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AGRITECH: DIGITAL INNOVATION FOR A SUSTAINABLE EUROPEAN AGRI-FOOD SECTOR

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INTRODUCTION

In June 2021 in its Communication “A long-term Vision for the EU’s Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040”[1], the European Commission stated that such areas are ‘a core part of the European way of life. They are home to 137 million people representing almost 30% of its population and over 80% of its territory’ and set out a long-term vision for the EU’s rural areas up to 2040. This Communication identified several challenges currently faced by rural areas and underscored the need for a profound transformation. More recently, in September 2024 the Strategic Dialogue on the Future of EU Agriculture produced its report to President von der Leyen[2]. Before presenting a set of guiding political principles and recommendations, the report clearly takes stocks of the tensions and growing challenges that EU Agri-Food systems are facing and also call for radical transformation based on innovation, knowledge, and technology. That Agri-Food ecosystems need radical transformation is recognised and documented by several other sources[3]. While the challenges and the need for transformation affect Agri-Food in general, in this report we focus especially on agriculture as it is the component of the ecosystem facing most challenges and, especially, political tensions as the recent protests in the spring of 2024 show.

Agriculture in the EU faces several challenges today including demographic change (global increase in the world population but shrinking and ageing population in the EU rural areas), climate change, environmental degradation, geopolitical instability, changing supply networks, evolving consumers’ demands, and slow growth in Total Factor Productivity. Furthermore, the sustainability of smaller farms is threatened. The concentration of control over land[4] as well as input and downstream markets has squeezed farmers’ profit margins, forcing smaller producers to scale up or disappear from the sector altogether, contributing to the wider trend of rural-urban migration.

EU Agriculture is called, together with other macro-regions, to feed a growing World population, while reducing its environmental impact and ensuring the resilience of rural communities. At the same time farmers should have a fair return from their activity and financial support should help the decreasing number of small farms. On the one hand, previous technological innovations[5] have produced important advances (among others, they have driven productivity, improved living conditions for farmers, increased food availability, and contributed to trade surpluses). On the other hand, they have also led to heavy agrochemical and energy use[6] as well as monoculture production, driving soil degradation, polluting water systems, damaging biodiversity, creating pest and disease resistance and impacting public health and nutrition. All of this threatens the future of agriculture itself, leading to a growing consensus that a substantial transformation is necessary. Agriculture activities account for nearly 11 % of the total global anthropogenic GHG emissions[7], which is sizeable but should also be considered in relative terms (i.e., the transport sector account of 80% of GHG emissions). The major GHGs produced in the agricultural sector are methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The recent (2023-2024) farmers’ protest in Europe are an indication of the tensions that currently characterise EU agriculture. In response to such protests, the Commission has proposed changes to reduce the administrative burden on farmers (i.e., related to conditionality) and other measures to address their concerns.[8]

In this context, one of the most prominent solutions being put forward in policy and agribusiness circles is the adoption of digital technological innovations. These are being presented as a suite of innovative solutions to tackle the current sustainability challenge and other issues faced by the food and farming sector[9]. Digital and precision technologies can potentially disrupt food supply, farming practices and policies[10]. Digital technology can change agricultural policymaking itself, as it yields new data and facilitates analysis[11]. These are the promises of the digital transformation of Agri-Food systems, through what can be broadly called FoodTech and AgriTech. FoodTech can be defined as the intersection between food and technology; the application of technology to improve food production, the supply chain and the distribution channel. E-commerce platforms, digital marketing tools, and online marketplaces can help them reach a wider customer base and diversify their revenue streams. AgriTech is the use of technology in agriculture, horticulture, and aquaculture to improve yield, efficiency, profitability, and environmental sustainability. AgriTech can be products, services, or applications derived from agriculture that improve various input/output processes, it includes what is also referred to as Precision Agriculture or Precision Farming (and also Agriculture 4.0). AgriTech can potentially help farmers produce higher yields, less crop damage and use fewer inputs such as water, fuel and fertiliser. It could make a CO2 saving contribution in agriculture in the EU until 2030. Digital farming involves utilising digital technology to observe, monitor and manage farming activities and other parts of the supply chain in an integrated manner, with mass data collection, storage and analysis forming a fundamental component.

But besides the promises, there are also the challenges; in many EU rural areas, Internet access (especially for lack of high-speed broadband infrastructure) is limited, and this holds back the use of big data. These technologies are still expensive for most farmers, especially for the smaller ones. The EU is also facing an ageing workforce on farms, and the introduction of new technologies could result in a “two-speed” EU agriculture. This would exacerbate a situation where the major markets in the EU food and farming supply chain are highly concentrated. Finally, automation of work in agriculture may create new jobs but also cause the loss of jobs for low skilled workers involved on routine task (on this aspect see the short not included as Annex). So, the promise of technology also brings the risk of some segments of rural communities falling behind or disappearing altogether. Well-balanced policies are needed to make sure that digital farming and food systems can be harnessed to support the EU’s green and digital transitions in a sustainable manner. This aspect concerns many of the current EU policies such as The Common Agricultural Policy (CAP), the European Union’s Green Deal, the Farm to Fork and the Biodiversity strategies.

