Marketing communication for professional investors – APRIL 2025

THE GROWING NEED FOR SUSTAINABLE SOLUTIONS TO CONVENTIONAL AGRICULTURE AND LAND MANAGEMENT

BNP PARIBAS
ASSET MANAGEMENT

The sustainable investor for a changing world

INTRODUCTION

In the summer of 2024, the Potsdam Institute for Climate Impact Research delivered a stark warning about the state of our planet: six of nine planetary boundary processes have breached safe levels and are expected to deteriorate further in the absence of global system changes. Each sector of the economy affects these planetary boundaries differently, with food systems – especially crop and livestock agriculture – having the most significant environmental impact, mainly due to their direct land footprint combined with unsustainable downstream food processing. Fortunately, many researchers and practitioners remain optimistic about the feasibility of transitioning away from harmful agricultural practices toward more sustainable methods.[1] While transitioning to more sustainable agricultural methods is expected to involve substantial upfront costs (see text box on the right), the long-term benefits present a compelling investment opportunity.[2] Over time, these practices can lead to greater efficiency, resilience against environmental and economic shocks, and a more stable global food system.

This paper seeks to urge the mobilisation of greater private sector investment to close the funding gap and accelerate the transition to a sustainable and equitable agricultural future. It is organised as follows: Section one highlights the urgent need for transformation. This is underscored by the alarming degradation of natural resources, the depletion of ecosystems and the mounting pressures on global food systems, which collectively threaten the stability of our planet's environmental and economic future. Section two highlights the costs of the continuation of unsustainable agricultural practices, by showcasing real-world cases where environmental occurrences have contributed to price instability and spikes, and global supply chain disruption, among both essential and non-essential commodities. Finally, section three outlines investable segments across listed equities, which are profitable and can deliver a positive return on invested capital. This is supported by company case studies. Finally, in the appendix we review some areas at earlier stages in their development cycle.

THE HEALTH LINK

According to the Planetary Health Diet, it is crucial for global diets to shift away from processed and animal-based products towards predominantly plant-based foods. This transition is essential to promote both environmental sustainability and human well-being. The environmental solutions explored in this paper can contribute to the sustainability of this transition.

1 It is important to be mindful that corporate action cannot take us all the way as: (1) 'whole of society' changes could help mitigate remaining negative impacts and (2) demonstrating potential for abatement does not ensure its realisation. Additionally, enacting sustainable solutions does not mean the benefits will be felt by everyone, and equitable distribution of food should remain a priority.

2 Nature-in-the-balance-what-companies-can-do-to-restore-natural-capital-vf.pdf (mckinsey.com)

THE ESTIMATED COST OF TRANSITIONING GLOBAL FOOD SYSTEMS

Studies on the UN Sustainable Development Goals (SDGs) show that c.$260 billion of annual investment is required to meet the targets of SDG 2, which focuses on ending poverty and hunger, with $140 billion specifically required for sustainable agricultural practices. Another study from the World Economic Forum (WEF) highlights that sustainably transforming the global food system would require additional investment of $300-350 billion annually until 2030.

While projected to yield societal returns exceeding 15 times the initial cost, these targets are far from being met; only 4% of climate finance between 2021 and 2022 was allocated to agriculture, forestry and other land use, despite these sectors' considerable contributions to greenhouse gas emissions. Furthermore, while governments provide, on average, $600 billion a year in agricultural support to countries that generate two-thirds of the world's agriculture, only 5% of the funding supports conservation, and only 6% supports research and technical assistance. In fact, most of this funding provides income support.

Source for top text box:
https://eatforum.org/eat-lancet-commission/the-planetary-health-diet-and-you/
Sources for bottom text box:
Four Ways Investors Can Boost Sustainable Agriculture | International Institute for Sustainable Development (iisd.org)
Which aims to increase the productivity of small-scale food producers, encourage the integration of sustainable food production systems and build knowledge around genetic resources and infrastructure requirements with the aim of eliminating global hunger
More and Better Investments Are Needed in Agriculture and Food Systems (iisd.org)
WEF_100_Million_Farmers_2024.pdf (weforum.org)
Redirecting Agricultural Subsidies for a Sustainable Food Future | World Resources Institute

THE GLOBAL STATE OF AGRICULTURE

The availability of agricultural land is stretched close to feasible limits; currently, 45% of habitable land – equivalent to 48 million square kilometres, or five times the size of the US – is used for agriculture.[3] On average, each person depends on a farming area roughly the size of one-third of a football field. However, by 2050, it is estimated that this available land base will be reduced by half due to population growth, urbanisation and human-induced erosion and pollution.[4],[5]

Global population vs. arable land projections

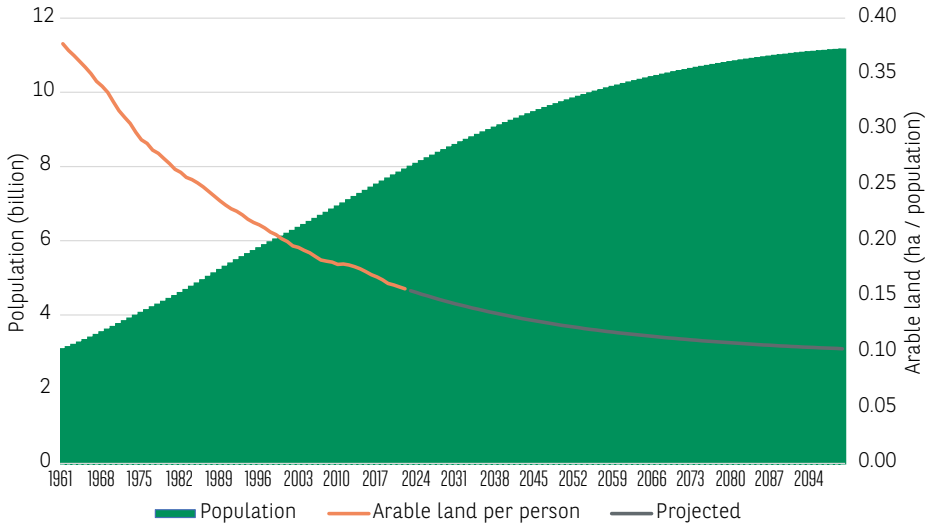


Image: https://www.fao.org/faostat/en/#data

In addition to the expected decline in availability of land, the agricultural sector also faces mounting challenges that could reduce the productivity of existing farmland. This can be explained through a series of interconnected challenges: As food production increases, essential nutrients are progressively depleted from the soil, leading to declines in soil quality and consequently, in crop yields. Additionally, agriculture accounts for a significant proportion of global water withdrawals, contributing to water stress, which then necessitates further extraction. While reliance on chemical inputs can enhance yields, it also poses risks to biodiversity, especially key pollinator populations, which, as they decline, reduce yields. Furthermore, there are limits to yield enhancement. The following section examines these challenges in closer detail.

