Common sense sustainability: Transforming agriculture for the future

Food for a Better World

No time to waste

Executive summary

How digital, ecological, and societal shifts are reshaping the agri-food value chain

Since the 1960s, agricultural and agro-industrial practices have become increasingly standardized, largely driven by free trade agreements. This trend has contributed to several of the challenges we face today, including reduced genetic diversity in livestock and crops, ecosystem degradation, soil erosion, and water pollution. These impacts carry costs not only for society, but also for the sector itself, which is increasingly deprived of the benefits provided by healthy ecosystems.

By 2050, the global population is expected to stabilize at approximately 9.5 billion people . Achieving accelerated and sustainable growth and ensuring food security will be further complicated by the impacts of global climate change and extreme weather events .

In recent years, the term resilience has become ubiquitous, featured in political speeches, reports, project calls and media discourse. The emergence of this term follows the crises experienced by the agricultural sector, be they weather-related or financial, which have revealed the sector's vulnerability to uncertainties.

The definition of resilience is the capacity of an ecosystem, biotope, or group of individuals (population, species) to recover after an external disturbance (e.g., fire, storm, deforestation, etc.). However, the notion of resilience as the ability to recover is insufficient to describe the need for global adaptation of the entire agricultural and agro-industrial system. Indeed, the target should not be to get back to the point prior to external disturbance, but rather to transform the current rules of the sector. Great agility is needed against extremely rapid changes to anticipate and act during uncertainties.

Many innovations in agricultural practices are still limited to the experimental microplot. To be more agile, we need to be able to test on a larger scale, under more varied conditions, and more rapidly. But the risk is essentially borne by the farmer. While the presence of a farm advisor generally encourages farmers to take the plunge into innovation, what we need is a regulatory framework, as well as the support and participation of the entire value chain.

This paper aims to remind us of the challenges weighing on the sector and explain how digitalization can support and accelerate these transformations.

[01] Flowers, T. J., & Muscolo, A. (2015). Introduction to the Special Issue: Halophytes in a changing world. AoB PLANTS, 7, plv020. https://doi.org/10.1093/aobpla/plv020
[02] Flowers, T. J., & Muscolo, A. (see upper footnote)

PART 1:

The current agricultural and agro-industrial model showing its limits

According to the World Bank, the value of food and agricultural product trade has significantly increased, while the share in gross domestic product (GDP) has steadily declined in the last several decades. Indeed, the added value of agriculture, forestry, and fishing has multiplied by a factor of 3.3 since the 1980s ($1.17 trillion USD in 1981 against $3.87 trillion in 2022). However, the share in GDP dropped significantly (7% in 1981 against 4.3% in 2022) . This data shows how agriculture is growing in output but shrinking in economic weight. As such, the current model is unsustainable in that it generates massive hidden costs and depends on fragile systems.

1.1 The hidden cost of excessive specialization

The Food and Agriculture Organization of the United Nations (FAO) highlights the significant hidden costs of our current agrifood systems, equivalent to $10 trillion, or nearly 10% of global world GDP . Compared to the value of agricultural production ($4.3 trillion) the hidden costs lead to unprecedented impacts. This means that for every unit of value agriculture produces, it generates 2.5 times more in hidden costs.

Biodiversity is affected by agricultural standardization, particularly through intensive farming practices. Indeed, converting natural habitats into agricultural land leads to the loss of species habitats, while monoculture farming homogenizes habitats, reducing the variety of species that can thrive. The use of pesticides and fertilizers further disrupts ecosystems. An Oxford Academy article published in the European Review of Agricultural Economics highlights that biodiversity preservation is crucial for crop production, as 75% of the

[03] World Bank. “Agriculture, forestry, and fishing, value added (constant 2015 US$)” – available on : https://data.worldbank.org/indicator/NV.AGR.TOTL.KD
[04] World Bank. “Agriculture, forestry, and fishing, value added (% of GDP).” – available on : https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS
[05] FAO. “Hidden costs of global agrifood systems worth at least $10 trillion.” https://www.fao.org/newsroom/detail/hidden-costs-of-global-agrifood-systems-worth-at-least--10-trillion
[06] European Review of Agricultural Economics. “Technical and economic effects of biodiversity standards on wheat production” (https://academic.oup.com/erae/article/doi/10.1093/erae/jbab012/6271234)
[07] Bedolla-Rivera, H.I. et al. (2023). Analyzing the Impact of Intensive Agriculture on Soil Quality: A Systematic Review and Global Meta-Analysis of Quality Indexes. Agronomy, 13(8), 2166 (https://doi.org/10.3390/agronomy13082166)

world's food crops rely on animal pollination. Biodiversity also provides natural pest control. However, intensive agricultural practices threaten biodiversity by destroying habitats, promoting monocultures, and using harmful chemicals.

Soil quality is also impacted by intensive and standardized agriculture, mainly driven by monoculture and the use of pesticides . The use of chemical fertilizers and pesticides degrade soil structure and reduce its fertility over time, while monocultures deplete essential nutrients from the soil, requiring more chemical inputs to maintain productivity. Also, monoculture reduces the diversity of soil organisms that are crucial for maintaining soil health. Finally, the lack of crop rotation and cover crops can leave soil exposed and more susceptible to erosion by wind and water.

The impact on human health is also massive. Exposure to pesticides leads to chronic health issues for farm workers and nearby communities, including respiratory problems, skin conditions, and even cancer. The routine use of antibiotics in livestock can contribute to antibiotic resistance, making it harder to treat infections in humans, while standardized crops and monoculture may lead to deficiencies in essential nutrients (available in the crops) . According to the United States Environmental Protection Agency (EPA), the impacts of pesticides on human health can vary depending on the type of pesticide and the level of exposure. For example, organophosphates and carbamates can affect the nervous system, other pesticides can cause irritation to the skin and eyes, some can affect the hormone or endocrine system in the body or even be carcinogenic (i.e., there is the potential to cause cancer).

Agriculture plays a significant role in global greenhouse gas emissions (GHG), contributing an estimated 23% of the total. This impact includes land conversion (converting forests and grasslands), fertilizer use, and livestock emissions.

[08] Kirkhorn, S. et al. (n.d.). Human Health Effects of Agriculture: Physical Diseases and Illnesses. NASD Online. Retrieved from https://nasdonline.org/1827/d001772
[09] Marechal, A. et al. (2022). Comment réduire les émissions de GES dans l'agriculture.
[10] Gray, E. et al. (2021). Global Climate Change Impact on Crops - NASA Climate Change: Vital Signs of the Planet (https://climate.nasa.gov/news/3124)
Sentlinger, K. et al. (n.d.). Water Scarcity and Agriculture. The Water Project. Retrieved from https://thewaterproject.org/water-scarcity/water-scarcity-and-agriculture

1.2 Climate impacts agricultural map

Over time, the effects of climate change are increasingly felt on yields due to greater variability in temperatures and precipitation, disruptions to ecosystem services, and the increasing frequency and severity of extreme weather events, like droughts, floods, and heatwaves.

First, the agricultural map is going to change. According to a recent NASA study published in Nature Food, climate change could impact maize (corn) and wheat production by the end of the century if greenhouse gas emissions remain high. Maize yields are expected to decrease by 24%, while wheat yields might increase by approximately approximately 17%[10]. Historical places for these crops, including Mexico, the eastern United States, and eastern Europe should review their crop choices. The main issue from this change is a general decrease in global yield on the world scale, as new zones will not completely replace old zones, leading to a food security issue.

