting for Planting Agricultural Players"

Total Emissions
- Combustion of fossil fuels
- Application of fertilizers
- Crop residue management
- Purchased electricity
- Change in soil carbon stock

4 Emission calculation

Activity data collected
- Types and usage of fossil fuels and fertilizers
- Kilowatt hours of electricity
- ……

×

Emission factors
- IPCC default emission factors
- Regional/Country specific emission factors (recommended)

Source: GHG protocol; Guidelines of GHG Emissions Accounting for Planting Agricultural Players in Beijing; lit search; BCG analysis.

Exhibit 8. Three Scopes of Emissions with Indicative List of Activities Defined by GHG Protocol

	Scope 1: Direct emissions	Scope 2: Indirect emissions	Scope 3: Indirect emissions
Description	**Direct GHG emissions** • Occur from sources that are owned or controlled by the company	**Indirect GHG emissions from energy consumption** • Occur from generation of purchased energy consumed by the company	**Other indirect GHG emissions** • A consequence of the activities of the company, but occur from sources not owned or controlled by the company • Optional reporting category
Example	• Drainage and tillage of soils • Rice cultivation • Enteric fermentation • Manure management Not Exhaustive	• Electricity, heat, steam, etc. purchased for own use	• Production of purchased agricultural materials • Transportation of sold agricultural products/waste • business travel of farm employees Not Exhaustive
Options for declaration	Scope 1&2 (Common practice)		
	Scope 1&2&3 (Optional)		

Source: GHG protocol.

- **Scope 3:** All other indirect GHG emissions which derive from a company's activities, but which originate in sources not owned or controlled by the company. Although the GHG protocol provides a list of commonly used activities, companies retain autonomy over what to include. As a result, Scope 3 emissions could prove controversial for many corporates.

In most of the reporting systems based on the GHG protocol, Scope 1 and Scope 2 are often required, while Scope 3 is generally optional.

Step 2: Defining GHG gases

The Kyoto protocol has identified the six greenhouse gases most commonly emitted as a result of corporates' operations, often referred as the "Kyoto basket of six": carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and hexafluoride. However, companies are still free to report other types of GHG gases relevant to their major operating activities.

Step 3: Identifying relevant activities

Once the auditing boundary has been set, agricultural players will need to identify the related activities or emission sources within the boundary. Government will issue accounting and reporting standards for some industries and outline the emission sources/activities that should be included in the calculation. However, due to the diffuse nature of agriculture, there is as yet no unified emission accounting standard. This may lead to inconsistency in results reporting between players with very similar business operations.

In China, some local governments have issued emission accounting and reporting standards for agricultural players in the region. For instance, the Beijing municipal government issued the "GHG Emissions Accounting Guidelines for Agricultural Crop Planters (DB11/T1564-2018)" in 2019. The guidelines listed five major emission sources which should be included in emission accounting, such as combustion of fossil fuels, application of fertilizers, crop residue management, purchase of electricity and changes in soil carbon stock. Agricultural players should refer to national or local emission accounting and reporting standards first and identify relevant emission sources/activities to be included.

Step 4: Calculating emissions

After identifying sources of emissions, companies can start to calculate their carbon emissions by multiplying their activity data (AD) by their selected emission factors (EFs).

- **Activity data:** This measures the magnitude of identified emission activities. For combustion of fossil fuels, the activity data refers to the fossil fuel type (gasoline or diesel) and usage (tons or litres).

- **Emission factors:** These vary by activity, region or country, and environmental condition. The IPCC has stipulated default emission factors for companies to leverage where more accurate EFs are unavailable. Many international NGOs or industry associations have also published regional and industry-specific EFs for companies to use. Nevertheless, companies are encouraged to use the national level EFs as they provide a better estimation.

- **Multiply the AD by the EFs:** With their AD and EFs, companies can arrive at their GHG emission amount by a quick multiplication. For some activities that emit GHG gases other than carbon, the results need to be converted to CO_2 equivalent (CO_2e) using a conversion coefficient called Global Warming Potential (GWP).

Leverage Technology to Achieve Carbon-Neutral Agriculture

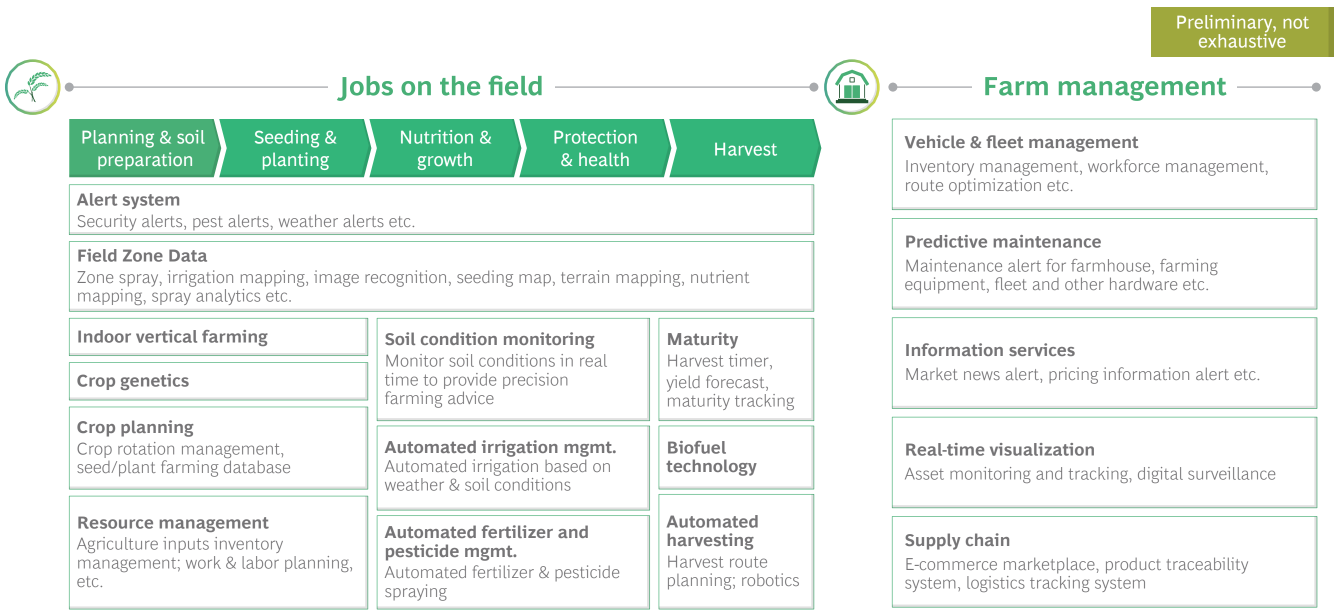
Panorama of Technologies in Agriculture

Over the past fifty years, advancements in machinery have drastically transformed the agriculture industry by expanding the scale, speed, and productivity of farm equipment, leading to rapid increases in land yield and farmers' productivity. According to the FAO, global agriculture output more than tripled between 1961 and 2011.[11] Nevertheless, the need to meet fast-growing demand for food while lowering GHG levels poses a new challenge for agriculture, with far much more sophisticated and innovative tools needed to deliver the next productivity leap. The good news is that agriculture is on the cusp of another revolution, thanks mainly to three technology forces: data analytics, connectivity, and automation.

- **Data analytics:** As technology evolves, the availability and quality of data collected on and about farms increases rapidly. It is estimated that by 2050 the average farm will generate 4.1 million datapoints per day, compared to 190,000 in 2014.[12] By tracking, collecting, and analyzing multiple types of data such as weather, soil and seed conditions, and probability of diseases, farmers can leverage agronomic insights to make more informed decisions.
- **Connectivity:** Wireless networks can transmit information or data. Network participants can include humans, animals, plants, and infrastructure (e.g., equipment and buildings). The network enables data flows between different objects and allows them to be sensed and controlled remotely, creating opportunities for more interactions in real time.
- **Automation:** Replacing human labor for certain tasks with computer-aided equipment under some form of autonomous control. Automation technologies can help to ease farmers' workload and deliver efficiency, reliability, and productivity gains at minimal impact to the environment.

