Sustainable Agriculture: The New Green Revolution

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The global agriculture system is on the verge of a new revolution.[1] Sixty years after the *green revolution* brought abundant food supplies to the world, the way food and fiber is produced on the farm is about to undergo another era of sweeping change.

The transformation ahead will shape the future of billions of jobs, trillions of dollars of output and the world's oldest industry. What is at stake is whether we have a livable planet, or not.

Introducing BloombergNEF's Sustainable Agriculture research

BNEF is deepening its coverage of sustainable agriculture, providing a stream of research and analysis on the solutions to agricultural greenhouse gas emissions and biodiversity loss. This paper outlines BNEF's view on the pathway to a net-zero and nature positive agricultural system, which form the Sustainable Agriculture team's focus area.

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The planet size impact of food

The global agriculture system is vast. It employs nearly 1 in 4 people in the world, generates more than $8 trillion in annual revenue, and it occupies and alters over 50% of habitable land on earth.

You should find that last point troubling. It is just one of a long list of statistics that reveals the enormous impact that the agricultural system has on the planet.

Agriculture's impact is probably the biggest problem you have never heard of. Of all human industries and activities, agriculture is the single largest driver of threats to the stability of the earth system.[2] It trumps even our fossil fuel-dependent energy system as the greatest risk to our children inheriting a livable planet.

Breaking boundaries

The reason is sixfold. The science of planetary boundaries – popularized by the 2021 David Attenborough documentary *Breaking Boundaries* – shows that there are nine processes that regulate the stability and resilience of the earth system. These are essentially the physical, chemical and biological process that have kept earth in a "goldilocks" state for the last 12,000 years.[3]

These nine planetary processes have boundaries, or tipping points, beyond which we risk triggering irreversible changes that could destabilize the earth and send it into a new, less livable state.

According to the best estimate of scientists, we are currently breaching six of these nine boundaries. Agriculture is the major driver of at least four of these transgressions: it is driving 80% of biodiversity loss;

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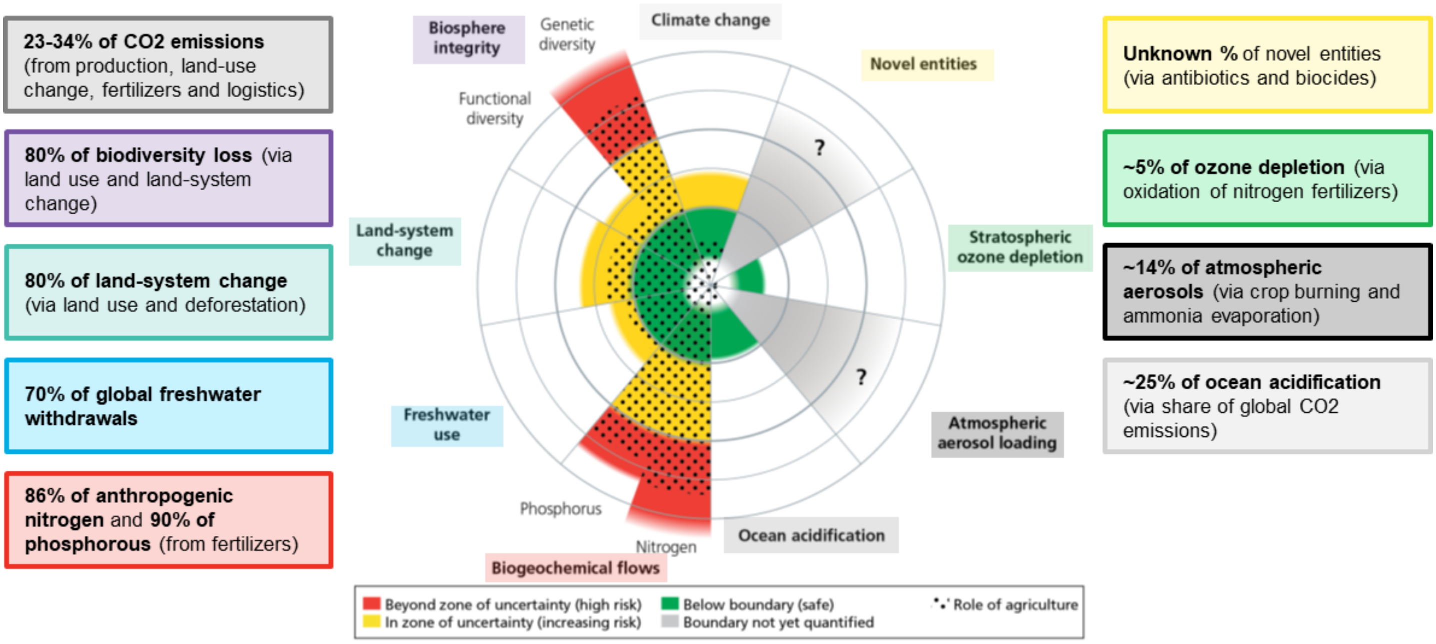
[1] BNEF adopts a broad definition of agriculture, as one that encompasses crop and livestock production, aquaculture, fisheries and forestry for food and non-food products. However, this article focuses mostly on food.