Second, water quality and availability will be impacted by intensive and standardized agriculture. The intensive use of pesticides and chemical fertilizers can lead to the contamination of groundwater and watercourses. This can impact health since these chemicals can seep into the soil and reach drinking water sources. Additionally, excess nutrients such as nitrates and phosphates from fertilizers can trigger algal blooms, which deplete the water's oxygen levels and harm aquatic plants and animals. We must also mention the impact of agriculture on water scarcity. Agriculture accounts for about 70% of global water withdrawals[11] and intensive irrigation practices can deplete local water resources, especially in regions where water is scarce. This phenomenon is amplified when irrigation systems are not efficient.

In this paper we focus on technological solutions to address these changes. However, we must not forget the non-technological solutions we have. Trying to find ways to irrigate better, via artificial intelligence (AI) and other smart methods, is one effective pathway. Attacking the root cause could have an even higher impact. Tackling water scarcity by selecting species that need less water, or halophyte species that can grow in a salty environment due to water withdrawal proves our ability to adapt. Some solutions also lie in our ancestors' techniques, such as kaolin, a natural protection against pests for fruit trees made of white clay, vegetable charcoal (biochar) which improves soil fertility and sequesters carbon, natural soil protection with humus and straw (which helps retain moisture, prevent erosion, and improve soil structure), and even plant synergy (intercropping tomatoes and basil for instance, which improves resistance to diseases and pests while increasing productivity).

[10] YouGov 2025, https://fr.yougov.com/consumer/articles/35521-consommateurs-achats-environnement
[11] Sentlinger, K. et al. (n.d.). Water Scarcity and Agriculture. The Water Project. Retrieved from https://thewaterproject.org/water-scarcity/water-scarcity-and-agriculture

1.3 The end consumer is now a prescriber

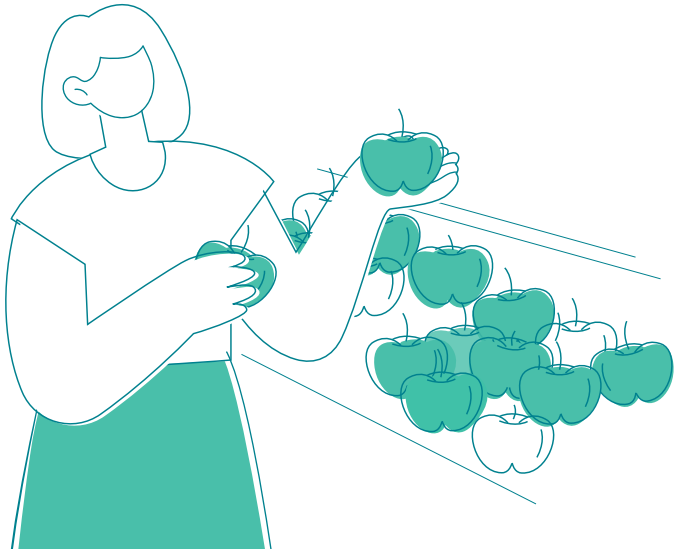
The request for transparency in the most developed regions of the world is clearly shown by trends towards more natural, healthier, authentic, and safer food. This need for transparency is strongly felt by consumers, who no longer hesitate to change their habits and behaviors to obtain food that meets their requirements. As early as 2018, a study conducted by experts from XTC World Innovation, Kantar Taylor Nelson Sofres (TNS), and Gira Conseil for Salon International de l 'Alimentation (SIAL) 2018 concluded that consumers in Europe, the United States, Russia, and Asia were increasingly demanding regarding production and farming conditions, product composition, and storage. Consumers are also willing to pay more for the products they consume to benefit from guarantees of fair production and marketing[12].

Among the different ways to bring transparency to the consumer, it is important to focus on two definitions, namely the difference in meaning between transparency and traceability. Transparency is a concept that can cover very different realities depending on the context. Overall, it involves making something visible that was not previously, such as farmers hiding behind a product (in the case of short circuits) or food additives present in an ingredient list (in the case of yuka). Traceability, on the other hand, is a much more precise notion. It is the path taken by a product throughout its manufacturing process, its origin, and all the steps of its journey before arriving in a store. Consumers are equipping themselves with tools, such as mobile applications, to verify that a product complies with healthy production and has the most neutral environmental impact possible.

Beyond the high expectations of consumers, several legal obligations now require professionals in the agri-food sector to comply with standards in favor of transparency, as well as reduced production circuits. This transparency also benefits companies in the sector, both economically and as it relates to corporate image and reputation.

Transparency in the food industry is also a matter of simplifying and clarifying information for consumers. The Grocery Manufacturers Association (GMA) based in Washington, DC conducted the Consumer Information Transparency Initiative. The initial results of this study revealed that consumers consider full disclosure as the clearest indication of transparency, meaning they want both positive and negative information related to what they consume. As a result, an increasing number of smartphone applications and websites are being developed to translate this information into simple terms, using gauges, symbols, or labels to make information more accessible.

We should also mention the will to eat local. Globally, six out of 10 consumers say they prefer to buy food produced in their country (60%). Of that group, Italians are the most inclined to turn to local products (74%), followed by Swedes (71%) and Indians (70%). In addition, 67% of French people share this view, which is 7 points higher than the global average.



For consumers, the correlation between the level of environmental concern and the desire to buy local products is noted across most countries, except in markets in the United States, Singapore, and the United Arab Emirates[13]. Given this preference, shortening the logistics chain from the place of production to the final consumer is a strong lever for reducing greenhouse gas emissions.

It should also be noted that for Europeans, the scale of what is considered a local product is not necessarily the same as for other regions of the world. According to a survey conducted by the Observatoire Cetelem[14], on average, 64% of Europeans consider a local product to be one manufactured in the region where they live. Almost one-third (31%) believe that local means national.

Consumers play a pivotal role in the promotion of local food, as their purchasing decisions directly influence the types of products that are bought and consumed. However, it appears that this choice is not as simple as it seems, despite government appeals. Hervé Prince, professor of law and director of the Centre for Business and International Trade Law at the University of Montreal (UdeM), and Marcel Groleau, president of the Union of Agricultural Producers (UPA), remind us that "one of the fundamental rules of the World Trade Organization (WTO), an organization to which almost all countries in the world adhere, limits governments that wish to promote national preference."

Under current international trade rules, countries are prohibited from discriminating against foreign products in favor of domestic ones. If, for instance, Canada were to restrict European imports to promote local consumption, the EU could seek authorization from the WTO to impose reciprocal trade barriers. Given Canada's strong dependence on international trade, withdrawing from such interconnected systems would prove extremely difficult.