Enabled by these three driving technologies, innovations such as artificial intelligence, drones and robotics, satellite visualization tools, connected sensors, and other emerging technology solutions are changing the agribusiness landscape. They are also helping to increase yields, improve efficiency, and build sustainability and resilience of crop cultivation. Innovation is happening across the value chain—technologies have empowered farmers with planning and soil preparation, seeding and planting, nutrition and growth, crop protection and health, and harvesting. (See Exhibit 9.)

Exhibit 9. The Potential of AgTech is Broad and Includes Various Solutions Across the Whole Value Chain



Source: World Bank; United Nations; lit search; BCG analysis.

11 United Nations Food and Agriculture Organization, *Report on Environmentally Smart Agriculture*, Chapter 6.
12 Estimated by "OnFarm", an agricultural data analysis provider.

Potential agricultural applications of tech are drawing attention globally. (See Exhibit 10.) Over the past five years, investment in AgTech start-ups has more than doubled. In addition, as the pressure for sustainable agriculture becomes more acute, we expect to see accelerated growth in AgTech financing.

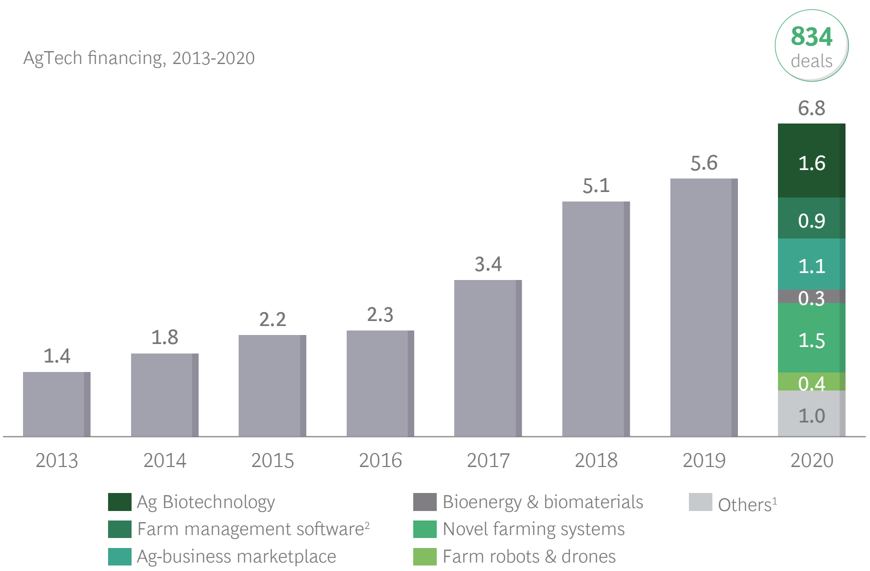
Attracted by the commercial potential, an increasing number of players are betting on AgTech development. Currently, there are three major types of AgTech players. (See Exhibit 11.)

- **Incumbent agricultural giants:** Large industry players such as leading agricultural machinery player, pesticides player, and fertilizer player are offering digital solutions to their customers to solve their unmet needs. For instance, promoted the digital agriculture platform, provided a user-friendly one-tool solution controlling automated and connected equipment, with tailored seed scripts and seeding prescriptions for further yield-optimization. Large industry players also strengthened their digital farming offerings, including real-time nitrogen sensors, optimal nitrogen recommendation software, data analytical services and various smartphone apps for digital farming.
- **AgTech players:** New agriculture technology players provide farmers with cutting-edge technology and equipment. Successful players are typically characterized by high specialization and innovative strength, such as farm robotics, mechanization and equipment. As the technology capability and market mature, players have been expanding their technology offerings to other parts of the value chain. For instance, XAG, one of the world's largest AgTech players, started with drones, gradually built up its capabilities and evolved towards integrated digital agriculture solutions.
- **Information technology companies:** Traditional tech players are also exploring opportunities in agriculture. What they lack in agricultural expertise, they make up for in substantial knowledge about consumers and data and analytics. This means their main focus is on building data analytics-driven smart agriculture solution platforms/systems to better inform farmers' decision-making about farm operation and production.

The Path to Carbon-Neutral Agriculture

Although AgTechs have come under the spotlight and been applied in agriculture, there has been little research into how AgTech can help deliver a carbon neutrality agricul-

Exhibit 10. Investments in AgTech Startups has Steadily Increased due to Positive Market Outlook



- In the last five years, financing for AgTech has **more than doubled**
- Investment in **drones & robotics** is relatively low, but **interest is expected to increase** due to labor shortages during pandemic
- Increasing pressure for sustainable environment and agriculture could **further drive interest** and investments in AgTech

Source: AgFunder Annual AgTech Investment Report 2021; BCG analysis.

Note: Focus on upstream deals with relevance for farmers and Ag input industry.

[I] Includes farm-2-consumer Egrocery, midstream technologies and miscellaneous.

[II] Includes marketplaces of Ag inputs and equipment as well as commodity trading.

Exhibit 11. With More Players Entering the Market, Competition Will Get More Intensive, with Three Major Types of Players

Digital solutions of big Ag players …

- All major Ag players invest in digital solutions, for many players set up as separate unit
- However, digital Ag is not considered an integral part of their business yet
- Most companies are mainly focusing on digitalizing their existing products with limited diversity in product offerings

… compete with AgTech players …

- Emerging space attracts a wide range of players focused on diverse set of technologies
- Advantages in their technology innovations and their expertise in agriculture
- Besides few leading players most companies still focus on innovations in one specific value chain with limited differentiated offerings

… and players outside the sector

- Increasing demand for data analysis and storage also appeals to tech players
- Their advantage lies in tech capabilities and ability in understanding customers rather than Ag knowledge, so their focus is on developing smart Ag platform
- However, Ag not assumed to become priority for tech players

Source: lit search; BCG analysis.

ture. At the same time, many GHG emissions reduction studies are still theory-based, and lack evidence drawn from real agricultural production. This report gives an overview of technology practices based on abundant agricultural carbon neutrality production experience. Meanwhile, a wealth of multi-matrix data calculation and analysis has validated their agricultural outcomes. Research outcomes are grounded in BCG's long-standing carbon neutrality experience and expertise, as well as XAG's experience/data from large-scale practices of digital agricultural infrastructure, intelligent agricultural equipment, AI platform technologies and primary interviews with farmers.

As mentioned in the previous chapter, use of fertilizer, on-farm energy use, drained organic soils, and management of crop residues are among the largest GHG emission sources within the farm gate. Furthermore, technology may have greater potential to reduce emissions from these sources. Reducing emissions from on-farm energy use, optimizing use of fertilizer, facilitating crop straw returning to the field, and optimizing farmers' agronomic practices will be four key levers to be focused on in this report. (See Exhibit 12.)

1 Reducing the Combustion of Fossil Fuel.

Modern intensive farming relies heavily on the use of fossil fuels for seeding, tillage, agrichemical spraying and grain drying. Combustion of fossil sources is the root cause of GHG emissions from on-farm energy use and releases significant amounts of CO_2 into the atmosphere. There are two methods to cut down these emissions: run machines on clean energy, and improve energy efficiency.

Adopt machines running on clean energy. The key to reducing on-farm fossil fuel combustion is to replace traditional oil-fired agricultural machinery with equipment which is powered by clean energy. The adoption of battery-powered drones and agricultural robots in farm operations is now recognized as an effective approach to sustainable agriculture. Compared to traditional self-propelled machines (e.g., tractors, combine harvesters), digital hardware solutions are mostly based on electrical power and semi-automatic or fully autonomous systems. In addition to robotics and drones, the agriculture IoT systems for crop monitoring use solar PV and therefore produce fewer life cycle GHGs.