3 Half of the world's habitable land is used for agriculture - Our World in Data
4 Is the world running out of farmland? - Geographic FAQ Hub: Answers to Your Global Questions
5 Humans have destroyed a third of Earth's farmland in 40 years | Science | AAAS

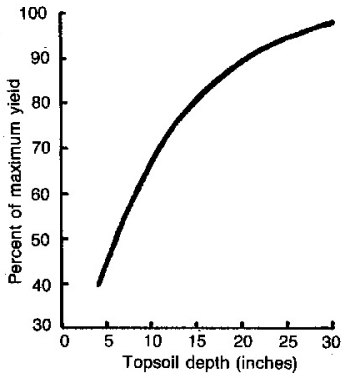


Image: Crop Yields Decline with Topsoil Loss | Pacific Northwest STEEP (Solutions to Environmental and Economic Problems) | Washington State University

As the name suggests, topsoil is the top layer of soil, down to about eight inches (20 cm) deep.[6] It contains most of the ground's nutrients which help plants grow. Recent research suggests that topsoil is declining in quality, partly due to exploitative farming practices aimed at achieving specific produce traits. This quality decline can reduce food's nutritional value. For example, a British Food Journal study concluded that eight oranges would have to be consumed today to derive the same amount of Vitamin A as our grandparents would have gotten from one.[7] Furthermore, topsoil is also disappearing; the UN Food and Agriculture Organization (FAO) has found that 90% of earth's topsoil will be jeopardized by 2050. To contextualize this, an equivalent of one soccer pitch erodes every five seconds,[8] dispersed by elements such as wind, water and the removal of vegetation. Nature cannot replenish topsoil quickly enough to compensate for this loss.[9,10]

Soil is not the only key ingredient for agricultural production threatened by environmental challenges. "For the first time in human history, humanity has thrown the global water cycle off balance," [11] jeopardizing the reliability of water flows, which can have significant implications for farmers' profits. [12],[13] With this unpredictability, the industry becomes more dependent on access to water resources (agriculture has an especially material dependency on freshwater availability, considering the sector is responsible for nearly 70% of global withdrawal volume[14]) to reintroduce stability (depending on the scenario, irrigation water requirements could double or triple by 2100[15]). This is difficult with increasing global water scarcity and exacerbates the situation. Notably, water management could be in the interest of farmers: "As water becomes increasingly scarce, farmland with sustainable water resources, including surface and groundwater, should see enhanced valuations."[16]

6 What is Top Soil? | Lakeland Landscapes Ltd
7 Dirt Poor: Have Fruits and Vegetables Become Less Nutritious? | Scientific American
8 FAO warns 90 per cent of Earth's topsoil at risk by 2050 | UN News
9 FAO warns 90 per cent of Earth's topsoil at risk by 2050 | UN News
10 There are initiatives to improve soil quality, examples of which can be found here: Cornell Soil Health | Research, outreach and lab services to protect and improve soil health planet-wide and Soil monitoring law: EU on the pathway to healthy soils by 2050 - Consilium
11 The system that moves water around the Earth is off balance for the first time in human history | CNN
12 Increases in extreme precipitation over the northeast United States using high-resolution climate model simulations – Geophysical Fluid Dynamics Laboratory
13 The effects of drought and climate variability on Australian farms - DAFF
14 Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks - ScienceDirect
15 Sustainability Research: Waterworld part II — Adapting water systems to climate change — A cascade of risks and opportunities
16 Asset Valuation In Ag Lending Should Built on Geospatial Data

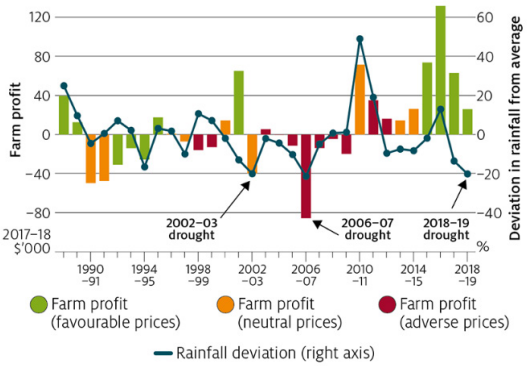


Image: The effects of drought and climate variability on Australian farms - DAFF

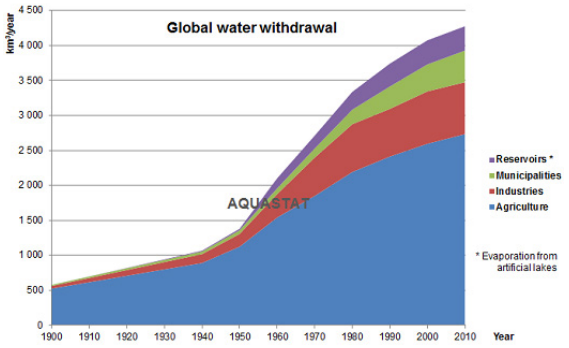


Image: 5 things you need to know about water | World Economic Forum

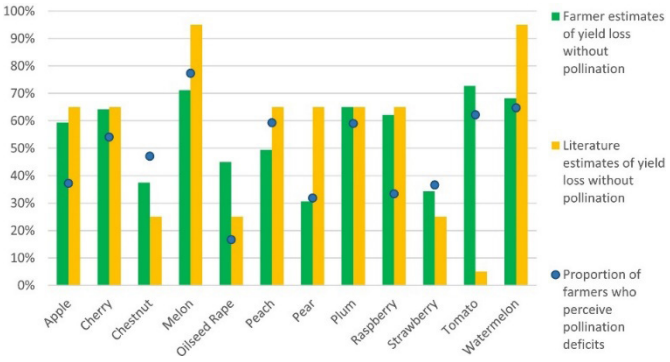


Image: Linking farmer and beekeeper preferences with ecological knowledge to improve crop pollination - Breeze - 2019 - People and Nature - Wiley Online Library

Biodiversity and agriculture also have a two-way relationship: Biodiversity is essential to the success of crops and livestock, improving resiliency, preserving health, improving soil fertility and boosting yields. Yet, agriculture can, through harmful chemicals and exploitative practices, contribute to the decline in biodiversity. In England, for example, the farmland bird index shows that populations of farmland birds have dropped by c. 40% since the 1970s due to rapid changes in land management practices – a downward trend that has persisted to this day. Birds play a crucial role in pest control and seed dispersal on farms, supporting ecosystem health and crop productivity.[17] Simultaneously, populations of key pollinators, including bees and hoverflies, have fallen dramatically between 1980 and today (the impact of neonicotinoids is a regularly cited contributor), resulting in severe pollination deficits for crops.[18] A study by Breeze et al. found that 'approximately 49% of farmers indicated that they experienced yield deficits due to pollination deficits in at least one crop they grew'.[19]

17 Presentation from Nick Reynard (Head of Hydro-Climate risks) and Dr John Redhead (Spatial Ecologist) – Both from the UK Centre for Ecology and Hydrology

18 Presentation from Nick Reynard (Head of Hydro-Climate risks) and Dr John Redhead (Spatial Ecologist) – Both from the UK Centre for Ecology and Hydrology

19 Linking farmer and beekeeper preferences with ecological knowledge to improve crop pollination - Breeze - 2019 - People and Nature - Wiley Online Library

THE FINANCIAL MATERIALITY OF THE STATE OF GLOBAL AGRICULTURE

The stability of global agricultural markets is increasingly at risk due to worsening environmental conditions, leading to financial volatility across key commodity sectors. This section highlights that yield fluctuations driven by environmental factors can significantly impact prices in both essential and non-essential food commodities. Essential commodities, often benefiting from geographically diverse production, may be somewhat insulated from extreme price swings. In contrast, non-essential commodities, which are more likely to be produced in concentrated regions vulnerable to environmental change, face a greater risk of sustained price increases due to jeopardized yields. There are exceptions to this, as highlighted in the analysis below through coffee.