---

[12]YouGov 2025, https://fr.yougov.com/consumer/articles/35521-consommateurs-achats-environnement

[13] PwC. (2024). Voice of the Consumer Survey. PwC. Disponible à l'adresse : https://www.pwc.com/gx/en/news-room/press-releases/2024/pwc-2024-voice-of-consumer-survey.html
Innova Market Insights. (2024). Consumer Behavior Trends: Global Sustainability & Ethics. Innova Market Insights. Disponible à l'adresse : https://www.innovamarketinsights.com/trends/global-consumer-behavior-trends/
McKinsey & Company. (2025). State of the Consumer trends report 2025. McKinsey & Company. Disponible à l'adresse : https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/state-of-consumer

[14] Observatoire Cetelem. (2019). Think Local, Act Local. Disponible à l'adresse :

[15] Consommation Locale et Localisme | ALIMENTERRE

[16] Ministère de la Transition écologique et de la Cohésion des territoires. (n.d.). Le mode de vie des ménages. Consulté à l'adresse : [https://www.notre-environnement.gouv.fr/themes/societe/article/le-mode-de-vie-desmenages6065#:~:text=Dans%20la%20vie%20quotidienne%2C%20la,de%20serre%2C%20production%20de%20d%C3%A9chets%E2%80%A6]

[17] UNICEF. (n.d.). Le phénomène de surconsommation dans les pays les plus riches entraîne une dégradation de l'environnement des enfants. Consulté à l'adresse : [https://www.unicef.org/fr/communiqu%C3%A9s-de-presse/le-phenomene-de-surconsommation-dans-les-pays-les-plus-riches-entraine-une-degradation-de-lenvironnement-des-enfants]

[18] Climate Change Impacts on Agriculture and Food Supply | US EPA. Disponible à l'adresse : [https://www.epa.gov/climate-impacts/climate-change-impacts-agriculture-and-food-supply] (https://www.epa.gov/climate-impacts/climate-change-impacts-agriculture-and-food-supply)

[19] Food and Agriculture Organization of the United Nations (FAO), Building resilience to climate change - https://www.fao.org/resilience/resources/ressources-detail/fr/c/1114154/

An article from Alimenterre (quoting Terre de Liens)[15], addresses the issue of local consumption and localism. It emphasizes that supporting local producers should not turn into an exclusive national preference, which could harm international solidarity and food diversity. Localism (as opposed to the notion of local consumption), involves systematically favoring local products while rejecting imports, which poses significant challenges. This approach, which may seem beneficial for protecting local jobs, can have adverse effects, such as increasing prices for consumers and reducing the available food diversity. Therefore, consuming locally has certain advantages, but also pitfalls. However, we can note that one of the primary reasons consumers wish to consume locally is their awareness of their environment and overall climate issues.

Although individual choices may appear trivial, the cumulative impact of consumer decisions related to food, consumption, transportation, and housing significantly contributes to biodiversity loss, the depletion of natural resources, and the acceleration of climate change. The situation has deteriorated over the past several decades. Human preferences and consumption patterns have significantly evolved and intensified their impact on the environment. Thus, the individualization of housing, the expansion of occupied spaces, and the improvement of comfort influence energy consumption and land artificialization.

If we examine the major areas of household consumption, we can see how each aspect of our daily lives impacts the environment. The first example that comes to mind is the car. Private vehicles are responsible for more than half of the greenhouse gas emissions from the transport sector and numerous emissions of atmospheric pollutants[16].

The example of food consumption is also essential. From farm to fork, several environmental pressures can be associated with food: water and energy consumption, greenhouse gas emissions, waste production related to packaging, food waste, etc. The agricultural production phase can also pose a risk as explained previously. Regardless of household food practices, food waste remains a major issue in France, where it is estimated that households waste 50 kilograms of food per inhabitant each year[17]. Reducing waste through responsible consumption, extending product lifespans, and advancing recycling are key priorities today in building a low-carbon, resource-efficient, and environmentally respectful economy.

Eventually, the degradation of the environment affects farmers' ability to interact with environmental resources, such as water and grass, and creates disruptions in their relationship with the land. Climate change impacts vary, affecting vulnerable, marginalized farmers and generally small-scale agriculture[18].

According to the FAO, the frequency of climate disasters over the past 30 years has increased. This includes droughts, heatwaves, frost, precipitation, floods, groundwater salinization, diseases, hail, and others. The FAO estimates that an average of 149 disasters per year worldwide occurred between 1980 and 1990, compared to 332 per year between 2004 and 2014.[19]

By promoting agrobiodiversity, improving soil health, and fostering the autonomy of agricultural systems, agroecology strengthens their resilience to hazards and change. Both technical and economic diversification serve as powerful levers of resilience, enhancing the system's capacity to absorb shocks and adapt over time.

Three capacities of agricultural systems need to be developed to improve their resilience to hazards and changes:

1. The buffering capacity: the system tolerates disturbances without deviating from its routine operation. For example, a dairy farm experiencing drought can tolerate this hazard if its forage stocks are sufficient.
2. The adaptive capacity: the system implements technical, organizational, or commercial adaptations to cope with hazards and quickly returns to a routine. For example, diversifying crop rotations to cope with repeated droughts.
3. The transformative capacity: the system undergoes profound transformation to endure. For example, in the face of a drastic drop in milk prices, an intensive dairy farm evolves into an economical and autonomous system, involving changing the breed of the herd or setting up a new production workshop.

Several resilience measures can strengthen agricultural systems:

- Diversification through crop rotations, variety selection, and varied agricultural practices improve adaptability.
- Soil conservation, achieved by adjusting intervention intensity and production expansion, helps maintain long-term fertility.
- Risk management strategies such as ensuring water access, protecting livestock health, and safeguarding economic viability are also critical to resilience.
- Effective water management—including replacing water-intensive crops, rationalizing irrigation, and improving soil structure to enhance water absorption and storage—further supports resilience.
- Livestock management can benefit from building forage reserves, diversifying feed, and adjusting feeding schedules during heat waves, alongside optimizing extensive practices like dynamic rotational grazing and transhumance.
- Adapting infrastructure and pastures by adding ventilation, misting systems, agroforestry, and natural shading helps mitigate heat stress and sustain productivity.

In 2017, during the Conference of the Parties (COP) 23 in Bonn, the international community adopted a decision to establish a working group on agriculture. The Koronivia Joint Work on Agriculture aims to collectively examine issues related to agriculture and food security, considering the vulnerability of agriculture to climate change.

The FAO recently published a report on the potential of agroecology to create climate-resilient livelihoods and food systems[20]. This report presents how agriculture has developed as a subject in the international political debate on climate change and the role agroecology plays in current climate policies. To support agroecology and promote climate resilience, it is essential to establish and strengthen functional and context-specific knowledge and participatory innovation systems. The FAO calls for the promotion of agroecology to strengthen resilience and designates it as a viable strategy for climate change adaptation.

[20] Food and Agriculture Organization of the United Nations (FAO), Building resilience to climate change https://www.fao.org/resilience/resources/ressources-detail/fr/c/1114154/

PART 2

React and anticipate, the role of technology in sustainable agriculture

Agriculture needs to evolve to be more resilient in the face of climate change. Agroecology and regenerative agriculture will be the cornerstone of this evolution, which technology will be an enabler of success.

Facing climate change requires two types of technologies: those that will help to attenuate greenhouse gas emissions and those that will enable society to adapt to climate change. Attenuation requires technologies that allow us to react to climate change, including smart irrigation systems and precision agriculture. Adaptation requires technologies to anticipate climate change and includes a wide range of tools, some of which are still being developed.

2.1 Rethinking production

Production needs to evolve. Overall, agriculture needs to be more efficient, use less intrants, keep a globally constant surface of cultivated land, and still feed the world.

2.1.1 Reaction technologies

Intelligent irrigation systems

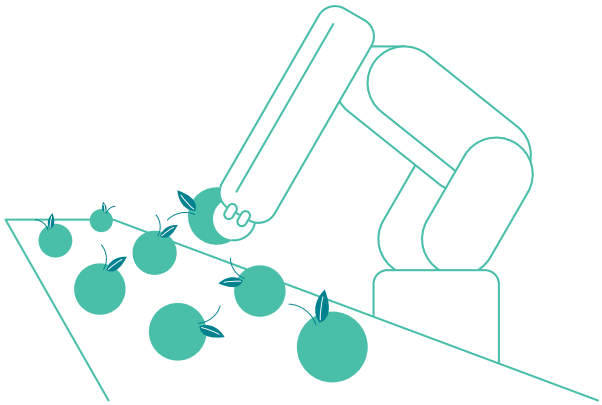
IoT and automation technologies allow society to improve the use of water resources in a world where water scarcity will become the norm. Digital technologies, such as automated irrigation systems, use weather data and sensors to adjust watering according to the specific needs of crops. This can reduce water consumption by 20-40%, while increasing yields[21].