Improving energy use efficiency via precise operations. Another practice to reduce energy use and CO_2 emissions on highly mechanized farms is energy efficient design. Traditional farming machinery is manually operated and fully depends on the driver's experience and expertise to follow the best route in the field. Failure by a farmer to follow the best route, especially on large-scale

Exhibit 12. Four Key Levers to Help Reduce GHG Emissions in Agriculture

Reduce fossil fuel use

- Replace traditional farming machines with electronic drones or robots
- Use precision technologies like autopiloting to increase energy use efficiency

Reduce agricultural inputs

- Variable rate application of fertilizers enabled by AI prescription map
- Smart fertigation system

Facilitate straw return-to-field

- Smart pest management solutions enabled by IoT sensors, satellite imagery and data analytics

Optimize agronomic practice

- Using integrated smart platform to help farmers make more informed decision throughout the full life-cycle of growing crops

Source: XAG expertise; BCG analysis.

farms, results in great fossil energy waste. Now, farm owners or service providers can leverage an automated steering system to enable tractors, transplanters, harvesters, and other large-to-medium machinery with autopiloting and precise operation. The centimeter-accurate navigation system turns diesel tractors into a self-driving machine. It allows the machines to follow a pre-planned route without any unnecessary detours and minimal overlaps, and covers the whole process from furrowing, seeding, and rice planting to harvesting.

Case study: Drones and Robots in Agriculture

Drone and robotic technology is giving agriculture a high-tech makeover. As the technology matures, they have been increasingly used in field work to replace traditional agricultural machinery due to their efficiency and lower energy costs.

A Swedish farming machine provider focuses on autonomous spraying and weeding machines. The company has launched a solar-powered spraying machine, the ARA robot, which leverages a multi-camera vision system and automation console to detect and selectively spray weeds with a micro-dose of herbicide. The machine is fully solar-powered and its power consumption is highly computerized to enable an 8-hour use per charge. The machine can also operate at night, further extending its daily throughput up to 96 hectares per 24 hours.

A domestic leading AgTech company has launched a lightweight unmanned ground agricultural vehicle. The vehicle is equipped with an extendable modular design and can easily switch between different wheel sets to adapt to various terrains or types of work. The electric-powered vehicle can replace traditional oil-fired machines for seeding, spraying, weeding, and field delivery work. Coupled with an ultra-precise navigation system, the vehicle also saves energy due to its efficient route planning. According to the company's social responsibility report, the company's drone and autonomous vehicle technologies have helped to cut fossil fuel usage by 280 million litres for its customers since 2007.

2 Cutting Down Agricultural Inputs.

Over-application of fertilizer and pesticide has long posed a risk to both food safety and environmental sustainability. Synthetic N fertilizers directly cause N_2O emissions. In addition, pesticide overuse not only causes food safety concerns but also erodes the soil's carbon sequestration ability, causing more carbon to be released into the atmosphere.

Variable application based on AI prescription map. By using remote sensing drones to produce a high-definition map full of data, then analyzing that data with AI technology, farmers can get a clearer picture of their field. The data includes the field boundaries, location of each tree, crop height, plant density, and pest and weed population. Farmers can then leverage AI insights to spray or fertilize more accurately, and calculate application rates based on crop needs.

For instance, with the AI-prescription map technology, farmers can precisely target crops infested with pests and weeds or suffering from low fertility. Then, they can send autonomous agricultural drones and robots to spray or fertilize, guided by the AI-prescription map, following the preset routes exactly. These machines, equipped with rotary atomizers, can spray the pesticide uniformly and turn them into micron-level droplets, which stick better to the front and back of crop leaves. This allows farmers to better protect their crops and increase productivity while cutting back on fertilizer and pesticides, and reducing GHG emissions.

Smart fertigation to increase nitrogen use efficiency. A smart fertigation system is another approach to accurately deliver nutrients. Unlike traditional fertilization, which involves spreading solid fertilizers above ground, smart fertigation incorporates fertilizers into irrigation water through the drip system, allowing liquid fertilizer and water-soluble fertilizers to be absorbed directly by the roots of crops. This helps to cut fertilizer use and reduce N_2O emissions.

In addition, cutting down on agrochemicals is instrumental in enhancing soil carbon storage. For instance, cutting these chemicals can help to preserve mycorrhizal, a species of fungi root trading between plants and soil and the key driver of soil carbon absorption. Research shows that plants with mycorrhizal connections can remove up to 15% more carbon from the atmosphere and store it into the soil than non-mycorrhizal ones.

3 Better Straw Return-to-Field.

Straw management is a key factor in controlling GHG emissions in agriculture. The mitigation potential of crop residues is primarily affected by GHG emissions from anaerobic decomposition and carbon losses from residue burning. In the past, in the absence of residue utilization technology, farmers tended to burn most of the crop straws after harvest, reducing soil nutrients and causing severe pollution.

Case study: Variable-Rate Application and Smart Fertigation

A Polish AgTech company has launched a platform which uses satellites to monitor the state of the crops in each field. With cloud computing and data analysis capabilities, the platform can create variable rate application files from individual satellite images. The platform specifies zones, rates and other parameters for drilling, fertilizing and spraying of different fields. Users can easily view the information on a desktop or mobile devices. Customers can also export the data in industry-standard formats for use by other manufacturers in precision agricultural machine operations.

An Israel-based company is mainly focused on development of smart fertigation systems. Its fertigation system samples and monitors, in real-time, the chemical and physical changes in the upper levels of the root zone. After the data (tensiometers, oxygen and pH, etc.) is collected, the system analyzes it using fuzzy-control algorithms and automatically activates irrigation and fertilization.

The smart fertigation system also employs an ultra-low drip system with numerous daily pulse irrigation intervals which helps to keep the oxygen levels in the soil high. The system helps farmers to increase crop yields, while using up to 50% less water and 70% less fertilizer.

As more countries start to ban or explicitly discourage straw burning, returning straw directly to the field has become the most economical and convenient method of residue disposal. Straw return-to-field is seen as one of the most effective ways of maintaining and improving soil fertility, helping to increase the organic carbon content and quality of the soil and delivering high annual yields. However, straw return may actually damage croplands unless there is a mechanism in place. Returned straws can be prone to harmful pests and diseases because, untreated, they often carry insect eggs or other bacteria and the commonly used crushing approach cannot eradicate these. Therefore, technology is crucial to identifying pest populations and taking control measures at the early stage to optimize the quality of straw returning.

Various technologies have been employed to detect insect pests and keep farmers informed promptly. In the air, remote sensing drones with multi-spectral cameras can fly over farmlands to capture areas covered by crop residues. On the ground, there is the IoT system that consists of high-resolution farm cameras taking field photos and sending them back to farmers for real-time monitoring via smart phone. If pests are identified, farmers can deploy drones to spray pesticide in a more targeted way and efficiently ward off pests.

4 Optimize Farmers' Agronomic Measures Through an Integrated Ecosystem.

Although technologies can help to cut the use of diesel fuel and agricultural chemicals while avoiding biomass burning, their respective GHG mitigation effects would be limited without proper agronomic measures. To give full play to the carbon-natural potential of agriculture, the solution is building an integrated ecosystem that can deliver higher yields for lower inputs. Using less resources to boost food productivity can bring a host of other benefits, including increased plant density, higher vegetation coverage and improved biodiversity.

Traditionally, agricultural decisions, such as when to sow seeds, irrigate crops, spray pesticides, or deliver fertilizers, were made mainly based on farmers' personal experience and judgment, so a misjudgment would lead to problems. Besides wasted energy and the overapplication of fertilizers mentioned above, uninformed agricultural decisions might also lead to inefficient use of land, unnecessary tillage or even degradation of farmlands.