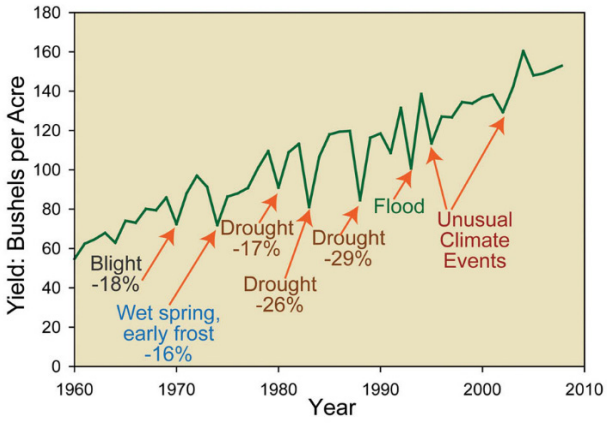


Image: uscornyields-large.jpg (999×700)Library

Corn, a core agricultural commodity, is particularly vulnerable to extreme weather, with droughts in key producing regions significantly affecting yields. For example, the US Corn Belt has experienced increasingly erratic and severe drought conditions in recent years. These dry spells reduce soil moisture and stunt plant growth, which can lead to lower harvests and short-term price spikes. [20] Volatile prices ripple through various industries, affecting costs for livestock feed, processed foods and ethanol production. They also create financial risk for farmers who depend on stable profits, food companies facing changing input costs (which are often passed on to consumers), and governments grappling with food inflation and trade imbalances.

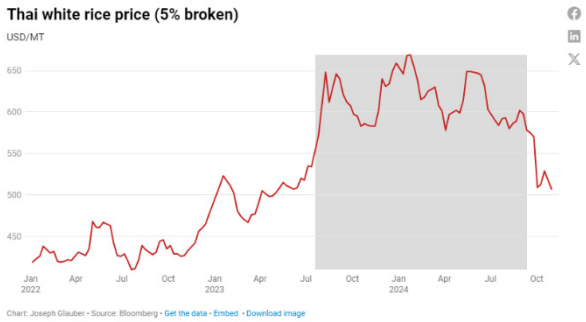


Image: India's export restrictions on rice continue to disrupt global markets, supplies, and prices | Asia and the Pacific Food Security Portal (grey zone represents the Indian export ban)

Rice is another food staple where disruption in supply can have profound consequences – not only economic but social impacts too – in comparison to corn. For example, in 2023, India, the world's largest exporter of rice, imposed a ban on non-basmati white rice exports in response to declining domestic yields caused by erratic monsoon patterns. This decision hugely disrupted global markets, as buyers tried to source alternative supplies. This period of increased prices strained budgets for import-dependent nations, particularly in Africa and Asia, exacerbating concerns over food security and inflation. The immediate financial fallout from India's policy show how environmental challenges to sustainable agriculture in one region can have cascading effects on global food markets.

20 Response of corn markets to climate volatility under alternative energy futures - PMC

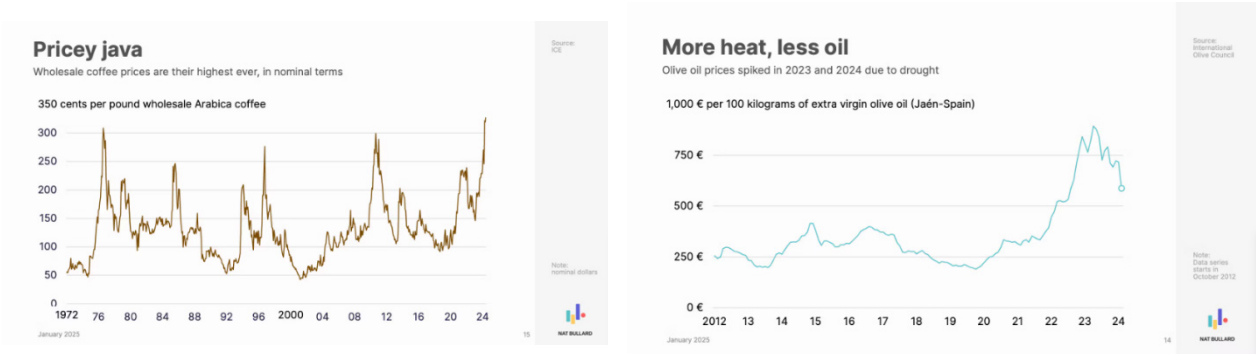


Image: https://www.nathanielbullard.com/

The effects of environmental challenges on agricultural commodity prices are not just limited to core food products, non-essential commodities are also affected: Prices for Arabica beans increased by more than 80% in 2024. Bad weather in Brazil and Vietnam was a likely contributor. [21],[22]

As another example, cocoa production is heavily concentrated in West Africa, with the region producing at least 70% of global output.[23] Erratic rainfall, prolonged droughts and shifting climate patterns have disrupted cocoa farming cycles, leading to lower yields and worsening crop diseases. In 2023-2024, adverse weather conditions exacerbated supply shortages, contributing to the price of cocoa reaching multi-decade highs.

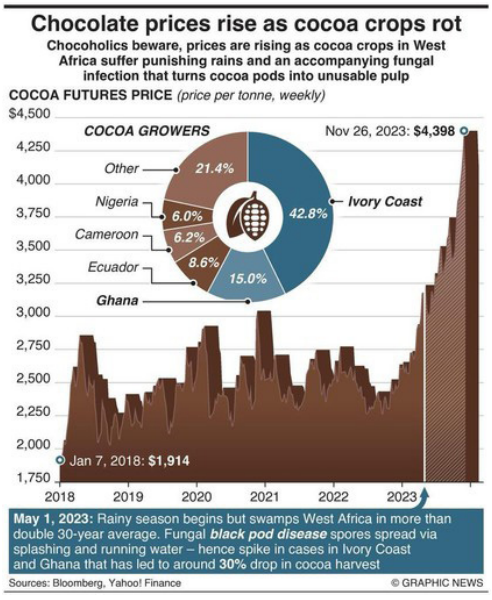


Image: Cocoa shortage: Where to buy your favourite chocolates for less as prices surge

This surge has affected chocolate manufacturers, who must navigate higher costs, potential supply chain disruptions and tightened profit margins. The price spikes also affect consumers through likely higher retail prices for chocolate products. To reinforce this, chocolatier Chocoladefabriken Lindt & Sprüngli said in its 2023 results that 'weather and climate conditions played a major role in the global shortage of cocoa beans that led to historically high prices.' The company had to increase its product prices and said it would need to further raise them this year and next if cocoa prices remain at current levels.[24]

Similarly, from 2022-2024, Spain, which produces more than half of the global supply of olive oil (followed by other Mediterranean countries Italy, Portugal and Greece) experienced continuous drought, keeping the country's olive oil production below average, along with other contributing factors including geopolitics (the 2023/2024 harvest is 34% short of the average of the past four years). This contributed to the peaking prices of olive oil which soared by 165% in three years.[25]