With climate change, droughts will become increasingly frequent. As a result, conflicts regarding the use of water will become more common and arbitration will be needed[22]. Intelligent irrigation systems will set a new standard for agriculture and will soon become essential to ensure we can continue feeding the world's growing population.

[21]S. Taneja, et al. "Comparative analysis of irrigation techniques", Journal of Agricultural Sciences, Vol.65 Issue.3, pp.213-221, 2018
[22]Analysis by France Stratégie, available here: https://www.strategie-plan.gouv.fr/publications/leau-en-2050-graves-tensions-sur-les-ecosystemes-et-les-usages

Precision agriculture

Precision agriculture uses advanced technologies to tailor care to each crop and seed, boosting productivity while minimizing the use of chemicals and other inputs. The use of sensors and drones allows for real-time monitoring of crops, thereby optimizing resource use; soil sensors can also measure moisture and nutrient levels, enabling targeted irrigation and fertilization. This reduces costs and minimizes environmental impact. Moreover, precision tools allow for the specific planting of seeds at the best place to improve their productivity.



Robotics

Harvesting and weeding robots automate repetitive tasks, increasing efficiency and reducing labor costs. For example, weeding robots can identify and remove weeds without using chemicals, thus preserving soil and water quality. They can also be equipped with sensor systems to identify the quality of the soil, the best seeds to plant, and the needs of those seeds.

With robotics, farmers can also precisely interplant different crops on the same plot and harvest them with exceptional accuracy, enabling the benefits of intercropping—where traditional agriculture would typically favor uniform crops to maximize economies of scale.

AI and predictive technologies

AI can analyze massive datasets to predict crop yields, identify diseases, and optimize planting schedules. For example, AI algorithms can forecast pest infestations, allowing agricultural producers to take preventative measures and reduce pesticide use. It can create an accurate roadmap for months or years to come that allows farmers to gradually adapt to a changing environment.

AI can also help to identify sick livestock and improve disease detection. This can allow for targeted treatment instead of culling a whole flock. As a result, farms can improve their resiliency toward zoonosis.

Finally, creating new seeds requires a huge number of experimentations, modelling, and other steps. Some experiments will be a success, but most will fail. However, the industry needs to focus part of the work on varietal innovation to ensure that we can rely on the most sustainable crops in a situation where climate change will hit hard. AI can help test multiple options, reducing the number of experimentations needed and improving success rates. Therefore, AI will play a crucial role in helping seed developers create new, improved varieties.

2.2 The importance of data

Data is the key to enhancing agriculture resiliency and fueling adaptation. This asset will also help build new businesses, as well as identify new crops that can withstand the impact of climate change.

Although widely used today by farmers and offered by various players such as equipment manufacturers, the industry must go further, integrating data from diverse sources, including privately owned, publicly available open data, farmer-owned, and seed producer-owned datasets. These data streams need to be seamlessly unified, and advanced tools developed to unlock their full value.

The Intergovernmental Panel on Climate Change (IPCC) suggested scenarios in which agriculture could become impossible in many places on the planet. This impact still needs to be assessed and then monitored, which requires live data that can be processed and used to create models of current scenarios. This can help farmers protect their crops from freezing or lead preventive actions against wildfires, for instance.

2.3 Consumer needs must be addressed

It's important to distinguish between citizens and consumers, as they have fundamentally different perspectives on products. Consumer behavior is often driven by short-term needs and fleeting trends. In contrast, citizens are more focused on long-term concerns, such as social impact, biodiversity, climate change, and future generations. Therefore, in conversations of this nature, it is advisable to replace the term consumer with citizen and frame the question about how to build a resilient agri-food chain around them.

Citizen want assurance that the products they buy are free from slavery, deforestation, chemical abuse, pollution, and water overuse. They seek fair products at fair prices. A current example is coffee, where availability is under pressure. Rising commodity prices have sparked a conflict between coffee processors and retailers, sometimes resulting in empty shelves. The root cause lies in farmers' inability to invest in their crops due to relentless price pressure from retailers. Fair pricing models show a better way: when farmers receive a fair payment, they can afford to send their children to school and sustain their livelihoods.

To gain and maintain trust, citizens and consumers need transparency. They expect to know what's happening at every step of the process—and ideally, farmers should also see how their products are used and valued downstream. An example of enabling technology is blockchain, which ensures the traceability of agricultural products from farm to table. This not only guarantees transparency and food safety but also allows consumers to verify the origin and quality of what they buy. For example, IBM Food Trust uses blockchain to track food products, reducing risks of contamination and fraud while building confidence in the supply chain[23].

[23] Supply chain insight: Inside IBM's Food Trust Blockchain system | Supply Chain Magazin

2.4 Adapt to new market interfaces

Globally, we see several emerging trends that aim to close the gap between farmers and consumers—a gap that traditional retail often makes unbridgeable.

Evolving access models

In many regions, new initiatives enable consumers to buy directly from farmers, fostering personal connections and encouraging buying habits based on seasonal availability. In the U.S., for example, nearly every town hosts farmers' markets, where local farmers sell their products directly to the community. This local model competes with major retail chains while providing farmers with a direct income. In the Netherlands, the Herenboeren initiative allows citizens to collectively purchase farmland and pay a farmer a fair income. In return, the farmer grows food for the community year-round, supported by and supplying directly to the members. Other models include food platforms that aggregate produce from local farmers and distribute it weekly to pick-up points in neighborhoods. On a larger scale, new types of retailers are entering the market, offering weekly grocery delivery services that bring farm-fresh products directly to consumers' homes.

Optimizing supply chains

Forecasting demand in agriculture is crucial for optimizing supply chains, reducing waste, and ensuring food security. Here are some key methods and technologies used to achieve precise demand forecasting:

- Machine learning and AI analyze vast amounts of data, including historical sales, weather patterns, soil conditions, and market trends, to predict future demand. AI-driven models can adapt to changing conditions and provide more accurate forecasts.
- Combining different forecasting methods (hybrid models), such as Seasonal Autoregressive Integrated Moving Average (SARIMA) and Long Short-Term Memory (LSTM) neural networks, can improve the accuracy of predictions. These hybrid models leverage the strengths of each method to better handle the complexities of agricultural data.
- Integrating data from various sources, such as satellite imagery, IoT sensors, and market reports, helps create a comprehensive view of the factors influencing demand. This holistic approach allows for more precise forecasting.

Running different scenarios based on potential changes in market conditions, weather events, and policy shifts can help farmers and stakeholders prepare for various outcomes and make informed decisions. Encouraging collaboration among farmers, suppliers, and retailers, and sharing information through centralized platforms can enhance the accuracy of demand forecasts and improve the overall efficiency of the agricultural supply chain. By leveraging these advanced techniques, the agricultural sector can better anticipate demand, reduce waste, and ensure a more stable supply of food products.

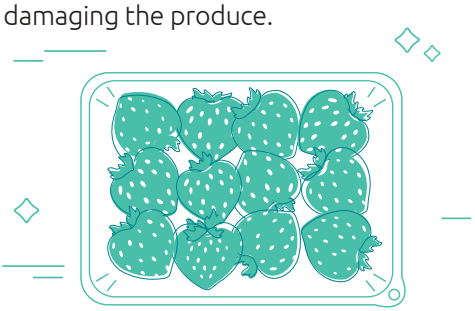
Extreme weather events can disrupt agricultural markets by reducing supply, disrupting supply chains, increasing input costs, and lowering product quality. However, agricultural trade can help address the resulting food security issues. The volatility of production is increasing and therefore this becomes more unpredictable for the traders and the processors. In practice, this means that the prices of end products will vary due to climate change[24]. This makes real-time planning and optimization more critical than ever.