Fortunately, farmers can now make more informed decisions and adapt better agronomic practices by leveraging smart agriculture platforms. These platforms adopt an end-to-end approach leveraging IoT sensors, robots, drones, and AI cloud computing to guide farmers

Case study: Technologies to Facilitate Straw Return-to-Field

A Canadian company develops precision pest management solutions that empowering farmers by combining real-time pest monitoring with variable-rate mating disruption enabled by automated pheromone deployment. Farmers can capture key information such as pest population on the farm through a network of cameras and sensors. The system also provides pest degree forecasting and alert services throughout the life cycle of the crops.

In addition, the company leverages pheromones rather than pesticides to control the pest population and protect crops. According to the company's description, pheromone performance in pest control is on a par with, or even better than, conventional treatments but with significantly less negative environmental impact. By reducing chemical spraying, the farmers can harvest healthier crops while improving farmland's carbon sequestration capability.

through the cycle of crop cultivation. The platform builds an agriculture ecosystem which integrates all hardware devices and software applications used in agricultural activities. Devices such as sensors, drones, and satellites are interconnected to monitor, track and collect a wide variety of data. After the data is collected and transmitted to the platform, software applications including vision and machine learning algorithms analyze it and generate information and digital solutions to help farmers optimize their agronomic practices. The collected data is then transmitted to the platform, quickly analyzed by AI technologies including image recognition and deep learning, providing farmers with digital solutions to make optimal agricultural decisions.

Generally speaking, the smart agriculture platform is designed to help farmers achieve comprehensive monitoring in three major aspects throughout the production process. Firstly, the comprehensive monitoring of the natural environment, including temperature, humidity, light, wind and rainfall, etc.; Secondly, the comprehensive monitoring of farmland conditions, including soil thickness, temperature, water content, pH, fertility and heavy metal content; Thirdly, comprehensive monitoring of crop conditions, including crop germination, density, height, health, and pest and disease conditions. The platform sends real-time information to farmers and provides actionable suggestions and solutions based on data analysis, helping farmers make scientific decisions, optimize resource allocation efficiency, increase production and curb greenhouse emissions. For example, through the analysis of soil and weather conditions, the platform helps farmers grasp the best timing for sowing, irrigation, and fertilization. The platform monitors and analyzes on crop density and growth conditions (such as germination rate, plant height, leaf size and shape, etc.). When it is found that the number of crop seedlings deviates from the target value, farmers will be prompted to replenish seedlings in specific areas in time to improve land use efficiency. In addition, with the help of the smart agriculture platform, farmers can keep an close eye on land degradation, and adopt relevant protective tillage techniques to reduce soil erosion, promote water storage, and enhance soil carbon sequestration capacity through vegetation restoration and soil disturbance reduction. All of the above lead to reduction in the carbon footprint of agriculture.

The current smart agriculture platform provides a series of digital solutions, such as crop growth simulation, cultivation mode optimization, plant protection guidance, abnormal field condition detection, grain yield measurement, extreme weather waring, and pests warning. As the technology gets mature, the application scenarios will become more diverse.

Case study: Integrated Smart Agriculture Platforms

Various players from different backgrounds have launched integrated agriculture systems to help farmers optimize their agronomic practices.

A digital farming platform supports farmers by monitoring and analyzing soil and crop conditions and tailor recommending treatments. The platform offers two solutions for farmers, namely “Scouting” and “Field Manager”.

The “Field manager” provides farmers with agronomic recommendations based on analysis of satellite data, weather data and field conditions. The “Scouting” service allows farmers to crop photos for disease recognition and treatment advice. It also features radar technology to alert farmers when disease risks are approaching their area.

What Does the Farm of the Future Look Like?

There is no simple panacea for the climate challenges faced by the agriculture sector. Nevertheless, farms are now building integrated ecosystems which incorporate all AgTechs to improve productivity, cut down manual labor costs and reduce carbon footprint.

XAG, a leading agricultural technology player, has built a fully automated cotton farm, also called the "Super Farm", to exemplify how technologies could help to achieve a sustainable agriculture without compromising the growing demand for productivity.

Traditionally, due to the absence of farmland data and lack of digital technologies, there has been a contentious tradeoff between farm productivity and ecosystem health. Since food production used to require a large input of agricultural resources, enhancing yields meant a compromise on climate change. To provoke a fundamental shift towards net zero farming, XAG launched the "Super Cotton Farm" project in Northwest China in April 2021. Two farmers who were born in the 1990s were selected to manage the cultivation of a 200-hectare cotton field, using new technologies that have never been implemented before. The project aims to establish an autonomous farm management model that is replicable and can be scaled up in the future. And as the snow-white cotton harvest season wrapped up in October 2021, the results have proved that a vast area of farmland can be managed by a smaller labor force at a reduced carbon footprint, without sacrificing higher production efficiency or yields. (See Exhibit 13.)

What sets XAG Super Cotton Farm apart from other traditional cotton fields is the introduction of an integral smart agriculture ecosystem, which has cut greenhouse gas emissions by 22% in total. To manage a cotton field of the same size, it usually takes at least 30 farm workers to finish tasks such as scouting, water valve control, cotton topping, pesticide sprays, defoliation, and harvest. In this case, two young people with limited farming experience have successfully grown high-quality cotton with 60% lower labor costs and gained an average output of 3,810 kg per hectare even after damage from natural disasters. This was done through building digital infrastructure such as farm cameras, weather stations, and soil monitors, as well as applying drones, robots, an autopilot console, and AI. (See Exhibit 14 and the sidebar, "The Green Magic of the Super Farm".)

The success of this model provides a lower threshold for rural youth to embrace the life of countryside and become tech-savvy farmers. They are encouraged to bring more low-carbon agricultural practices back to the villages, and once this project is scaled up, it will empower vast rural areas to become a new growth point of the carbon-neutral economy.

Exhibit 13. The "Super Farm" in Numbers

2 vs 30

Only **2** people are needed to manage a 200-hectare farm field which conventionally needed **30** people

3,810 kg/hectare

Achieved cotton production of **3,810** kg/hectare[1] in 2021 despite wind damage

~60% lower labor cost

Could save up to **60%** in labor cost, compared with traditional farms with same coverage