[2] Cambell, B. et al, *Agriculture production as a major driver of the Earth system exceeding planetary boundaries*, 2017.

[3] Stefen, W. et al, *Planetary boundaries: Guiding human development on a changing planet*, 2015.

80% of land-system change; 70% of freshwater withdrawals; 86% of anthropogenic nitrogen and 90% of phosphorous pollution; and a yet-to-be quantified but undoubtedly high share of pollution from novel entities, which affects how organisms function (Figure 1).

Figure 1: Estimate for agriculture's role in the status of nine planetary boundaries



Source: BloombergNEF, IPCC 2019, Campbell et al 2017, Rockstrom et al 2020

Four chief culprits

There are four chief culprits behind the agricultural systems outsized impact.

The first is the scale of land and sea use. Today, around 50% of all ice-free land is used for agriculture and 55% of oceans are industrially fished.[4] Expansion of farmland has come mostly at the expense of forests, wetlands and grasslands – areas that were rich in biodiversity but have now been cleared and replaced with monocultures. Agriculture is estimated to be the driver of 80% of deforestation, ecosystem loss and species extinction.[2] A large part of the problem is that we use land inefficiently – 78% of agricultural land is for grazing and feeding livestock, which supplies just 18% of our total calories.[5]

The second is water use. Of all human activities, agriculture consumes the most water. Around 70-84% of global freshwater withdrawals, including from rivers, reservoirs, lakes and aquifers, are for agriculture.[2] Many of these withdrawals are at unsustainable levels, driving the depletion of water bodies, degrading ecosystems and altering the water cycle at the local, regional and global level.

The third is fertilizer overuse. Humans now add more nitrogen to the soil than all of nature's processes

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[4] Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), *Global Assessment Report on Biodiversity and Ecosystem Services*, 2019.

[5] Ritchie, H., *Half of the world's habitable land is used for agriculture*, Our World in Data, 2019.

combined and add 2-3 times the amount of phosphorous.[2] Only around half of these nutrients are absorbed by the target crops, with the rest being lost to the environment, causing eutrophication of water bodies, air pollution and soil degradation. This has already created over 400 oceanic dead zones with low oxygen levels that cannot support marine life, covering a combined area greater than the UK.[4]

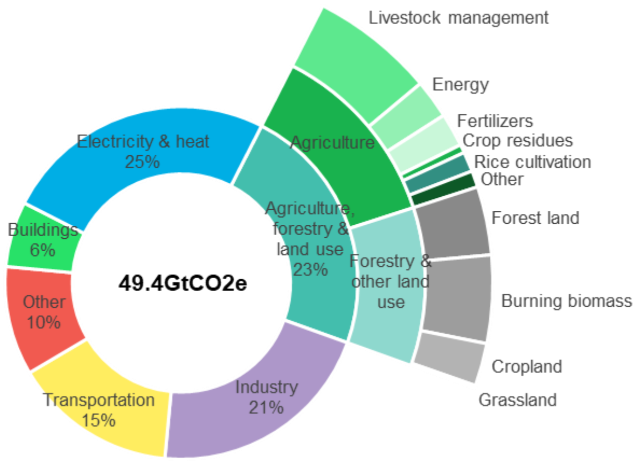
The fourth is pesticide use. Crop production accounts for 85-90% of pesticide use, and it is estimated that over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species.[6] This pollutes air, water bodies and soil, and is a major driver of extinction, particularly for insects which provide essential pollination services to 75% of crops. Currently 40% of insect species face extinction, with pesticides a major driver.[7] Pesticides also bio-accumulate in the food chain – all the way up to humans: a recent study found residues of the herbicide glyphosate in 80% of US human urine samples.[8]