Over the years, access to information has evolved dramatically—most data are now publicly available, shifting the power balance between traders and farmers. With equal access to data, the difference today lies in how traders leverage it: they use AI platforms to optimize their supply chains based on real-time demand and crop availability.

[23]Supply chain insight: Inside IBM's Food Trust Blockchain system | Supply Chain Magazine

Storage

Another key player in the supply chain is the storage sector. Companies operating large, climate-controlled facilities adapt storage conditions to specific crops, measure incoming quality, and apply advanced techniques to preserve freshness. These facilities ensure year-round availability of staple crops by maintaining quality between harvests. Technologies such as Near-Infrared (NIR) spectroscopy allow them to assess quality without damaging the produce.



For example, Capgemini implemented a program to measure quality and sugar content in strawberries before harvest. This enabled growers to optimize distribution channels, select the right packaging, and better predict sales. The result: improved quality and trust in the product, along with significant reductions in food waste.

2.5 Overcoming obstacles to the adoption of agricultural innovations to adapt to climate change and customer needs

As we have seen in the preceding sections, many innovations could help accelerate transformation needed to adapt to climate change, as well as to consumer expectations. Farmers who have lived through the Green Revolution have demonstrated their ability to adopt innovations very quickly. This adoption had the effects we described in Part 1. The challenge for the current generation of farmers is to restore what has been damaged, while avoiding making new mistakes. Today's farmers are connected, open to innovation, motivated to adopt practices that are more respectful of the environment—a mindset that will help protect their farms.

However, innovation adoption rates vary significantly between regions. While Europe and the United States often see new agricultural technologies reach 40% adoption rates, similar innovations are adopted in less than 10% in parts of Sub-Saharan Africa or Central Asia[25]. These disparities reflect not an inherent resistance to change, but rather different risk environments, infrastructure limitations, and economic constraints.

[24]https://www.oecd.org/content/dam/oecd/fr/publications/reports/2024/07/oecd-fao-agricultural-outlook-2024-2033_e173f332/96f19970-fr.pdf

Adopting innovative technologies or practices also entails risks. In agriculture, it can, at least initially, increase labor and structural costs. It also requires training and apprenticeship.

For example, some innovations, such as milking robots, help address labor shortages in the dairy industry but come at a significant financial cost. Institut de l'Élevage (IDELE), a French livestock institute, reports that while time savings drive high adoption rates, annual disposable income can drop by €35,000 for a two-partner farm with 76 cows[27]. Despite improved efficiency, many case studies show notable declines in farmers' income after installing milking robots. Even top-performing robotized farms only reach average profitability[28].

When they arrive on the farm, innovations are not always mature, because experimentation, even in the field, cannot reproduce the biological and physical conditions specific to each farm. Unlike most economic sectors, therefore, the risks associated with maturing innovations are not always separated from those associated with adoption. As such, farmers often act as "full-scale" testers.

Pioneering farmers are both those who first adopt innovations and those who produce them on their farms. They adapt what already exists, test prototypes, interact with researchers and technicians to create new products or processes, participate in farming collectives, and play an essential role in peer-to-peer dissemination.

These farmers are thus end-users who can intervene in all segments of innovation, from conception to dissemination.

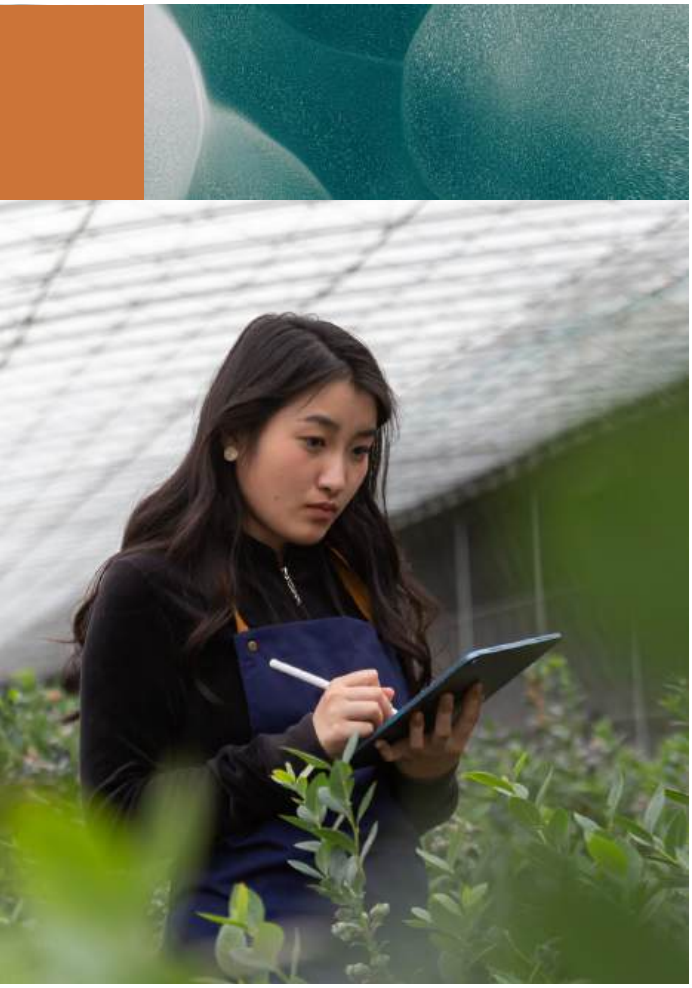
Public innovation policy has developed tools to support pioneering companies. For example, rather than granting direct subsidies, France, like other European countries, has favoured tax expenditures managed by the Ministry of Higher Education and Research, such as the research tax credit (CIR) and the innovation tax credit (CII)[29].

A farm cannot evolve without its upstream and downstream partners. As a result, many innovations are discarded because of the dependency farmers feel towards their commercial partners.

Public innovation policy has developed tools to support pioneering companies. For example, rather than granting direct subsidies, France, like other European countries, has favoured tax expenditures managed by the Ministry of Higher Education and Research, such as the research tax credit (CIR) and the innovation tax credit (CII)[29].

A farm cannot evolve without its upstream and downstream partners. As a result, many innovations are discarded because of the dependency farmers feel towards their commercial partners. Anticipating the reactions of trading partners slows down changes. Examples include:

- An article from *Les Echos* newspaper explains that France's organic hop industry is facing significant challenges with its buyers, as brewers demand hop varieties with specific aromatic profiles that are poorly suited to the local climate and therefore highly vulnerable to disease. Unable to find buyers for their terroir-adapted hops, they were left with a large stock that proved difficult to sell. This drop in income put a brake on varietal innovation[30].
- In this same article it is mentioned that in large-scale cereal production, wheat variety blends—which effectively reduce the need for plant protection products—face resistance from most millers. Millers prefer to purchase pure-variety batches, as they require large, uniform quantities to maximize silo efficiency and fear that blends could lead to reduced volumes.
- Combinations of several plant species are rarely practiced, due to a lack of sorters in most cooperatives[31].