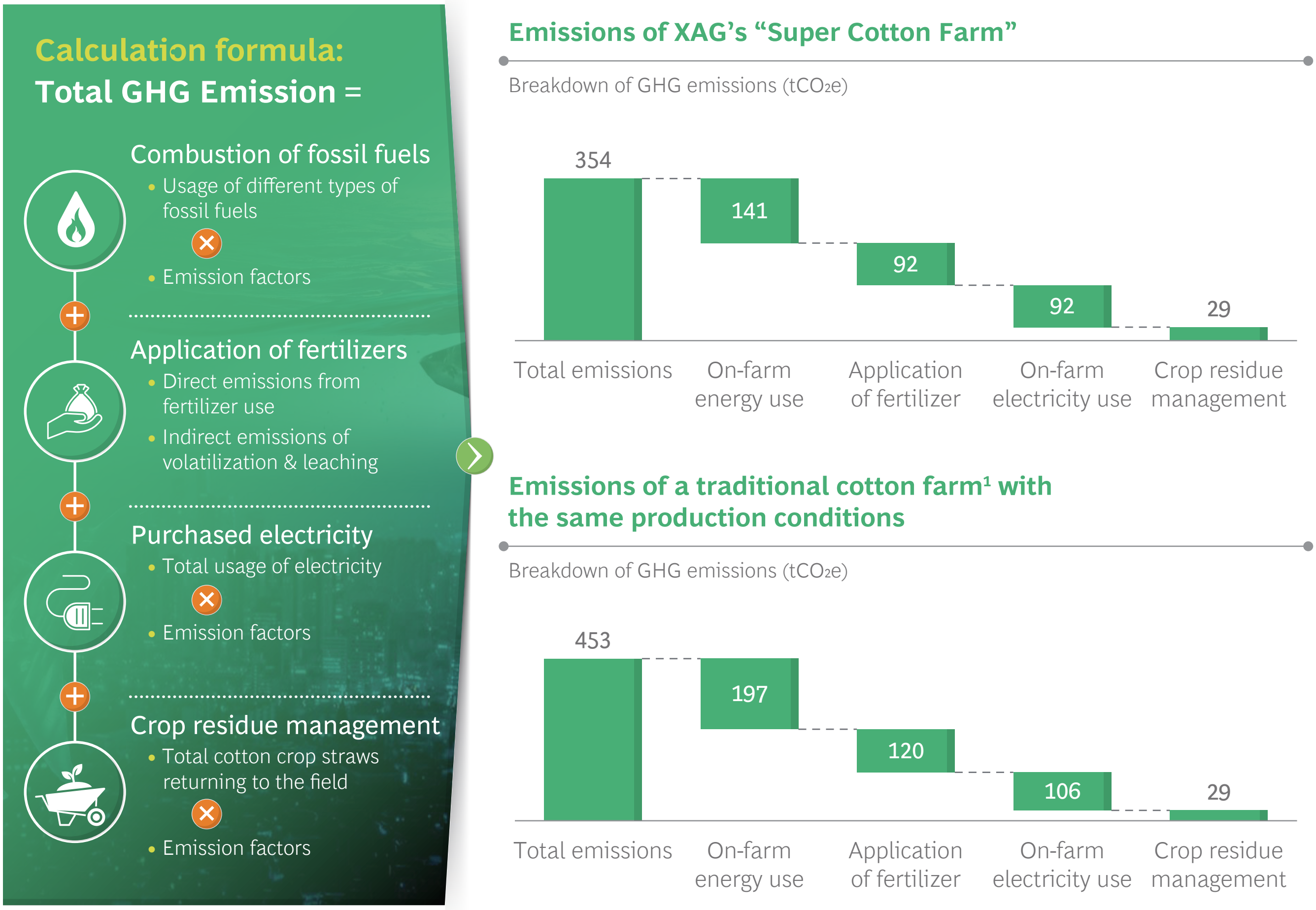
~22% fewer GHG emissions

~22% reduction in GHG emissions from four main emission sources within the farm gate

Source: XAG internal data; BCG expert interviews; BCG analysis.

[1] The average output could achieve 4,500 kg/hectare if disaster-affected area is excluded.

Exhibit 14. XAG's "Super Farm" Emits About 22% Less GHG Gases than Traditional Farms



Source: XAG internal data; lit search; BCG expert interviews; BCG analysis.

[1] The activity data for traditional cotton farms is based on experts, agriculture scholars and farm owners' views on the average usage of energy, fertilizers, electricity and crop straws production of the farm with same coverage.

The Green Magic of the Super Farm

Reduce Consumption of Fossil Fuel with Smart and Electric Equipment

Fossil-fired tractors are used heavily throughout the whole cotton growing process, from seeding and mulching in the early stage of cultivation, pesticide spraying and fertilization during crop protection, to returning cotton straw after harvests. However, just one tractor can consume up to one ton of diesel oil per day when deployed for deep tillage.

On XAG's Super Cotton Farm, two young managers adopted a more sustainable solution: first, they replaced tractors with electric agricultural drones for crop spraying to control pests, eradicate weeds, and conduct the harvest-aid defoliation. Second, for circumstances where large machinery is necessary (tillage, seeding, and harvest), the automated steering system was installed to transform diesel machines into self-driving vehicles that can follow the shortest straight path on the cotton fields. Fossil fuel waste was further avoided by the removal of human error from manual operations. As a result, these two basic measures have helped reduce 30% of energy driven GHG emissions on the Super Farm.

Inaccurate operations easily occur when people driving traditional agriculture machine, and it causes huge waste of diesel fuel

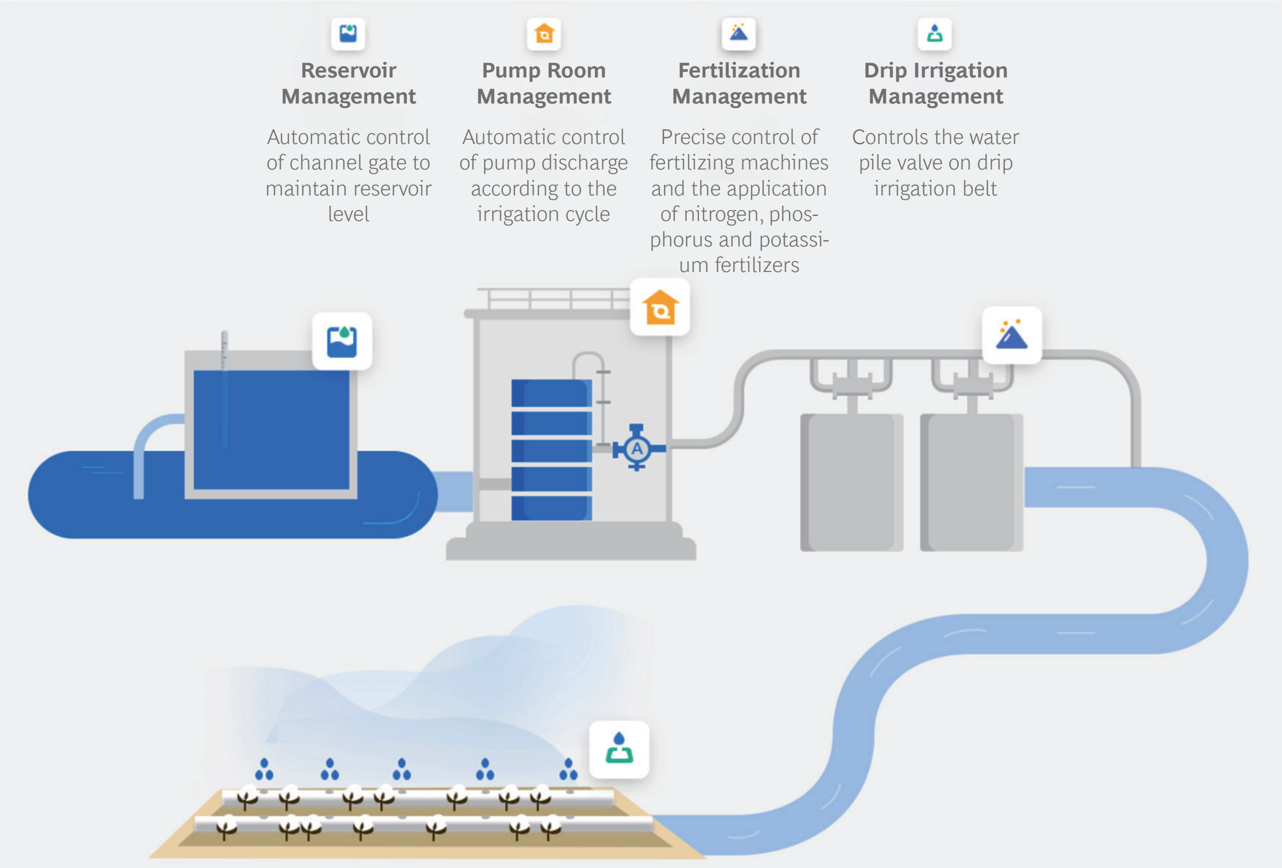
After installed the automated steering system, traditional agriculture machines can follow the shortest straight path on the cotton fields to avoid unnecessary fuel consumption