Twin crises

Together, these four culprits are driving the biodiversity crisis, which rivals the climate crisis in both severity and risk. That is because we are dependent on nature's services for 99% of our food supply, 60% of our medicines and at least $44 trillion, or around half, of economic output.[4,9]

The one planetary boundary agriculture plays a non-dominant (but still large) role in, is climate change. Here it is responsible for at least 23% of anthropogenic greenhouse gas emissions (if you just count the emissions associated with production of food and fiber and the land use changes that result - Figure 1),[10] or as much as 34% (if you include all stages of the food system, from farm to fork to landfill).[11] The vast majority of these are non-energy related, which makes them some of the hardest to address.

Figure 2: 2016 global emissions by sector*



Source: BloombergNEF, IPCC, WRI, UN FAO

*Notes: *breakdown of sub-sector emissions may be imprecise due to discrepancies between sources*

Agriculture's grand challenge

The agricultural system can clearly not continue down this path. The industry's grand challenge is to transform to meet three key goals. First, it must halt its contribution to the biodiversity crisis and become nature-positive by 2030, a goal set out in the 2022 Global Biodiversity Framework (GBF) adopted by the COP15 United Nations Biodiversity Conference in Montreal in December. Second, the sector must

[6] Hendrichs, J. et al, *Area-wide Integrated Pest Management, Development and Field Application*, CRC Press, 2011.

[7] Sanchez-Bayo, F. and Wyckhuys, K., *Worldwide decline of the entomofauna: A review of its drivers*, Biological Conservation, 2019.

[8] Ospina, M., et al, *Exposure to glyphosate in the United States: Data from the 2013–2014 National Health and Nutrition Examination Survey*, Environment International, 2022.

[9] World Economic Forum, *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy*, 2020.

[10] Intergovernmental Panel on Climate Change, *Special Report on Climate Change and Land*, 2020.

[11] Crippa, M. et al, *Food systems are responsible for a third of global anthropogenic GHG emissions*, Nature Food, 2021.

become carbon neutral, as required by the 2016 Paris Agreement. Third, production must scale up to feed 10 billion, increasingly affluent, people.

In a nutshell, the agricultural industry needs to produce more, using less. Less land, less water, less fertilizer, less pesticides and with near zero emissions. How can this possibly be done?

Five pillars of a sustainable food system

BNEF's research indicates that there are five broad solutions that offer the most promising and pragmatic path to a sustainable agricultural system, which can feed the global population with food it wants to consume, while operating within planetary boundaries (Figure 3).

These are the development and adoption of:

- Sustainable proteins and fats
- Green agrochemicals
- Sustainable intensification technologies
- Carbon-smart farming practices
- Biodiversity markets and finance

Figure 3: Five pillars of a sustainable agricultural system

Sustainable proteins & fats	Green agrochemicals	Sustainable intensification	Carbon-smart farming	Biodiversity markets & finance
Calories with a much smaller footprint	***Fertilizers and pesticides with fewer side effects***	***Producing more, using less***	***Farms that become carbon sinks***	***Restoring and protecting natural capital***
Technologies that reduce the greenhouse gas emissions, and land and water requirements of protein and fat production	A new generation of fertilizers and pesticides that are less hazardous and produce fewer greenhouse gas emissions	Technologies and innovations that increase farm productivity while using less land, fertilizer and water	Mechanisms to support technologies and farming practices that reduce emissions, sequester carbon and increase biodiversity	Economic and policy instruments that recognize the monetary value of nature and biodiversity
Alternative proteins	Green fertilizers	Precision agriculture	Voluntary carbon markets	Biodiversity markets
Feed supplements	Biostimulants	Perennial crops	International carbon trading	Natural capital
Consumer trends	Biopesticides	Gene editing	Regenerative agriculture	Green finance
Eco-certification and labeling	Agricultural robots	Controlled environment	Zero-emissions machinery	Disclosure and reporting
National agriculture and environment policy				

Source: BloombergNEF

Sustainable proteins and fats

Producing protein and fat in a more sustainable way is the most substantial challenge for the food system because of the large environmental impact, history and tradition of livestock farming. The core challenge is to produce protein using much less land and with near zero greenhouse gas emissions.