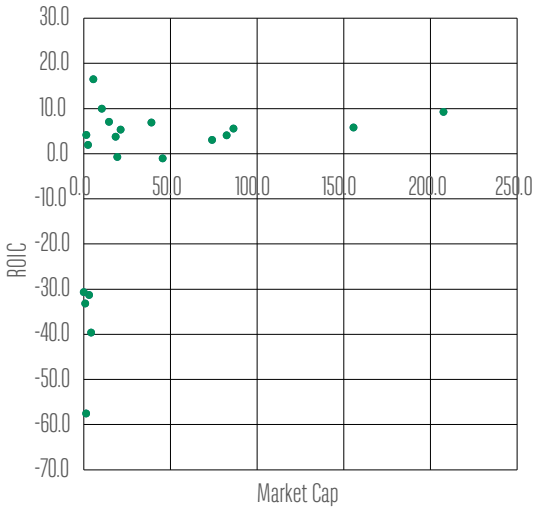
21 Coffee prices at record high after bad weather - BBC News
22 Helping Vietnam's Coffee Sector Become More Climate Resilient – State of the Planet
23 Cocoa shortage: Where to buy your favourite chocolates for less as prices surge
24 Cocoa and Coffee Prices Have Surged. Climate Change Will Only Take Them Higher. - WSJ
25 Spanish Olive Oil Prices Soar 165% in Three Years | ESM Magazine

THE STATE OF THE GLOBAL PUBLIC MARKET INVESTMENT LANDSCAPE IN AGRICULTURE & WHERE TO FIND PROFITABILITY

Corporate entities are expected to play a pivotal role in driving the scaling up and integration of sustainable agriculture solutions, with estimates suggesting that corporate-led initiatives could restore environmental conditions to levels last observed in 1970.[26] In the context of the agricultural sector, transformative corporate action must adopt a multifaceted approach, focusing on the implementation of a holistic strategy that spans the entire supply chain – from the cultivation of raw crops/livestock to their harvesting, storage and sale.

The companies facilitating this transformation require significant private sector investment to scale up their efforts, drive research and development, and push the adoption of their products and services. Fortunately, some present a compelling financial opportunity: As global demand rises for consistently supplied sustainable products, and regulatory pressures incentivise environmentally responsible practices, companies that lead in this transition are well-positioned to outperform their peers. Investments in sustainable agricultural businesses can generate attractive returns through enhanced efficiency, reduced exposure to material environmental risks, reduced resource costs and access to premium markets that reward sustainability. This is not true of all sectors, however, with some earlier-stage companies struggling to achieve profitability and scale. The section below will explore some companies on the higher end of the Returns on Invested Capital (ROIC) spectrum, which fall in segments like next-gen agricultural machinery, food ingredients and enzymes and forestry management.

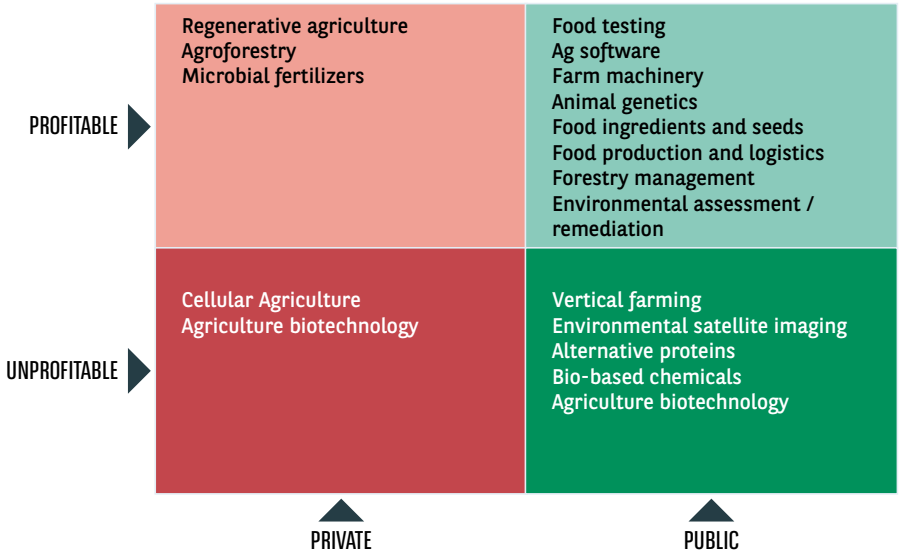
Mkt Cap vs. ROIC



Level 2 Theme	Mkt Cap $mm	ROIC
Next-Gen Agricultural Machinery	225.9	8.7
Food Ingredients & Enzymes	170.2	6.1
Forestry Management	125.2	2.4
Land Remediation & Environmental Consulting	88.9	4.9
Animal Health & Nutrition	82.5	4.1
Smart Farming & Processing	51.0	6.0
Food Testing & Safety	39.0	6.9
Alternative Protein & Plant-based Products	4.3	-39.6
Bio-based Chemicals & Products	3.1	-31.3
Green Fertilisers, Seeds and Crop Protection	2.4	-23.8
Environmental Data Analytics & Services	1.4	-57.5
Vertical & Indoor Farming	0.0	-30.7

26 Nature-in-the-balance-what-companies-can-do-to-restore-natural-capital-vf.pdf (mckinsey.com)

Broad Example Segments*



*Based on average observation
Source: Bloomberg, BNPPAM, 2025

EXAMPLE INDUSTRIES

1. Next generation agriculture

Precision agriculture is one type of next-gen agricultural technology which, as the name suggests, uses sensor networks to inform farmers of the state of their crops and soil, allowing them to make precise decisions about inputs such as fertiliser, pesticides, water. Not only can the solution conserve resources, but it has also been proven to help faster identification of disease breakouts and prevent excess fertiliser from seeping into ecosystems, which would unbalance nutrients levels.[27]

The initial cost of integrating precision agriculture is relatively high. For example, installing camera sprayers could cost between $180,000 and $320,000. Systems then require continuing operational expenditure, including on hardware and software maintenance. However, research has shown that, in the long run, it is highly likely that the financial benefits will outweigh the costs. For example, the US Department of Agriculture documented in a 2016 report how GPS-based precision-farming technologies reduced corn farming expenses by $13 to $25 per acre (this was reinforced by researchers from Michigan State University, who also found that this could save US corn and soybean farmers an estimated $500 million in fertiliser costs[28]).

John Deere (US) and Kubota (Japan) are market leaders in precision agriculture. Deere's patented technology, ExactRate, is a factory-installed fertiliser system that precisely monitors and controls the application of liquid fertiliser during planting.[29] Kubota's technology aims to reduce greenhouse gas emissions in farming and support sustainable food production through automated machinery and precision agriculture to improve resource efficiencies.

27 The next step in precision agriculture | The Alan Turing Institute
28 Here's how precision agriculture could help farmers reduce fertiliser use (anthropocenemagazine.org)
29 sustainability-report-2020.pdf (deere.com)

2. Food ingredients & enzymes

Sustainable food ingredients and enzymes serve a crucial role in modern food production by enhancing nutritional profiles, improving taste and texture, and extending shelf life, all while reducing resource intensity. Essentially, they allow manufacturers to optimise processes—requiring fewer raw materials and less energy—so they can meet consumer demand for more environmentally responsible and health-focused products. Through precise enzymatic actions that break down proteins, fats and carbohydrates, these solutions also help cut operational waste, boosting efficiency and profitability for food producers. The global food ingredients business is expected to grow to $220 billion in 2025, has shown a CAGR[30] of approximately 5.2% over the past five years. The food enzyme market, while smaller at about $4 billion in 2025, is expected to grow at a faster rate of about 7.6% CAGR.[31]

Investing in sustainable ingredients and enzymes companies can yield higher margins by reducing costs associated with waste management, energy consumption and raw material usage. Moreover, these companies often develop proprietary technologies and patents, which can drive licensing revenue or give them a competitive edge in negotiating supply agreements with major food processors.