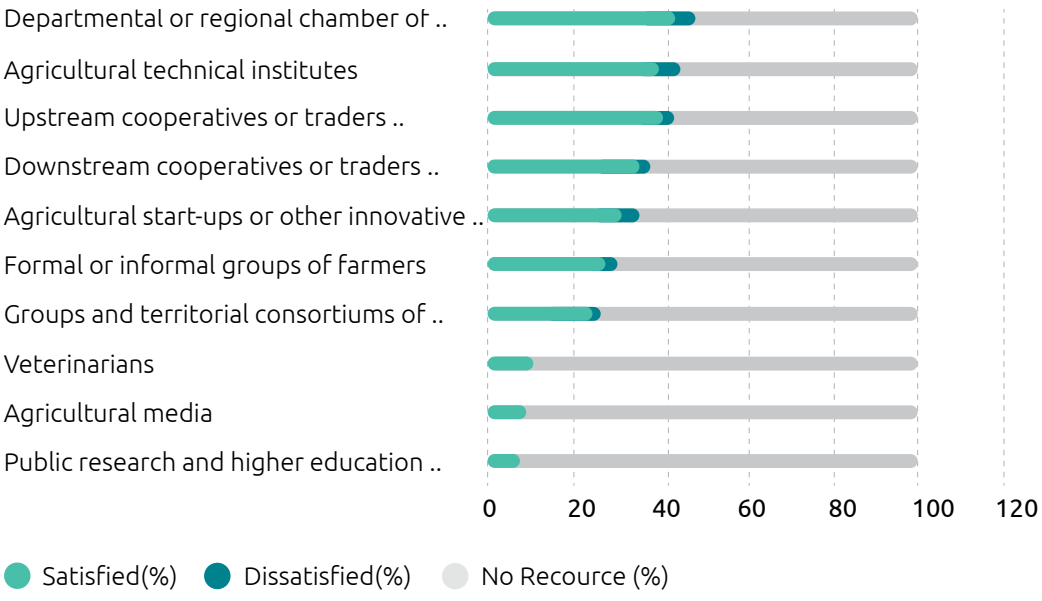
Open-source tools

If the technological solutions mentioned above entail significant costs, an alternative could be to adopt open-source tools. Low-tech or open-source solutions can substantially reduce these costs, focusing investments primarily on implementation and training rather than licensing fees. For example:

- FarmOS and OpenTEAM: Open-source farm management platforms with growing user communities across North America, Europe, and increasingly in Africa and Asia. Another example is the open-source software Ekylibre[32] .
- In France, the Centipede GPS network is expanding rapidly, enabling tractors to be equipped with affordable steering assistance for precision farming-without the need to replace existing tractors[33] .
- In Rwanda and Costa Rica, the open-source traceability system INATRACE has been deployed in pilot sites to enhance supply chain transparency[34].

While open-source solutions offer cost advantages, they require farmers to undertake self-training efforts, sometimes extending to computer code or electronics.

Farmers' satisfaction with advice according to the advice provider



[25]D.Fiocco et al., " Agtech: Breaking down the farmer adoption dilemma", McKinsey (link to the article)
[27]A.Vermeulen, "Robots de traite : le prix à payer" (link tot he article)
[28]D.Caillaud et al, "Impact économique du robot dans la traite" (link tot he article)

Agriculture advisory services

Agricultural advisory services play a crucial role in the adoption of innovative farming practices. Research from the *Cour des Comptes*[35] found that farmers adopt innovation more when they receive frequent advice.

While advisors serve as key facilitators in spreading agricultural innovation, current public policy frameworks do not adequately encourage farmers to consult advisors regularly, particularly during the critical early stages of transitioning to sustainable practices. This gap is especially pronounced for farmers considering the shift to agroecological or regenerative approaches, which require substantial changes in management practices and often involve higher initial risks.

The advisory landscape varies significantly across regions and development contexts. In developed countries such as those in Europe, North America, and Australia, well-established consulting networks exist, with specialized firms increasingly focusing on regenerative agriculture and agroecological transitions. Organizations like International Federation of Organic Agriculture Movements (IFOAM), BioSuisse, Bio Austria, FederBio, Bund Ökologische Lebensmittelwirtschaft (BÖLW), Soil Association, or the National Federation of Organic Agriculture (FNAB) in France, alongside specialized consulting firms, provide comprehensive services including training, transition support, and ongoing management guidance for farmers adopting regenerative practices.

In developing countries, advisory services often feature more hybrid models that combine multiple organizational forms and funding sources. Advisory services can be provided by producer associations, NGOs, or cooperatives, often directly linked to export markets (e.g., organic coffee, cocoa, cotton), and supported by international programs. These advisory services often rely on different delivery mechanisms adapted to local contexts and resource constraints. Mobile-based advisory services, including SMS and voice call systems, have proven particularly effective in reaching farmers with timely information on weather, market prices, and agronomic advice[36]. These digital extension services can complement traditional face-to-face advisory approaches and help overcome geographical and resource barriers that limit access to conventional extension services.

Decision support tools (DST)

Decision support tools (DST) represent a complementary approach to human advisory services, offering data-driven insights to support agricultural decision-making. Despite their availability in various formats, studies across multiple countries have shown that uptake of agricultural DSTs remains disappointingly low[37]. While numerous DSTs exist in Europe focusing on soil health, nutrient management, and water retention, their adoption, effectiveness, and development needs are not well understood[38].

Current limitations of DSTs for agroecological applications are significant and multifaceted. Modern DSTs integrate multiple data sources including local weather records, agronomic plot characteristics, and satellite imagery to provide risk indicators and intervention recommendations. However, these tools face challenges when applied to complex agroecological systems that operate at landscape scales and involve intricate ecological interactions.
The complexity of agroecological systems also presents fundamental modelling challenges. Traditional DSTs often focus on individual farm fields or specific crops, but agroecological approaches require understanding of system-level interactions, biodiversity effects, and landscape-scale processes.

---

[29] Crédit d'impôt recherche (CIR) | Entreprendre.Service-Public.fr

[30] B.Weiss, "La production de houblon tirée vers le haut par l'essor des microbrasseries" (link to the article)

[31] https://www.action-agricole-picarde.com/les-trieurs-facon-saluent-lautorisation-des-melanges-de-semences

[32] Ekylibre – Farm management information system, https://doc.ekylibre.com

[33] https://docs.centipede.fr/

[34] https://www.sustainable-supply-chains.org/topics/digitalisation-traceability/inatrace

DSTs require adequate data resources, and while modern computer systems can store considerable quantities of data, capturing the complexity of ecological interactions remains challenging. Key limitations include:

- Data availability and quality: Agroecological systems involve complex interactions between soil biology, plant communities, and ecosystem services that are difficult to quantify and monitor systematically. Many DSTs lack sufficient long-term data on these ecological processes to make reliable predictions.
- Scale mismatch: Most existing DSTs operate at field or farm scale, while agroecological benefits often emerge at landscape scales through habitat connectivity, pollinator networks, and watershed-level processes.
- Model complexity: While AI-driven technologies in agriculture often appear promising in theory, their practical viability remains questionable, with many DSTs becoming unavailable over time. The challenge lies in developing models sophisticated enough to capture ecological complexity while remaining user-friendly and accessible to farmers.
- Validation challenges: The long-term nature of agroecological transitions and the site-specific variability of ecological processes make it difficult
  to validate DST recommendations across diverse farming contexts.

Despite these limitations, DSTs continue to evolve and show promise for supporting agroecological transitions when designed with appropriate stakeholder input and realistic expectations about their capabilities.

Studies carried out in the livestock sector by the French food safety agency Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (ANSES) and Institut National de l'Agronomie et de l'Environnement (INRAE) show that innovation is often introduced under duress, whether as a result of a change in regulations, such as an eco-antibio plan, or a major health crisis, like a epizootic disease, which require a rapid response. We can imagine that this dynamic is the same with technological adoption[39].