Precision Agriculture to Optimize Fertilizer Use and Improve Soil Health

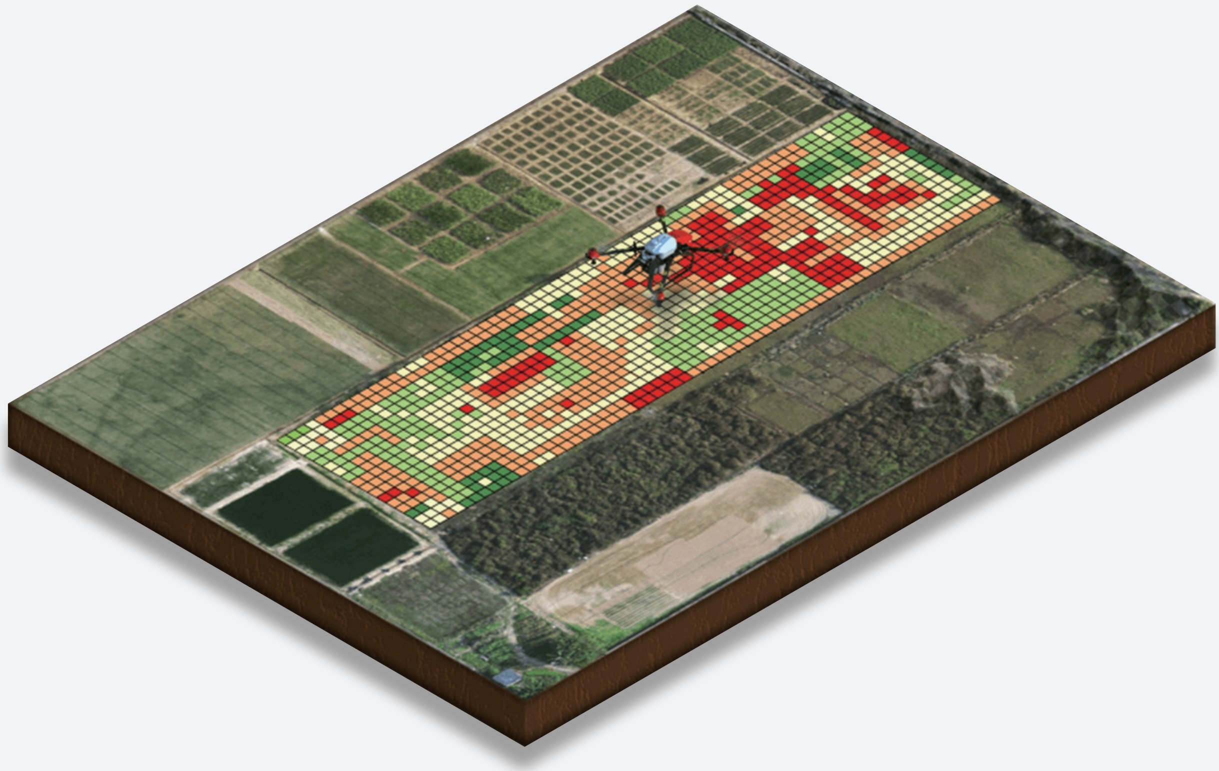
In the fertigation system, pump houses play an indispensable role connecting water pumps with thousands of valves and transferring water through tapes to cover the whole cotton field. Previously, a long-term work force was needed to manually open and close the valves spread across the fields. However, traditional water pumps are not precise and struggle to guarantee a steady, equal flow rate in every corner. When this inaccurate irrigation network is used for fertilization, it leads to large-scale excessive release of fertilizers to the soil.

To prevent this, the Super Farm has modified the water supply mechanism, through connecting all water pumps to an IoT system and turning to smart electronic valves which are monitored by industrial-grade electronic water meter. This allows the fertigation system to be remotely reviewed and controlled by laptop or tablet PC. Farm managers can switch the water valves on or off from kilometers away instead of sending workers to operate them manually. The smart electronic valves combine with automatic fertilizer applicators to deliver high-precision fertigation. Precise control over the amount of fertilizer used has led to the conservation of 900,000 tons of water and a 23% decrease of in the amount of fertilizer used.

At the same time, the Super Farm used fully autonomous drones to conduct crop spraying with less water and chemicals, helping to increase the carbon sequestration ability of fertile soil. The AI prescription map technology has led to a 36% decrease in the amount of pesticides used, racking up over 130,000 RMB in savings.



Connect water pumps, smart electronic valves and automatic fertilizer applicators to agricultural IoT system to control irrigation remotely and deliver high-precision fertigation



Using AI to analyze high-resolution farm photos and provide protection solution for crops in different areas, and to direct drones to spray precisely

Post-Harvest Cotton Residue Treatment Avoids Biomass Burning

As straw burning became widely banned as an air pollution reduction measure, the Super Farm decided to return all residues to field after harvest. Although straw return can release greenhouse gases due to decomposition, mainly NO_2 and CH_4, their emissions are substantially lower than those generated by burning.

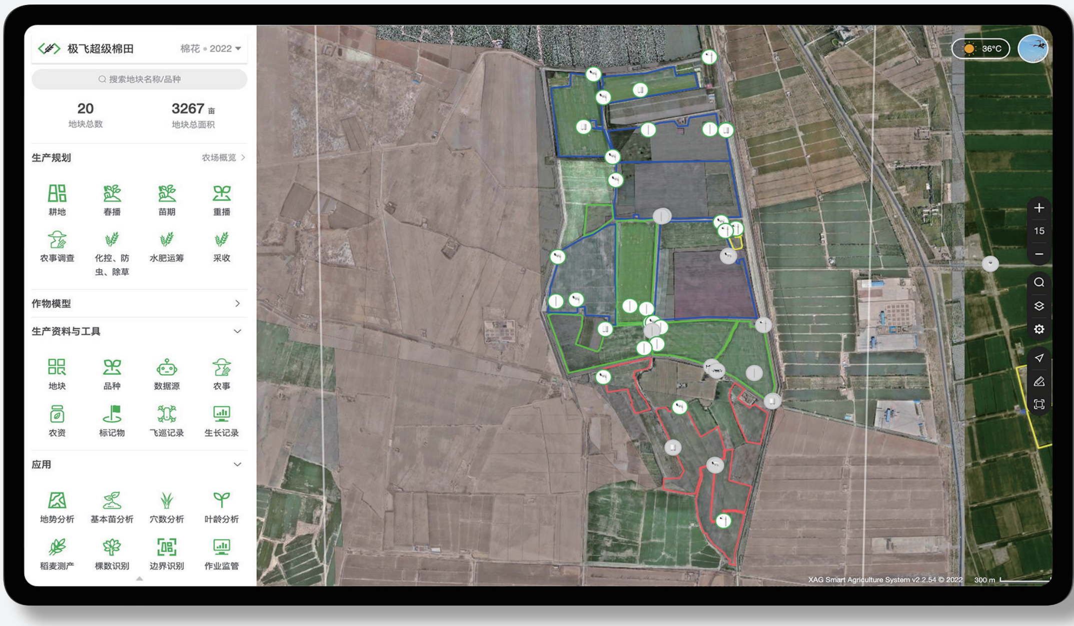
However, untreated cotton straw might preserve the larva and eggs of harmful pests and provide an ideal hatching place for dreadful crop diseases to overwinter. To figure out the pest population in areas covered by cotton straw, drones equipped with multi-spectral cameras scouted the fields. The IoT system on the ground also took crop images regularly and sent them back to the farm managers' mobile phones to ensure timely diagnosis. Besides, managers can also use drones to spray pesticides precisely at night, when pests are more active. It is more efficient than traditional way