DSM Firmenich, for instance, uses advanced flavour and fragrance solutions that minimise the carbon footprint while still meeting evolving consumer taste preferences, positioning itself as a profitable partner for food manufacturers. Its products help to reduce sugar consumption and contribute to plant-based foods through taste and texture improvement.

Novonesis channels significant resources into enzyme research to optimise process efficiency, lowering operational expenses and helping clients differentiate their products in crowded markets. Its products can reduce energy, chemical and water usage, and agricultural waste.

Meanwhile, Kerry Group has built a broad portfolio of ingredient solutions that cater to health, taste and sustainability trends, creating substantial potential for expansion across multiple consumer segments.

Together, these market leaders benefit from macroeconomic drivers—such as global population growth, heightened regulatory scrutiny, and the surge in consumer demand for 'clean label' offerings— illustrating that the sector presents a viable investment opportunity.

30 Compound annual growth rate
31 Marketsandmarkets.com - Global Food Ingredients Market Report and Global Food Enzymes Market Report

3. Forestry management

Forestry's sustainability credentials have a mixed reputation. In a 2017 study commissioned by the North American Forest Partnership, nearly four out of five respondents thought wood was a renewable material; however, fewer than one in five associated the forestry sector with sustainability. This misconception – that wood production cannot be sustainably coupled with improving the state of the natural environment – poses significant risks, as sustainable forestry holds substantial potential for 1) mitigating climate change[32] with an estimated global abatement potential of c.25% of current CO2 emissions from fossil fuels by 2030, and 2) reducing the damage of waste and plastic pollution (for example, through packaging alternatives).[33]

In fact, sustainable forest management is characterised by several key principles and practices that ensure the long-term health and productivity of forests while balancing environmental, social and economic values for today's and future generations. These characteristics include, but are not limited to:

- A mosaic landscape principle
- Controlled harvesting
- Obligation to reforest
- Restricted use of pesticides and fertilisers
- Stream management and water quality
- Habitat protection
- Safeguarding of soil health
- Social responsibility
- Adaptive management.

Following sustainable forest management principles in line with certification standards such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) allows forest investments to play their role as a source of sustainable timber products and answering the increasing demand for wood products worldwide. Such an approach also addresses global biodiversity loss in terms of fauna and flora, fostering resilient ecosystems, providing livelihoods for local communities, and ensuring the rights of indigenous people and other stakeholders are respected.[34]

Rayonier is an example of a sustainable forestry company, managing 2.7 million acres of sustainable forests, with a firm commitment – disclosed in its 10K statement – to limit harvesting to a sustainable yield. Rayonier planted 43 million seeds this year, to ensure no net forest loss. These activities removed seven times more carbon than was emitted. [35]

In addition, forest managers can go beyond certification standards. This is the philosophy applied in the BNP Paribas Future Forest Fund, an SFDR[36] Article 9 fund, aiming to shape the commercial forests of tomorrow, by using systematic 'signature actions' that go beyond sustainable forestry obligations, to help combat climate change and improve asset resilience and biodiversity.

32 https://www.weforum.org/stories/2024/04/sustainable-forestry-climate-action-development-biodiversity/
33 145912_24pp (forestresearch.gov.uk)
34 A balancing act – Investing in sustainable forestry while safeguarding biodiversity
35 https://www3.weforum.org/docs/WEF_Investing_in_Forests_2021.pdf
36 Sustainable Finance Disclosure Regulation

Despite the sustainability credentials and growth potential of sustainable forestry companies, in Europe, only 5% of the total funding for terrestrial ecosystem restoration is currently generated by the private sector.

4. Smart farming and processing

The future of agriculture depends on smarter, more efficient systems that enhance productivity while preserving natural resources. Regenerative agriculture, which focuses on soil health, biodiversity and carbons sequestration, is gaining traction as a key solution for long-term sustainability. In tandem, advancements in supply chain management, such as AI-driven logistics and waste reduction strategies, are transforming how food is processed and distributed. These innovations, covered in more detail below, not only improve environmental outcomes, but also create profitable investment opportunities in a rapidly evolving market.

Regenerative agriculture is another solution to revitalise and transform current production patterns. Notably, 'regenerative' is a broad term generally understood to mean farming that improves, rather than degrades, ecosystem health[37]. Today, most regenerative practices align with Regeneration International's definition: "'Regenerative Agriculture' describes farming and grazing practices that, among other benefits, reverse climate change by rebuilding organic soil matter and restoring degraded soil biodiversity – resulting in both carbon drawdown and improving the water cycle."[38],[39],[40]

Regenerative agriculture is expanding. In a 2019 report, the Croatan Institute, based in North Carolina, found $47.5 billion worth of investment assets in the US fulfilling regenerative agriculture criteria.[41] Vital Farms[42] is one example that can be spotlighted - the chicken farms practise pasture-raising, allowing each laying hen an average of 108 square feet of outdoor space, which is significantly larger than the confined spaces typical in conventional egg production. This model not only improves animal welfare and reduces risk of avian flu, but also contributes to soil health by allowing chickens to graze, fertilise and aerate the land naturally. All farms are organic (this is an internal Vital Farms requirement, although some choose not to complete the official certification process), with no chemical use. This model is scalable – the company now has 275 family farms across the United States and is looking to expand its business model by educating farmers on the benefits of regenerative agriculture.

Shifting focus to food waste as a means of driving systemic change: In 2022 alone, the world wasted 1.05 billion tonnes of food. For context, this equates to 19% of food available to consumers. This is in addition to the 13% of the food lost in supply chains, as estimated by the FOA, from post-harvest to retail.[43] This a two-fold blow, not only contributing almost five times the total emissions of the aviation sector to global warming but also occurring in a time when one third of humanity faces food insecurity. [44]

37 'Regenerative agriculture' is all the rage – but it's not going to fix our food system (theconversation.com)
38 The many meanings of 'regenerative' agriculture | Sustainable Food Trust
39 Of note, the rising movement supporting regenerative agriculture in the last five years has been critiqued by researchers as there is lacking contextual information to the growing body of advice. For example, practices including no tillage, no pesticides etc... are unlikely to lead to benefits in all places practiced. See this article for advice in the conclusion on how to engage appropriately with regenerative agriculture: https://pmc.ncbi.nlm.nih.gov/articles/PMC8023280/
40 It is important to remember that regenerative practices have a deep history, passed down through varying indigenous peoples across the globe
41 Investors say agroforestry isn't just climate friendly — it's also profitable (mongabay.com)
42 https://vitalfarms.com
43 Food-Waste-Index-2024-key-messages.pdf (unep.org)
44 Food-Waste-Index-2024-key-messages.pdf (unep.org)

While the global food system is a 'complex web of stakeholders and activities involved in the production, aggregation, processing, distribution, consumption and disposal', [45] there is significant investment potential: a study by the World Resources Institute and the Waste and Resources Action Programme researched 700 companies, and for every dollar invested in cutting food waste, the median company saw a $14 return. [46] Companies positioned 'closer to the fork' (such as food retailers and manufacturers) generally achieved greater financial gains than those 'closer to the farm'[47]. This is likely because retailers and manufacturers can more accurately forecast demand and adjust food packaging and labelling to reduce excess and extend shelf life.