2.6 New organizational forms and knowledge sharing

Collective farmer organizations emerge as catalysts by distributing risk, facilitating knowledge exchange, and creating supportive peer communities. These networks take diverse forms across agricultural contexts but share common characteristics in supporting innovation and technological adoption. Producer cooperatives, which are particularly strong in Europe and parts of Latin America, often focus on collective investment in technologies requiring scale. Learning networks, common across Africa and Asia, emphasize knowledge exchange around complex practices. Equipment-sharing cooperatives, found globally but particularly in North America and Australia, enable access to expensive machinery that would be prohibitive for individual farmers.

Strategic partnerships between research institutes, private companies and farmers' organizations are currently supporting European innovation. Nowadays, there is hardly any public funding that does not involve private interests and the involvement of user farmers[40]. Nevertheless, while institutional research boasts strong credentials and advanced centers of expertise-such as Arvalis, French National Research Institute for Agriculture, Food and the Environment (INRAE), and Wageningen University—collaboration remains challenging. Partnerships involve a great deal of red tape and take a long time to set up. Consortia are fragmented and often focus on very specific use cases or very small experimental territories, which have difficulty scaling up. However, collaboration between institutional research, the private sector and farmers also make it possible to limit experimentation costs. In some cases, they can give a competitive edge to farmers.

Digital platforms facilitate the sharing of knowledge and experience between farmers, but platforms are not everything. Local farmer networks remain essential for enabling effective knowledge transfer. Agroecology is particularly dependent on these tools insofar as farms using agroecological methods are rarer and thus require more developed peer-to-peer learning networks.

[35]https://www.ccomptes.fr/sites/default/files/2025-02/20250224-synthese-Innovation-en-matiere-agricole.pdf
[37]D.Petraki et al, igital Tools and Decision Support Systems in Agroecology: Benefits, Challenges, and Practical Implementations, 18/01/2025
[38]D.Iakovidis et al, Optimising decision support tools for the agricultural sector, 3 April 2024

The global knowledge-sharing landscape is diversifying through several channels. Some examples include:

- Farm Hack in North America represents a collaborative open-source agricultural knowledge sharing community that has brought together farmers, engineers, and developers since 2011 to reduce barriers to knowledge exchange and create a growing repository of agricultural technologies.
- WeFarm[41] in Africa operates an innovative peer-to-peer knowledge sharing platform.
- AgriInfo[42] provides a comprehensive agricultural information system that keeps farmers up to date on evolving EU policies, regulations and standards.
- Tools like Wiktrop[43] document tropical practices and Pl@ntNet offers a plant identification tool developed by scientists from agricultural research institutes, enabling species identification through photography using machine learning.

Social media platforms have also become important informal knowledge networks, as have WhatsApp groups that facilitate real-time communication and advice sharing among farming communities. The effectiveness of these tools depends on their integration with existing social networks and their ability to bridge traditional knowledge systems with modern agricultural practices.

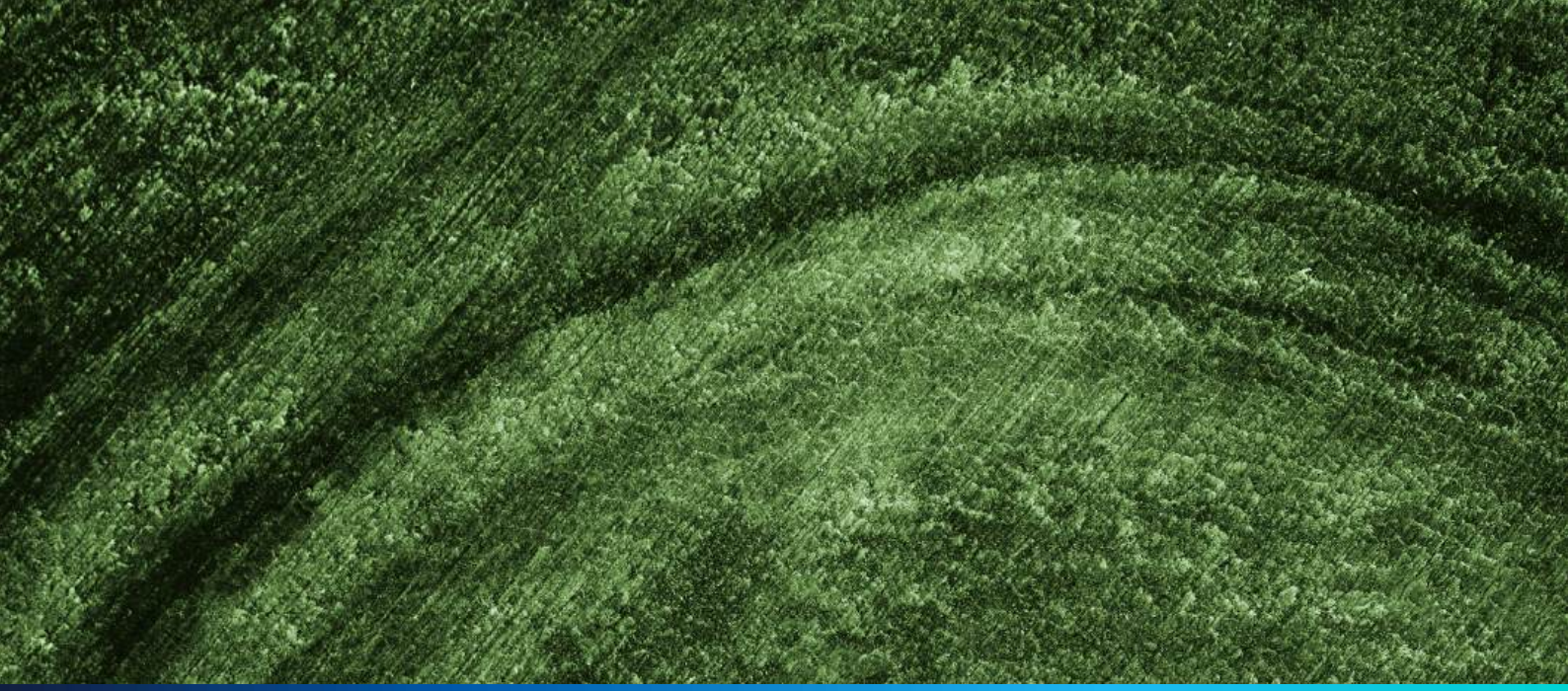
Despite the proliferation of digital platforms, several significant challenges impede effective agricultural data sharing:

- Data standardization and interoperability pose major problems as the lack of common standards across platforms limits data exchange. In addition, different measurement units and classification systems create compatibility issues, while technical barriers prevent seamless integration between tools.
- The digital divide constitutes another significant obstacle. Unequal access to internet connectivity, particularly in rural areas, combined with varying levels of digital literacy among farmers and cost barriers for accessing premium platforms or high-speed internet, limits collaboration.
- Data quality and reliability also raise important concerns. Inconsistent data collection methods across different sources, challenges in verifying the accuracy of user-generated content, and the absence of standardized validation processes for shared practices compromise trust in these systems.
- Privacy and intellectual property concerns also impede adoption. Farmers' reluctance to share sensitive operational data, unclear property rights over contributed knowledge and practices, and concerns about commercial exploitation of traditional knowledge constitute barriers to open sharing.