AI and IoT System to Optimize Cotton Yield and Increase Plant Density

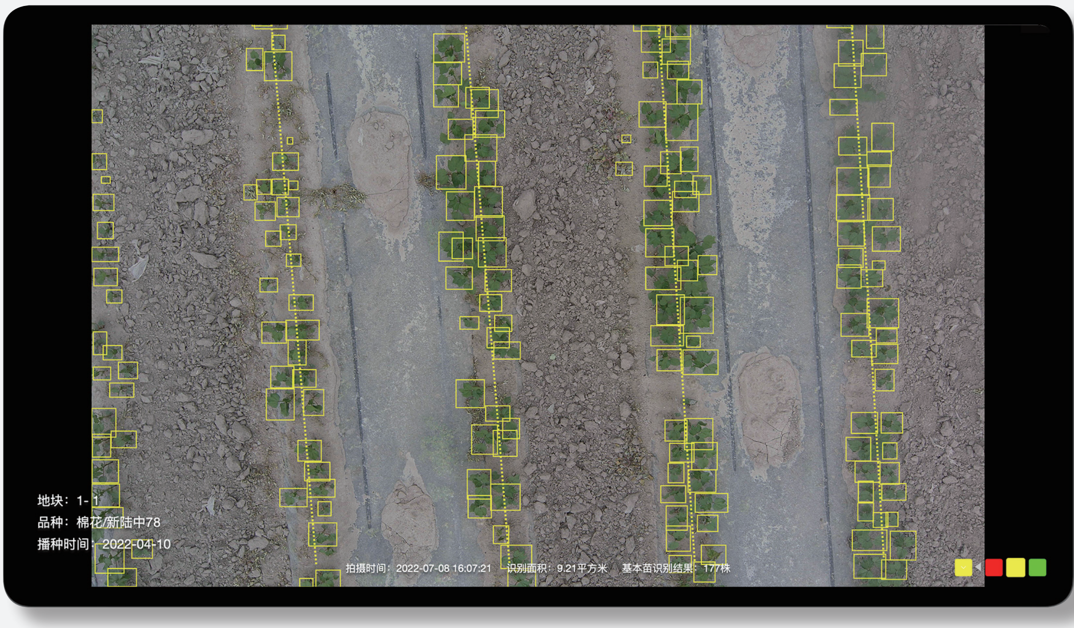
Just a few days after the Super Farm completed crop seeding, the field was struck by three windstorm disasters in succession in the space of one month. As soon as the gale destroyed the plastic mulching and drip tapes, the cotton seeds would be completely exposed and would struggle survive on the bare ground, meaning severe yield loss if no action were taken. Depending on the degree of damage, the farmers took actions to bridge the yield gap and restore vegetation. In less impacted areas, the farm managers sent remote sensing drones to take high-resolution field images that were transmitted to the XAG Smart Agriculture System for analysis. AI could identify the level of crop damage and decide the exact areas that needed reseeding to secure proper crop density. For fields with irreversible losses, the managers could leverage the AI-backed digital platform to understand the scale of the most-affected areas as well as the extent of crop damage. Knowing the post-disaster population of seedlings and plant distribution, they deployed drones for customized crop care services to secure a desirable output.

The example of "Super Cotton Field" illustrates how administrators can make scientific decisions with the help of digital platforms facing climate change, and take appropriate measures in time to optimize output and restore damaged vegetation. In fact, by integrating digital infrastructure, smart agricultural equipment, Internet of Things and artificial intelligence technologies, the smart agriculture platform helps administrators fully understand the overall real-time situation of the farm and the crop growth details at different stages of “cultivation and harvesting”, and refine their agricultural production planning and implementation. Administrators of super cotton fields can use this platform to plan their production calendar and agricultural materials management, monitor key indicators of fields and crops throughout their life cycle, and program intelligent agricultural equipment to perform agricultural tasks according to preset routes.

Assistance for farm administrators in making precise decisions also indirectly suppresses agricultural greenhouse emissions. For example, by helping administrators determine optimal planting densities, excessive damage to soil fertility and soil erosion can be avoided, while protecting the soil’s carbon sequestration capacity.



Smart agriculture system records the situation of zones, materials, and equipment in different growth phase, to help managers make decision wisely

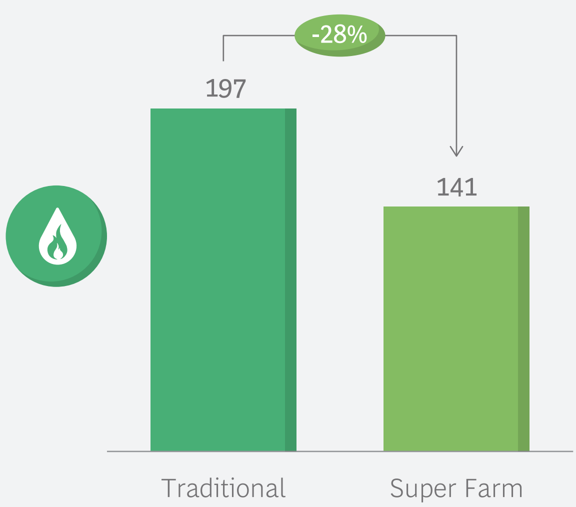


The platform can collect multi-dimensional data and monitor the key indicators for plants in real time, with pre-set conditions. When indicators reach a certain value, the platform can control the smart machine to automatically conduct farm work

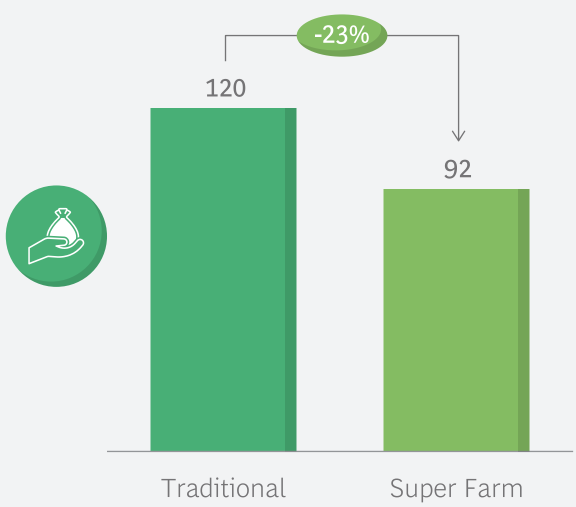
Exhibit. GHG Emissions Breakdown by Source (1/2)

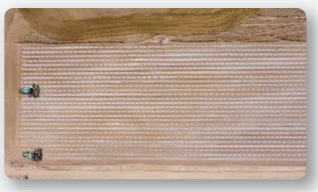
Effects and Key Drivers

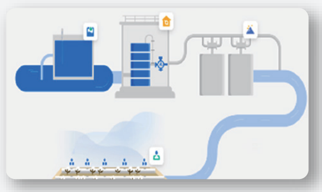
Emissions from combustion of diesel (tCO_2e)



Emissions from application of fertilizers (tCO_2e)







- Replace oil-fired agriculture machines (such as tractors) with **electric drones or automated vehicles** for field works including spraying pesticide and applying fertilizers

- Installed **automated steering system** to transform diesel machines into **self-driving vehicles** that can follow **the shortest straight path** on the farm and save energy

- Use **smart fertigation system** and **AI/IoT System** to deliver **high-precision** fertigation and avoid fertilizer overdoses

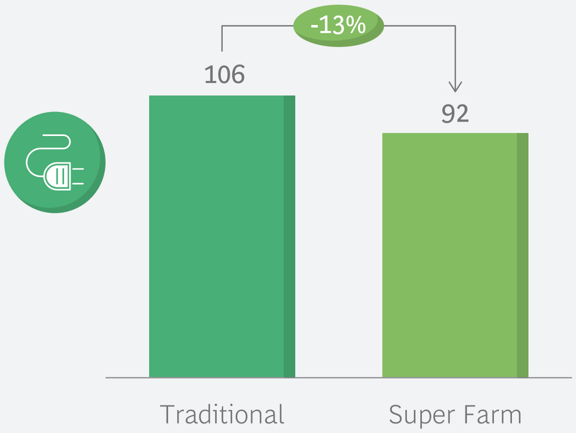
- Use AI to **analyze high-resolution farm photos** and provide suggestion for spraying based on different growth phase in different areas; use drones to **spray precisely**, increasing soil's carbon sequestra-tion capacity and cut GHG emission indirectly

Source: XAG internal data; BCG expert interview; BCG analysis.