The scale and impactof food loss and waste

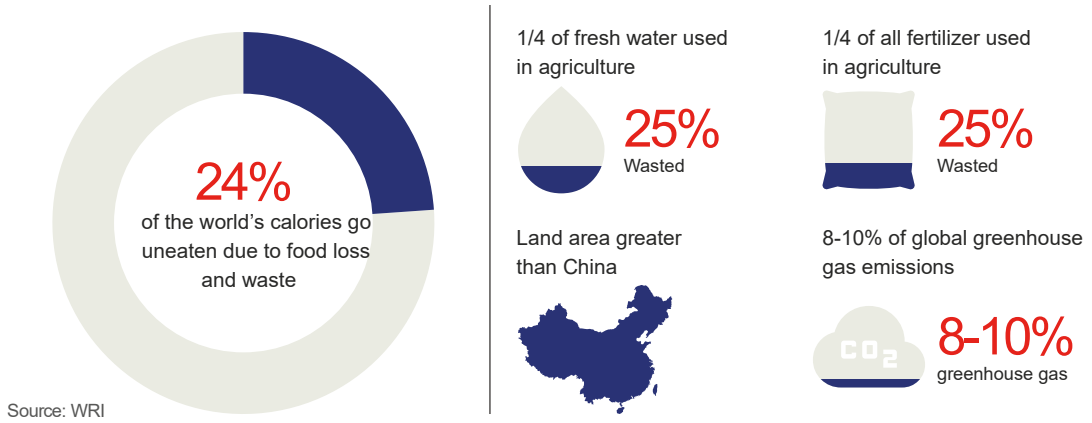


Image: Report_Lineage_US_Letter_V7_2024-11-21.pdf

Due to the complexity of tackling this issue, there are new initiatives and investment opportunities across the supply chain. Examples include: 1) Lineage, which is a publicly listed leading provider of temperature-controlled warehousing and integrated solutions, for the storage, handling and movement of food across the world (also featured in The Economist here)[48]; 2) Odd Box, which is a private company that tackles food waste on farm, taking fruit and vegetables where too much was produced or 'too odd' to be sold by retailers with cosmetic specifications and delivering them to the door of households via a subscription service[49] and 3) Too-Good-to-Go, which is a mobile app that sells expiring food at a significant discount by collecting data from participating retailers to encourage waste reduction[50].

45 food_waste_index_report_2024.pdf
46 Food waste: a triple win opportunity | Ruffer | Investment management
47 Food waste: a triple win opportunity | Ruffer | Investment management
48 Lineage - 2023 Sustainability Report - Compressed – 11.06.24.pdf (onelineage.com)
49 Our Mission (oddbox.co.uk)
50 Too Good To Go | About Us | More Information – Too Good To Go

CONCLUSION

As global population growth continues and natural resource constraints become more pressing, the need for sustainable agricultural solutions has never been more urgent. Limits of arable land, soil and freshwater availability will increasingly challenge food production, requiring both innovation and investment to ensure long-term productivity, reliability and environmental resilience. While technological advancements such as automation, genetic improvements and AI-driven farming can offer significant efficiency gains, they cannot fully overcome fundamental challenges related to water scarcity, extreme weather and soil degradation.

However, within these constraints lie substantial investment opportunities if carefully managed. Sectors such as precision agriculture, bio solutions and sustainable forestry, as highlighted in this paper, are already demonstrating profitability while addressing critical sustainability issues. These industries provide essential services, from improving resource efficiency to restoring ecosystems, making them attractive both financially and environmentally. Furthermore, as highlighted in the appendix, emerging innovations – include agroforestry, seed technology and drip irrigation - will likely expand the scope for high impact investment over time.

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APPENDIX

Appendix 1: Further explanations on agricultural solutions which are either typically private, or not yet fully profitable

1. Agroforestry

There are two approaches to tackling biodiversity and forestry loss – solutions which improve environmentalism at current levels of production (which increase land-use intensity and transform operational practices), and those which shift current land use patterns. To address the former: Agroforestry is the intentional combination of trees and shrubs with crops or livestock to reduce nutrient and pesticide runoff, and increase carbon sequestration, soil quality, erosion control, habitats and increasing ecosystem resilience. [51] While it is estimated c.1 billion hectares, similar to the size of Canada, are engaged in agroforestry systems globally, the formalisation of this as a 'solution' is nascent.[52]

Agroforestry has many supporters: on the one hand, Project Drawdown ranked an agroforestry practice called silvopasture (a method that incorporates trees and livestock together) as the ninth most impactful climate strategy in the world (above rooftop solar power, electric vehicles and geothermal energy); on the other, the investment returns on projects like this are big. For example, Project Drawdown research shows that a 40% increase in silvopasture would move Earth Overshoot Day by four days by 2050.[53] This conclusion is echoed by others: Götsch, a leader in regenerative agriculture, estimates that agroforestry systems can create eight times more profit than conventional agriculture.[54] Finally, Assenmacher, founder of the German company Forest Finance, which connects investors to sustainable forestry and agroforestry projects, expects between 4% and 7% return on investments at least; his company had already paid out $7.5 million in gains to investors.[55]

Corporate activity in this field is still at an early stage: Propagate Ventures[56], a US-based private company, offers farmers software-based economic analysis, on-the-ground project management, and investor financing to help add trees and tree crops to agricultural models. One of its main goals is to get capital from interested investors to the farmers that need it. The company has been very successful; it has expanded into eight states and is working with more than 20 farms, having received >$1.5 million in seed funding. Other examples include Dean's Beans[57] and Al Gore's Caney Fork Farms[58]. The profitability of agroforestry is beginning to be recognised – although notably this is typically from private markets, as, for most, the idea of agroforestry is still quite new.

2. Alternative proteins via agricultural biotechnology

One pressing problem with food supply chains is the number of livestock we rear. For example, of the world's mammal biomass, livestock make up 62%, humans comprise 34%, and wild mammals, just 4%, are the remainder. [59] Furthermore, grazing land for animals uses about two-thirds of the world's agricultural land. Of the one-third used for crops, about half are to feed humans, the rest are to feed livestock or produce biofuels. [60]

51 Agroforestry—The Next Step in Sustainable and Resilient Agriculture (mdpi.com)
52 Agroforestry: An increasingly popular solution for a hot, hungry world
53 Silvopasture - Power of Possibility
54 Investors Say Agroforestry Isn't Just Climate Friendly — It's Also Profitable - Regeneration International
55 Investors say agroforestry isn't just climate friendly — it's also profitable (mongabay.com)
56 Propagate (propagateag.com)
57 Mission – Dean's Beans Organic Coffee Company (deansbeans.com)
58 Local Organic Farm in Tennessee | Caney Fork Farms
59 Europefornature.eu, Red Alert: Wild Mammals Make up Only a Few Percent of the World's Mammals
60 ourworldindata.org: global land for agriculture

As populations grow and per-capita income rises, taking protein consumption higher with it (more specifically, by 14% by 2030 compared to a base period average of 2018-2019[61]), this becomes increasingly difficult to maintain. Apart from significant associated water and carbon issues, there are also human health concerns as various antibiotics, hormones and industrial pollutants are present in animal products. Finally, large and sometimes crowded populations of livestock and their required grazing and croplands encroach on wild habitats and increase the chances of new diseases crossing into humans (zoonosis).

Re-imagining conventional agriculture involves exploring innovative methods that can reshape food production. One example of this is alternative protein via shifts to plant-based diets and biotechnological solutions[62]. Fundamentally dietary shifts away from animal proteins could save greater than 500 million hectares of land, which could be reforested or provide a locus for other nature-based solutions.[63] There are three main types of alternative proteins.