An often cited fix are feed supplements, which are additives or medicines that reduce the amount of methane that livestock (particularly cattle and sheep) release through their digestive processes. A variety of products have already hit the market, boasting reductions of 30-45%, and much more may be possible using additives like Asparagopsis seaweed

These are an important tool to reduce emissions, but they will do little to address the biodiversity loss driven mostly by the enormous land requirements of livestock.

The reality is that more radical change to protein production will be necessary if we are to live within the planet's boundaries. There are currently three promising avenues.

The first is plant-based proteins. Since 2011, food products that are made from plants (for example, grains, legumes and nuts) or fungus (mushrooms) and imitate meat have been much hyped, attracted billions of dollars of capital, and are already in supermarket shelves and restaurant menus – for details see: *Alternative Proteins: Fake It Till You Make It* (web | terminal). Their champions include leading brands such as Impossible Foods, Beyond Meat and many others. However, the industry has faced headwinds in recent years on taste and health concerns, and their uptake appears to have stalled. But it is early days for the technology, and their proponents will keep on improving their products and finding ways to push down the cost curve.

A second generation of alternative proteins is also under development, known as cultured, cultivated or lab-grown meat – for details see: *Meat Producers Contemplate an Alternative Future* (web | terminal). These are molecularly identical meats that are grown in a bioreactor using real animal cells. More than 100 companies are working on the technology, which has been approved for sale in Singapore and recently in the US. Cultured meat appears to have the potential to be truly disruptive, but key challenges will be achieving scale, cost reduction and consumer acceptance.

The third – precision fermentation – is currently being used to produce dairy products without cows. The process combines gene-splicing with age-old fermentation techniques to produce molecularly identical milk proteins from other organic materials, like soy or corn. It can produce meat, egg and fish proteins too, and can be refined to use green hydrogen, oxygen and waste CO2 as inputs. The technology has attracted billions in venture capital funding and is in the early stages of commercialization.

The behavior and acceptance of consumers will be definitive in determining how much of an impact these technologies will have. The use of logos or ratings on food items to reflect their environmental performance will help to direct consumer choices. Policymakers will have a major role at shaping this, but the politics are likely to be diabolically difficult due to the cultural importance of animal husbandry in almost every civilization. The consolation may be that animal rearing could go from factory farming back to its romantic ideal of a shepherd with a prized herd of loved animals, as there will likely always be a market for premium animal meat on a Sunday or special occasion. But daily staple proteins will almost certainly need to shift.

Green agrochemicals

The future food system will undoubtedly continue to need agrochemicals like fertilizers, pesticides and herbicides to enable high-yield farming. The challenge is to make and use these chemicals with fewer side effects.

A new generation of fertilizers and pesticides that are less environmentally hazardous and produce fewer greenhouse gas emissions are under development.

An obvious pathway exists to produce ammonia for fertilizers via green hydrogen, which will have significantly lower carbon emissions than the current natural gas-based process – for details see: *Hydrogen: Making Green Ammonia and Fertilizers* (web | terminal). This addresses the carbon emissions from production, but does nothing to mitigate nitrate pollution, so is an incomplete solution by itself.

Biostimulants could be an important complement. They are substances that contain living micro-organisms that help plants to better absorb nutrients and improve plant health, meaning less fertilizer needs to be applied for the same effect. Crop chemical giants like Bayer, BASF, Corteva and Syngenta and fertilizer giants like Yara and Nutrien are all investing in their development. For more details see: *Advancing Agriculture: Biologicals* (web | terminal).

Similarly, a variety of biopesticide products are also under development. They use naturally occurring substances and microbes to control pests, instead of direct toxicity from synthetic chemicals. These have had less efficacy and thus less promising results so far. Therefore more innovation is needed in this space, and it is a focus of many agrochemical players. Other candidates are transgenic crops, RNAi and nano pesticides, which improve the targeting of pesticides and could consequently reduce pollution.

Improvements in agricultural machinery and the application of artificial intelligence will also have a key role to play. Drones, selective sprayers and robotic weeders can all help to reduce indiscriminate spraying of pesticides, dramatically lowering the amount of runoff to the environment. Major equipment manufacturers like Deere & Co already have products in the market, and there are a large variety of innovative new players too.

Sustainable intensification

A variety of technologies and innovations are also under development to increase farm productivity and yields, while using less resources. These will be essential to scaling up production to feed billions of increasingly affluent people.