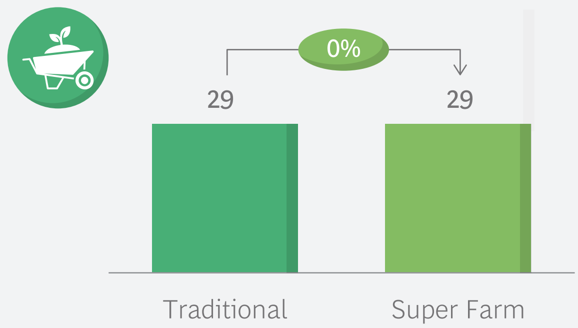
Exhibit. GHG Emissions Breakdown by Source (2/2)

Effects and Key Drivers

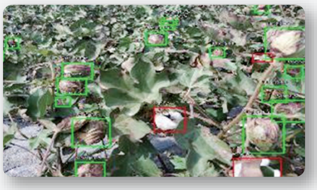
Emissions from use of electricity (tCO_2e)

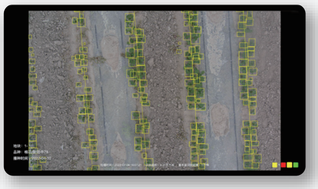


Emissions from straw return-to-field (tCO_2e)



The region has issued bans on burning of straws and all straws are returned to field, but technology could help to avoid pest breakouts and improve cotton productivity





- Avoid flood irrigation by leveraging **smart fertigation system** to remotely control valves in different areas and precisely control the usage of water and fertilizers while **saving electricity**

- The higher adoption rate of smart devices might increase electricity use and **offsite mitigation potential**; it is important to promote solar powered devices and further **improve current devices' performance** to save more electricity

- Leverage drone equipped with **multi-spectral camera** for field scouting; use **AI image analysis** to detect pest populations and take early action

- **AI and IoT systems optimize field treatment** and improve the productivity of each plant, allowing the same amount of cotton to be produced with less straws

Source: XAG internal data; BCG expert interview; BCG analysis.

Beyond the Farm: Future Challenges and Implications

Long Road Ahead: Potential Challenges

Agriculture, one of the world's oldest industries, finds itself at a critical turning point. The pressure from increasing food demand and rising global temperatures driven by GHG emissions has pushed the industry to the edge of technology transformation. Future agriculture will have to be run very differently, leveraging sophisticated technologies such as drones, sensors, and big data analytics to be more efficient, productive, and environmentally friendly. Although the future looks promising for AgTech, three main challenges remain that need to be addressed to accelerate AgTech adoption and fight climate change.

1 Challenging Agricultural Environment

Low standardization level: The first challenge comes from the diffuse nature of agriculture. Even within the same country, the type of crops planted varies greatly due to differences in geographic locations, weather, soil and water conditions, etc. This will also lead to different agronomic practices and technology needs, leaving limited space for standardization for AgTech service providers. It will take much investment and effort to develop and promote their technology solutions across different systems and crops. The long-term solution is to fully understand and characterize the underlying mechanisms to increase the level of standardization through fundamental science research.

Insufficient infrastructure: Infrastructure, such as high-speed Internet networks, is essential to unlocking the value of AgTech. Nonetheless, the infrastructure in most of the world's rural areas is insufficient, especially for smallholders and farmers in developing countries. There are some extreme cases in which farmers in remote areas don't even have access to the electricity or roads needed to transport and use advanced equipment and devices. In addition, most farms are still running on 2G or 3G networks which cannot support the real-time data transfer required for IoT technologies.

2 Farmer reluctance

Another challenge faced by AgTech players is how to encourage farmers to proactively adapt technologies in their daily operations. Currently, the slow adoption rate of AgTech among farmers is mainly due to three reasons.

- **Lack of awareness:** AgTech lacks exposure and publicity; many farmers lack information and clarity on what technology solutions are available to them or how those solutions could help.
- **Unattractiveness:** Some equipment and devices might be too expensive or not economically justified for farmers to adopt. In particular, for farmers with relatively small-scale farmland, it will take even longer to break even given the large initial investment of new technologies.
- **Difficult to use:** Some agriculture technology solutions are too complex and cumbersome, difficult for farmers to use, especially for those with no tech background or low education level.

3 Unfavorable Regulations

Compared to quickly evolving agriculture technologies, government regulations and guidance is moving more slowly. In some countries, the promotion of AgTech remains controversial. This is probably due to concerns around loss of job opportunities, food safety issues or privacy violations. The regulatory environment isn't favorable enough for a swift and smooth technology transformation. For instance, in India, pesticide spraying on farms using drones has previously been declared illegal. In the United States, the Federal Aviation Administration (FAA) has set height restrictions limiting commercial drones to no more than 500 feet above the ground. Countries including China and Japan have issued regulations on commercial drones' maximum loading capacity. These constraints would no doubt limit drones' range and consequently their usefulness, further hindering the adoption rate.

Implications for Key Stakeholders

Both government and industry players are critical in promoting the use of AgTech to fight climate change and improve productivity. The challenges faced by AgTech cannot be tackled by one party alone. To address them requires a coordinated effort. More importantly, they should provide affordable solutions to farmers that address their needs.

The role of government cannot be overstated. As many governments put forward carbon neutral targets, they will increasingly need to step up to the plate and foster healthy environment for the development of AgTech, mainly through three approaches.

- **Increase awareness:** To promote the awareness of sustainable agriculture and AgTech among both famers and consumers, especially in rural areas. In addition, to hold information sessions for farmers and introduce technology solutions which would boost the adoption rate.
- **Improve infrastructure:** Continue to invest in infrastructure, provide necessary infrastructure such as low latency and high bandwidth Internet connections at an affordable price for farmers.
- **Create a healthy regulatory environment:** Be more agile, flexible, and forward-looking in policy making. Constantly track and monitor the development of the AgTech market and provide regulatory support to guide and facilitate its growth. Consider providing subsidies for key technology areas and crack down on any illegal practices.

AgTech companies are well-placed to seamlessly bridge farmers' needs with technology capability and capital. To overcome the challenges faced by the sector, they will need to adopt a customer-centric approach in doing business, starting with the following three areas.

- **Adopt customer-centric R&D:** Develop technology solutions based on true customer needs; make technology solutions more accessible to customers with no tech background or low education level. For example, produce devices with good human-machine interaction experience and interfaces which are easy to operate.

- **Improve customer education:** Cooperate with government on information sessions for farmers (who are also the potential customers) to promote AgTech as well as their own brands; offer regular aftersales trainings for farmers to ensure they can fully unlock the value of those technologies and achieve high customer satisfaction.

- **Value-based pricing model:** Explore innovative pricing options which might better fit the farmers' needs. For instance, companies can offer various financing options such as low-interest loans, installment payment options or leasing options for farmers to minimize their financial risk. In addition, provide warranty programs for selected technology solutions. The warranty program only charges customers if the pre-set targets are meet.

Agriculture has come a long way and there are more frontiers to push in the future. Technology promises a way to find answers to climate issues by enabling sustainable agriculture. The technological transformation of agriculture will require significant efforts from both governments and industry players. It is a huge but critical undertaking, and those that embrace it at the outset may be best positioned to thrive in the new era of technology-driven and sustainable agriculture.

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