Planet based meat:

The first is plant-based meat (PBM), which involves replacing meat products with non-meat products such as tofu, tempeh, jackfruit and fungi-based meat. There are typically two categories: traditional (developed thousands of years ago mostly in Asia and including relatively simple derivatives from soybeans) and novel (characterised by the design and marketing of products as near-equivalent replacements for animal-based meat in terms of taste, texture and nutrition). These are relatively inexpensive, mainly based on the prices associated with peas, soy or wheat protein. This cost is typically 3.8–12.7 times lower than prices received for cattle, hogs, and broilers (poultry). Despite this, novel PBMs tend to cost more than their animal-based counterparts in a retail setting. This is likely related to processing costs (94.3% of retail costs are associated with food processing)[64].

Cellular/cultivated meat:

Cellular agriculture focuses on growing entire animal cells directly to produce tissue products. This approach uses techniques from tissue engineering to culture animal cells in bioreactors, often employing scaffolds and specialised growth media to guide cells into forming structures that mimic whole cuts of meat, dairy, or eggs. While precision fermentation is 'acellular'—producing isolated molecules—the cellular agriculture process creates complex, structured tissues that replicate the sensory and nutritional characteristics of conventional animal products. Key outputs from cellular agriculture include lab-grown meat. While people think about beef first, there are also efforts to produce many other things, like bluefin tuna. Taking this as an example, one begins with a tiny tissue sample —typically taken via a minimally invasive biopsy—from a live tuna. From this sample, the desired cells, usually muscle stem cells, are isolated and then expanded in a sterile, nutrient-rich and carefully controlled environment. These cells are then cultured in bioreactors using specialised growth media that supports rapid cell division while maintaining the cells' ability to differentiate into the various components found in tuna meat, such as muscle, fat and connective tissue. Once enough cells have been generated, they are induced to differentiate into the specific cell types needed to recreate the structure of a bluefin tuna fillet.

61 OECD-FAO Agricultural Outlook 2021-2030

62 Notably, PBM has been critiqued for nutritional value and ultra processing. However, 1) a study from the good food institute quotes that 'plant-based meat generally has fewer calories and less saturated fat than animal-based meat. It has zero cholesterol and almost always contains fibre' and 2) the products on the market are often a direct substitute for meat-based processed foods such as burgers and sausages. Plant-based meat nutrition facts - The Good Food Institute (gfi.org)

63 the-agriculture-transition-building-a-sustainable-future-v8.pdf (mckinsey.com)

64 Plant-based and cell-based approaches to meat production | Nature Communications

To achieve a realistic texture and appearance, the cells are seeded onto edible scaffolds that guide their organisation into three-dimensional tissue structures mimicking those of natural fish muscle. Over time, with additional maturation steps to develop flavour and nutritional characteristics, the cultivated tissue is harvested and processed into a product that closely resembles traditional bluefin tuna. This approach not only reduces the pressure on wild tuna stocks but also offers the promise of more consistent, contaminant-free seafood.

Fermentation:

Precision fermentation is a highly controlled process in which microorganisms—such as bacteria, yeast or fungi—are genetically programmed to produce specific, high-value molecules. In practice, scientists first insert a custom strand of DNA carrying the instructions for the desired product into a selected microbe. The modified microorganism is then cultured in a bioreactor under optimal conditions, where it converts simple feedstocks into complex molecules. The target product, which can include proteins (like dairy proteins, collagen or enzymes), fats, flavour compounds and vitamins, is subsequently harvested and purified. Think of it as genetically programming microorganisms to act as efficient cell factories. One example is taking the raw produced collagen and processing it into a material that mimics the structure and functionality of animal-derived collagen, forming the basis for bio fabricated leather. Another example is creating egg whites. Here, you first isolate the gene responsible for producing ovalbumin and then insert it into a host genome that instructs the modified microbe to produce egg white protein (strain engineering). The microbe is then grown in large bioreactors under controlled conditions, like brewing beer, to scale. This requires nutrient-rich mediums that will be converted into the target protein (fermentation). Finally, the fermentation broth is processed to separate the protein from the microbial biomass. The protein is then purified into a final product that retains the functional properties of egg whites, including foaming, gelling and binding, making it suitable for applications in food manufacturing. This method allows for the production of ingredients that are identical in structure and function to those derived from animals, yet without the need for animal rearing or slaughter.

These areas need to be scaled up to bring down costs and are dominated by venture stage and private companies. However, we can see progress. For example, in 2025 Meatly launched the world's first cultivated pet food product in the UK. It costs about £3.49 for 50 grams, so costs still need to come down, but they are not as prohibitive as in the past. For example, Mosa Meat's first burger cost about $330,000, but a Forbes 2022 report says that at that time costs had gone below $10. Cost parity will be needed for the industry to accelerate, although we should keep in mind the material benefits this brings to both the environment and human health. For example, cultivated meat would be free from E. coli risk.

An alternative is focusing on insects and crustaceans, which are cheaper to cellularly replicate, and some companies are focusing on higher value products such as blue fin tuna to reduce this cost gap. Another more popularised example outside of protein, is Oatly, which has played a critical role in not only providing an alternative form of cow's milk (oat milk has 30% less associated emissions, 7% of the water consumption and 7% of the land use per kg, L and m^2, respectively, of cow's milk produced[65]), but disrupting the traditional narrative surrounding it, labelled the 'Oatly Effect'.[66] By using catchy tag lines such as 'wow no cow' or 'it's like milk, but for humans' the company has grabbed the attention of many, spreading the message of sustainability and ethical consumption. [67]

65 The impact of milk types on the environment. Milk infographic. Dairy, almond, soy, rice, oat milk. Water use, greenhouse emission. Footprints from mil Stock Vector Image & Art - Alamy
66 How A Campaign Change the Perception of Plant-Based Milk Oatly (303.london)
67 https://www.oatly.com/

3. Seed technology

Another example of a significant driver of change in the agricultural system is advancements in seed technology, which has benefits which include, but are not limited to, improved crop resilience, reduced pesticide and herbicide use, enhanced nutritional value (through biofortification), increase yield and efficiency, lower water and fertiliser requirements and faster crop development cycles (allowing for quicker maturation and multiple growing cycles). Products could include drought-resistant and high yield corn, salad leaves that stay crisp for longer, and pit-less cherries. In fact, a recent survey by the International Seed Federation resulted in over 90% of seed industry professionals predicting that within two decades, new seed technologies will be able to reap these types of benefits.[68]

Consistent investment in seed technology is crucial for its advancement and scalability. Currently, public funding for agricultural research has stalled at around $30 billion annually, as reported by the World Resources Institute. In contrast, private seed companies typically allocate 15-25% of their annual revenue toward research and development, accounting for an estimated $10-25 billion each year solely focused on seed innovation[69]. To effectively scale up seed technology advancements beyond initial research to commercially viable levels, both public and private sectors must increase their contributions. One role that public market investors can play until higher penetration rates are achieved is to invest and support in other actors throughout the seed value chain, including last-mile distributors, regenerative farms and sustainable retailers.

4. Drip irrigation

Freshwater consumption is a considerable issue in the agricultural sector, responsible for nearly 70% of total freshwater withdrawal volume[70]. Drip irrigation, compared to traditional irrigation methods, can 'significantly decrease the water consumption of the agricultural sector, optimizing the water-energy relationship by reducing soil evaporation, increase the leaf area index and promote crop growth, thereby enhancing plant transpiration'.[71],[72] With weather patterns changing and growing uncertainty regarding precipitation patterns – consistent, cost-effective and sustainable irrigation is key.