Perennial crops are a notable example. These are a new generation of plants that grow and yield grain for several years, rather than dying after one season. Perennial plants tend to grow larger root systems, making them more drought and stress resilient, more tolerant of pests, able to store more carbon and better able to access nutrients. Perennial rice has already been deployed in China, producing competitive yields while reducing labor costs by 60% and seed, fertilizer and other input costs by 50%. Perennial wheat, legumes, oilseeds, sorghum and corn are also under development, but need much more investment and development.

Gene editing technologies will almost certainly continue to support productivity improvements – for details see: *Advancing Agriculture: Gene Editing* (web | terminal). Public investment in research and development and commercialization is however likely to be essential, as traditional agribusiness giants may not possess the incentive to develop plants that require less inputs, which are often their complimentary products.

Precision agriculture technologies and approaches will also help to maximize yields, whilst reducing inputs. Technology and GPS-enabled analysis of soil, topography, and sensing of crop growth patterns, plant health, moisture and nutrient levels enable farmers to determine exactly what a plant needs and when. This maximizes the amount of inputs that are absorbed, reduces waste and pollution to the environment. These technologies are already commercialized and will continue to improve, particularly via the increased capabilities of machine learning and AI. For more see: *Technology Radar October 2020: Precision Agriculture* (web | terminal)

Controlled-environment agriculture, which includes techniques such as indoor and vertical farming, is also garnering billions of dollars of investment – for details see: *Climate-Tech VC/PE Investment: Funding Continues to Grow* (web | terminal). These techniques have the potential to increase productivity, production density and reduce input use, but will require massive amounts of energy, steel and cement which may make their lifecycle impact less compelling.

Figure 4: A perennial rice crop in China's Yunnan province

Source: The Land Institute

Carbon-smart farming

There are a variety of land management practices that can help to sequester carbon in the soil, improve soil health, boost on-farm biodiversity and increase crop resilience. This includes regenerative agriculture, agroforestry, mixed-crop farming, use of electric machinery and more.

These techniques are well recognized and understood, and have the potential to improve the sustainability of farming en masse and to capture gigatons of carbon – for details see: *Advancing Agriculture: Regenerative Farming* (web | terminal). The challenge is in scaling implementation and overcoming barriers to adoption, which often boils down to a risk-reward tradeoff for the farmer. In the case of machinery, upfront cost remains a barrier.

In short, farmers need to get paid to overcome the risk of changing practices and to meet upfront costs. Carbon markets are the most obvious way to do this. In 2022, less than 1 million tons of carbon offsets were issued by farmers in the voluntary carbon markets, worth only a few million dollars per annum. The agriculture sector however has the potential to produce billions of tons of abatement and earn tens of billions in additional income if these are sold as offsets – for details see: *Agriculture Carbon Offsets Outlook: Barren to Bountiful* (web | terminal).

A variety of initiatives are underway to increase the agriculture sector's participation in carbon markets. Price will play an obvious role. If measures are taken to restrict the eligibility of cheaper credits which only avoid emissions, we project that the price of a voluntary carbon unit could rise up to $127 a ton by 2050 – for details see *Long-Term Carbon Offsets Outlook 2023* (web | terminal). Business model innovations, new methodologies, the variety of integrity initiatives currently underway and inclusion in compliance carbon markets will all play a key role in in creating more opportunities for farmers.

Other developments have the potential to increase (or decrease) incentives too. The rules for Internationally Transferred Mitigation Outcomes, which is UN speak for inter-country carbon trading, as well as a new global carbon market are under development and could increase demand or subsume the existing market – for details see: *Article 6: Friend or Foe for Voluntary Carbon Markets?* (web | terminal).

Biodiversity markets and finance

The headline goal of the GBF is to protect 30% of land and sea by 2030, up from 17% of land and 8% of sea today. This will require not only an end to agriculture and fishery expansion, but also an incorporation of more biodiversity on-farm, and a reduction in the current footprint of conventional agriculture to create space for the restoration of nature.

The key to achieving this will be money. Nature's services must be valued if they are to be protected and sustainably managed. There are a variety of credible approaches underway to do this.

Biodiversity credit markets are now being developed around the world, and these could create new revenue streams for farmers. The Australian government is in the process of designing a national voluntary scheme, and several private sector lead initiatives have also been announced. These markets are intended to be an improvement on biodiversity offset schemes, which are numerous and in most cases a tool to manage decline. Instead, the intent is that such schemes will incentivize the restoration and conservation of biodiversity above baseline levels. What will incentivize this demand needs to emerge.