Initiatives are emerging to address these challenges. AgDataHub[44] is working to improve agricultural data interoperability and sharing standards in Europe by providing agriculture with a shared, sovereign technological infrastructure to guarantee the digital development of agriculture and agri-food. The AgriDataSpace European consortium[45] , launched under European Commission mandate in autumn 2022, brings together experts from fifteen organizations representing ten member states to assess existing platforms and co-construct a roadmap to guide the deployment and maintenance of the future European data space dedicated to agriculture. Additionally, the Global Open Data for Agriculture and Nutrition (GODAN) initiative , established in 2014, seeks to make agricultural and nutritionally relevant data available, accessible, and usable for unrestricted use worldwide, currently bringing together 244 partners from national governments, non-governmental, international, and private sector organizations.

(GODAN) initiative[46], established in 2014, seeks to make agricultural and nutritionally relevant data available, accessible, and usable for unrestricted use worldwide, currently bringing together 244 partners from national governments, non-governmental, international, and private sector organizations.

[41] https://join.wefarm.com/
[42] https://agrinfo.eu/
[43] https://portal.wiktrop.org/fr
[44] https://agdatahub.eu/
[45] https://agridataspace-csa.eu/
[46] https://www.godan.info/



Conclusion

For over 10,000 years, agriculture has been a story of adaptation, rooted in local knowledge, shaped by ecosystems, and refined through generations of trial and error. Before the industrial era, as much as 80 to 90 percent of the global population worked the land, living in close connection with nature across continents. The last century, however, brought seismic shifts. The NPK revolution, mechanization, and the widespread adoption of chemical fertilizers, patented seeds, and GMOs drove productivity, but at a steep cost. Food production became increasingly disconnected from ecological balance.

For over 10,000 years, agriculture has been a story of adaptation, rooted in local knowledge, shaped by ecosystems, and refined through generations of trial and error. Before the industrial era, as much as 80 to 90 percent of the global population worked the land, living in close connection with nature across continents. The last century, however, brought seismic shifts. The NPK revolution, mechanization, and the widespread adoption of chemical fertilizers, patented seeds, and GMOs drove productivity, but at a steep cost. Food production became increasingly disconnected from ecological balance.

Today, the warning signs are impossible to ignore. Each year, 100 million hectares of healthy land are lost. Industrial agriculture has seen a 5 to 10 percent decline in output over just the past five years, accompanied by a dramatic drop in nutritional value. Climate change is accelerating these trends: maize yields may fall by 24 percent globally by 2030, while wheat faces 30 to 40 percent losses in key regions under high warming scenarios. Meanwhile, the essential nutrients in fruits, vegetables, and grains have declined significantly over the past 75 years[47].

The future of farming must be radically different.
To secure food systems for generations to come, agriculture must become resilient, regenerative, and rooted in common sense sustainability. This means:
Embracing low-input, fossil-free methods that restore soil health and biodiversity, reversing decades of depletion.
Leveraging data-driven agriculture, AI, and digital platforms for precision and transparency, empowering farmers to make informed decisions and optimize resource use.

Supporting organic and plant-based innovations that nourish both people and the planet, ensuring that productivity does not come at the expense of health or the environment.

Empowering younger farmers and communities to lead the transition toward ecological stewardship, fostering a new generation of innovators and caretakers.
Agriculture must evolve from an extractive industry to a regenerative force. By combining ancient wisdom with modern technology, we can build food systems that are not only productive, but also equitable, nutritious, and climate resilient.

Let us move forward with clarity, courage, and common sense to transform agriculture for the future we all depend on.

[47]United Nations Convention to Combat Desertification (UNCCD), At least 100 million hectares of healthy land now lost each year, 24/10/2023

Meet the Expert

Ophelie Petit

Senior Business Analyst – Geomatician, Agriculture and Environment Expertise Factory Lead, Capgemini France

Ophelie is a Senior Business Analyst and Geomatician at Capgemini France, leading the Agriculture and Environment Expertise Factory. She brings over 13 years of experience in geospatial systems and digital transformation. Her work focuses on sustainable agriculture, biodiversity, and innovative IT solutions. Passionate about green IT and community building, she drives projects that merge technology with ecological performance.

Nicolas Vogtenberger

Managing Consultant, Capgemini France Invent – Strategy, Sustainability, AI, Media

Nicolas is a Managing Consultant at Capgemini Invent, specializing in strategy, sustainability, and digital transformation. With experience spanning public and private sectors, he has led initiatives in AI, media, and corporate sustainability. Nicolas combines expertise in innovation and data-driven approaches to help organizations achieve impactful transformation. Passionate about teaching and thought leadership, he also mentors future leaders at Sciences Po and INSP.

Katelyn Clark

Strategic Delivery Lead with cross industry experience in Tech & Digital, IT Services, and Life Sciences, Capgemini USA

Katelyn is a specializing in PMO operations, cloud compliance, and enterprise staffing programs. She is recognized for mobilizing cross functional teams and advancing organizational impact through sustainability leadership. Katelyn is committed to continuous improvement, scalable delivery, and stakeholder satisfaction in complex, regulated, and fast paced environments.

Mariane Clement

Senior Business Advisor,BTS (within APPS, Capgemini France)

Mariane is a Business Advisor at Capgemini with expertise in digital transformation and supply chain management. She leads end-to-end projects from business requirements to go-live, ensuring alignment across stakeholders and enterprise architecture. Her experience in retail, hospitality, and food sector made her passionate about delivering impactful solutions.

Jenneke Veenhuizen

Managing Business Advisor at Capgemini Netherlands, focusing on sustainable business transformation and ESG/CSRD compliance, with a primary focus on the Private market (CPR/Retail, EUC & MHT)

Jenneke brings deep expertise in implementing clients' sustainability strategy, transforming business processes, supervising the technical and/or functional integration and configuration of sustainability (data)initiatives, and supports organizations in creating long-term value through innovation. She also helps clients navigating and align with evolving sustainability regulations. With a strong legal background and extensive leadership experience, Jenneke drives impactful strategies that enable responsible and future-focused growth.

Chiara Pinto

Strategy & Transformation Consultant,Invent (People Practice France)

Chiara is deeply inspired by diverse cultures and people, and she is committed to empowering communities. She focuses on innovation and bringing bold ideas to life to create positive change. Her motivation to work in international development stems from meaningful volunteering experiences in Africa and her desire—as both a citizen and a professional—to help expand opportunities for all. Embracing new environments and cultures reflects her adaptability and resilience.

Sophie Rodenas

Managing PMO, BTS (within APPS, Capgemini France)

Sophie is an expert in IT project management and digital transformation. She leads complex IT projects for public-sector clients and has strong expertise in business analysis, change management, and structuring IT processes. Her background spans project portfolio governance, functional design, user support, and major system deployments, which strengthened her ability to coordinate diverse stakeholders, drive functional and technical evolutions, and ensure successful delivery in high-stakes environments.

Jacko Obels

Global Thought-Leader & CTO Agribusiness, Capgemini Netherlands

Thought leader on Agribusiness & Commodity Trade, Jacko focuses on the Sustainability of the agribusiness and the food value chain. Climate crisis is threatening our security of food, livelyhoods, a lively planet and our biodiversity. It's not the economics that counts, but whole new business models for farmers that secure a sustainable family income and create a liveable planet. Digital Transformation can support that change of the business but it's only one of the ingredients.

About Capgemini

Capgemini is an AI-powered global business and technology transformation partner, delivering tangible business value. We imagine the future of organizations and make it real with AI, technology and people. With our strong heritage of nearly 60 years, we are a responsible and diverse group of over 420,000 team members in more than 50 countries. We deliver end-to-end services and solutions with our deep industry expertise and strong partner ecosystem, leveraging our capabilities across strategy, technology, design, engineering and business operations. The Group reported 2025 global revenues of €22.5 billion.

Make it real. | www.capgemini.com

2C-025.26