Not only is drip irrigation environmentally sustainable, but it can also increase yields by 28.92%, 14.55%, 8.03%, 2.32%, and 5.17% relative to flooding irrigation, border irrigation, furrow irrigation, sprinkler irrigation, and micro-sprinkler irrigation, respectively.[73] Notably, drip irrigation is not just practised on small-scale farms – studies show that these practices can be used by farms which are transforming into stable, profitable businesses.[74]

68 Will farmers benefit from hunger-ending seed innovations? | World Economic Forum (weforum.org)
69 Will farmers benefit from hunger-ending seed innovations? | World Economic Forum (weforum.org
70 Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks - ScienceDirect
71 A Review of Drip Irrigation's Effect on Water, Carbon Fluxes, and Crop Growth in Farmland (mdpi.com)
72 "Notably, more wet, and dry soil cycles from drip irrigation may increase soil CO2 emissions. However, it also enhances crop photosynthesis and improves crop net ecosystem productivity by creating more favourable soil moisture conditions, indicating greater carbon sequestration potential" (extracted from source above)
73 Review on Drip Irrigation: Impact on Crop Yield, Quality, and Water Productivity in China (mdpi.com)
74 Cost-effectiveness of investments in drip irrigation projects in Ukraine | International Journal of Green Economics (inderscienceonline.com)

The global irrigation industry market size is estimated to reach $41.9 billion by 2025, with sustainable irrigation systems such as centre pivot, solar-powered and AI-enabled irrigation systems reaching $2.5, $2.3, and $1.9 billion respectively[75]. Public companies like Valmont, through its Valley subsidiary, are providing irrigation solutions (using centre pivots) that saved an estimated 4.2 trillion gallons of water globally in 2023 – generating about 40% of water savings when compared to flood irrigation.[76] Orbia is another example which, through its subsidiary Netafim, is 'growing more with less' through delivering water with little to no waste to the roots of each plant.[77]

5. Anaerobic digestion

Nutrients are essential for organisms, but human activities have interfered in the biogeochemical cycles, and an excess of nutrients, mainly nitrogen (N) and phosphorus (P), has been commonly recorded. The US Environmental Protection Agency (EPA) reports that only 35% of rivers and streams in the United States exhibit good water quality for P and 38% for N pollution. This leads to negative environmental impacts. One example of this is eutrophication, the process where excess N and P infiltrate bodies of water and act like fertiliser, causing excessive growth of algae which can lead to hypoxia, or, in other words, ecosystem 'dead zones' (with less sunlight, there is less photosynthetic for marine plants).[78]

Agriculture is the largest source of N pollution in the US, accounting for more than 50% of nitrate, ammonia (NH3), and nitrous oxide (N2O) emissions.[79] Crop farms apply nutrients on their fields in the form of chemical fertilisers and manure which fertilise crops. However, when these are not fully absorbed by the crops, they can be lost from the farm fields and negatively impact air and downstream water quality because of the link between soil geochemical, hydrological and meteorological processes.[80] Livestock farms also contribute through both inputs (animal feed) and outputs (manure). Although, large livestock farms are required to have a manure management plan under the Clean Water Act but the effectiveness of these regulations in preventing nutrient runoff has not been well studied.[81]

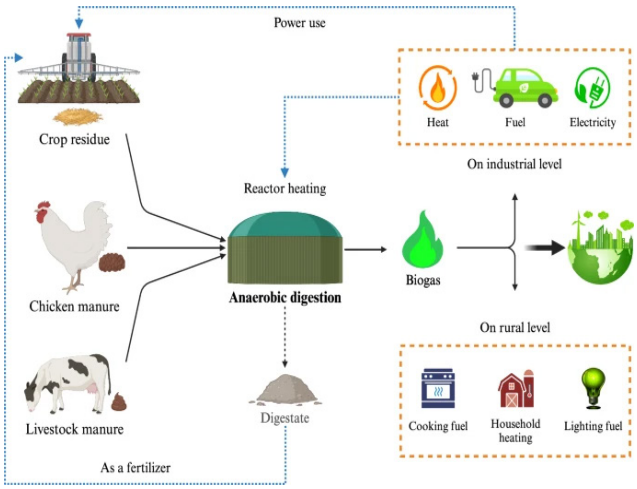

Image: Anaerobic digestion of agricultural waste for biogas production and sustainable bioenergy recovery: a review | Environmental Chemistry Letters (springer.com)

75 Irrigation Industry Statistics: Market Data Report 2024 (worldmetrics.org)
76 2024-sustainability-report.pdf (valmont.com)
77 Sustainable Agriculture | Netafim
78 Nutrient Pollution | SpringerLink
79 The Economics of Nutrient Pollution from Agriculture | Annual Reviews
80 Sources and Solutions: Agriculture | US EPA
81 The Economics of Nutrient Pollution from Agriculture | Annual Reviews

There are solutions to nutrient pollution in addition to the solutions listed above, which can also contribute positively to nutrient pollution: anaerobic digesters and precision agriculture are examples. Anaerobic digestion, illustrated in the image to the left[82], is an advanced farm management process which involves adding waste organic material, including manure and excess crops, to a digester tank. Bacteria then break down the organic waste, producing biogas instead of carbon dioxide due to the absence of oxygen inside the digester. The methane can then be used on an industrial scale for heating, fuel (including for farm equipment) and electricity and then rurally for cooking fuel, household heating and lighting. The left-over material is called digestate, which is rich in nutrients like N and P so it can be used as fertiliser on farms, to improve the circular bioeconomy and nutrient recycling.

Currently, anaerobic digestion is in its infancy (as highlighted in the UK Government's Energy Whitepaper (2020) which mentioned hydrogen 129 times, and anaerobic digestion just twice – although both are alternatives to traditional natural gas[83]). However, several public companies make them; Anaergia is one example. Anaerobic digestors was the original focus of the company when it started in 2007. The business has now expanded into broader waste and water treatment technologies. It has provided technologies to over 1,000 agricultural waste anaerobic digestion projects that treat feedstocks[84]. New and innovative anaerobic biodigesters are also in development: Bioletric manufactures and sells 'compact' anaerobic digesters known as pocket digestors, to farmers across Europe. BNP Paribas contributed to the growth of this by providing them with a series of credit facilities, mostly in the form of a 'sustainable impact loan.' [85]

6. Packaging

The downstream effects of the agricultural industry are significant (12.5 million tonnes of plastic products were used in plant and animal production with another 37.3 million tonnes used in downstream food packaging).[86] However, there are also solutions available to mitigate these negative consequences, including alternative delivery models for packaging, as well as mechanical and advanced recycle and plastic alternatives. These have been addressed in our previous research paper on redesigning our relationship with plastic, which can be found **here**.

82 Anaerobic digestion of agricultural waste for biogas production and sustainable bioenergy recovery: a review | Environmental Chemistry Letters (springer.com)
83 Savills UK | Spotlight: Anaerobic Digestion – May 2021
84 Anaerobic Digestion Technology For Agriculture | Anaergia
85 Biolectric is achieving growth with its anaerobic digesters (bnpparibasfortis.com)
86 Assessment of agricultural plastics and their sustainability: A call for action

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