Possible candidates are disclosure and reporting frameworks like the Taskforce on Nature-related Financial Disclosures (TNFD), target-setting regimes and natural capital accounting frameworks. All essentially work by making firms aware of their impacts and dependencies on nature, thereby encouraging them to invest in its conservation or restoration to mitigate the risk of its continued decline. If TNFD goes the same way its sister Taskforce for Climate-related Financial Disclosures (TCFD) has in gaining widespread usage, then it will be a material driver of activity. Similarly, Science Based Targets for nature could drive demand for biodiversity credits, as its sister program has for carbon offsets. The incorporation of natural capital accounting at a national level into measures of wealth will be another important driver of change.

More prosaic measures in the financial sector could also be transformative. For instance, banks and lenders around the world currently incentivize landowners to conduct fence-to-fence farming, as this is regarded for valuation purposes as the only form of productive land. Areas of forest on title which host pollinators, purify water, enhance the nutrient cycle, control erosion and more, are effectively penalized as non-productive areas. Banks are however beginning to recognize the essential services provided by nature, and the superior resilience and long-term performance this brings to the farm. Initiatives such as the Finance for Biodiversity Pledge are a good example.

Biodiversity is also beginning to be valued via the issuance of new products, such as green bonds and debt-for-nature swaps. These could lower the cost of finance for farms with more sustainable practices, as well as help incentivize the restoration and conservation of nature – for details see: *Rainforest Finance: How to Make $500 Billion Flow* (web | terminal).

Policy reform

The elephant in the room in the agriculture sector – as in energy – is policy. The best estimates are that governments currently allocate more than $500 billion per year in agricultural subsidies that are harmful to the environment. A key goal in the GBF is to “eliminate, phase out or reform” these, a process that is already underway in some jurisdictions – for details see: *Biodiversity COP’s Bold Targets Now Need Follow-Through* (web | terminal). The EU Common Agricultural Policy has already undergone a first phase of reforms and the UK is undertaking a comprehensive subsidy overhaul.

Removing and altering subsidies is of course hard. But the fact that the 196 parties to UN Convention of Biological Diversity signed up to a quantitative target of reducing these by at least $500 billion suggests they have the intention. These efforts will likely be dogged by a lack of consensus on what is an “environmentally harmful subsidy” and the lack of experience in redirecting such support toward nature-positive activities in an effective, efficient and politically acceptable way.

Other policies on fertilizers, pesticides, water use and land practices will be essential to developing, deploying and scaling up many of the solutions outlined here. Many – such as agricultural robots and precision agriculture – should be easy, as they offer a win for the environment, farmers and consumers. But some, like perennial crops may be resisted by incumbents, and alternative protein production, which reduces the need for livestock farming, will likely be political dynamite. But like with the energy transition, navigating vested interests and ensuring a just transition for affected communities will be a key part of reorienting a core part of the economy.

What's missing?

There are two often cited elements to reducing the agriculture sector's footprint which haven't made the list above – food waste reduction and diet change.

These are similar to energy efficiency and demand reduction in the energy sector. In an ideal world, these are potent, low-cost solutions that should be pursued first. However, in practice they are difficult to advance and scale, as there are often disincentives for corporations and inconveniences for individuals in doing so. Our focus is therefore on transforming supply, as this is the most critical challenge, and also presents the most opportunities.

Navigating the transition ahead

In many ways, the changes underway in the agriculture sector mirror those BNEF has tracked in power, transport, and industry. Confronted with a need to address emissions, biodiversity loss, changing consumer preferences and potentially disruptive new technology, agricultural supply chains will undergo vast transformations over coming decades. With those changes come significant threats to the products and business models of sluggish incumbents, and opportunities for more nimble and innovative players to create trillions of dollars of new value.

We think the above framework outlines the key features of a pathway to a net-zero and nature-positive agricultural system. As technologies, policies, practices and sadly environmental damage advance, the picture will undoubtedly evolve.

BNEF will be producing an informative array of in-depth research on all of the topics outlined above, to inform the potential opportunities from the revolution ahead. Our suite of Sustainable Agriculture research can be found here: (bnef.com | terminal).

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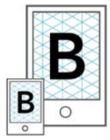

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