This report aims to provide insights and suggestions on how the promises of digital farming can be realised and the challenges overcome by developing future scenarios. It builds on secondary sources, analytical and theoretical reasoning, and experts’ knowledge. In Section 2 the report provides a synthetic analysis of the state of play of the EU Agri-Food system, a review of the relevant technological development and of the ongoing relevant policies. In Section 3, four possible future scenarios for the development of the digital transformation of Agri-Food systems will be elaborated and illustrated, which are then assessed in final Section 4 which concludes with policy relevant implications and recommendations.

STATE OF PLAY

THE EU AGRI-FOOD SYSTEM WITH A SPECIAL FOCUS ON AGRICULTURE: CHARACTERISATION AND MAIN CHALLENGES

The picture below provides a synthetic snapshot of the quantitative dimension of the entire food chain in the EU. There were 9.1 million farms across the EU in 2020; they used 38.4 % of the EU's land area and employed 8.7 million persons. Value added from agriculture was 1.4 % of GDP in 2022. In 2020, there were 291 000 enterprises in the EU processing food and beverages; they employed 4.6 million persons and added €227 billions of value. In 2022, some 1.3 billion tonnes of agriculture, forestry and fishery products and 1.6 billion tonnes of food, beverage and tobacco products were transported by heavy goods road vehicles registered in the EU. On the one hand, it is evident that the entire Agri-Food ecosystems is vast and complex and entails several verticals, besides agriculture. On the other hand, for the reasons explained in the introduction in what follows we zoom on the situation and on the challenges of agriculture only.

	Agriculture	Food and beverage processing	Food and beverage wholesaling and retailing	Food and beverage serving activities
Number of holdings enterprises (million)	9.1	0.3	1.1	1.5
Employment (million)	8.7	4.6	8.4	7.3
Value added (€ billion)	173.9	226.8	293.0	107.2

Figure 1 Snapshot of the EU Agri-Food Source: Eurostat (2023, p. 5)[12]

Agricultural land in the EU plays a crucial role in food production and rural economies. The EU's utilised agricultural area covered 157.4 million hectares of land in 2020, representing 38.4% of its total land area[13]. This share varies significantly across Member States, ranging from less than one-tenth in Sweden and Finland to over half in Luxembourg, the Netherlands, Hungary, Romania, and Denmark, and peaking at 71.7% in Ireland. In absolute terms, France (27.4 million hectares) and Spain (23.9 million hectares) had the largest utilised agricultural areas in the EU, accounting for 17.4% and 15.2% of the EU total, respectively. In 2020, more than three-fifths (62.3%) of the EU's utilised agricultural area was arable land used for crop production, primarily for human and animal consumption. Permanent grassland made up almost one third (30.5%) of the utilised agricultural area, mainly serving as fodder and forage for animals. The remaining share was used almost exclusively for permanent crops (7.1% of the total agricultural area), including fruit (such as grapes) and olives. FAO data show that over the past 20 years, Europe has experienced a consistent reduction of about 10% in agricultural land, affecting all types of land use[14]. This decline is mainly attributed to urban expansion, including transport infrastructure, afforestation, and the withdrawal of farming activities.

The EU farming sector has undergone significant structural changes over the last few decades with increased concentration, characterised by a reduction in the number of farms, an increase in farm size, and a declining share of young farmers in the agricultural workforce. Data show that the number of farms has decreased steadily, dropping from 14.2 million in 2005 to 9.1 million in

Figure 2 Developments in land use in the EU, 2000-2020, Source: FAO (2022), Land use indicators

2020, while the average farm size has increased from 11 hectares to 17.4 hectares[15]. So, between 2005 and 2016, the number of farm holdings under 50 hectares fell by 29.4%, with over 4 million holdings disappearing in just 10 years. All the major markets in the EU food and farming supply chain are becoming highly concentrated1[6], a trend exacerbated by recent mega-mergers[17]. In this context, before the definition of the new Common Agricultural Policy (CAP) for 2023-2027, there were many calls for putting small farmers at the core of the CAP to ensure better food and more sustainable practices[18]. The decrease in the total number of agricultural holdings is primarily due to the disappearance of farms smaller than five hectares, which constitutes nine out of ten disappearing farms. Meanwhile, farms larger than 50 hectares are the only category that has increased (+9.7%). Several factors explain these structural trends. These include the low profitability of farming and better job opportunities outside of agriculture,

increased productivity through technological progress, and a higher degree of rationalisation due to improved farm machinery, the latter requiring a larger scale to be efficient. Along with changes in the number of farms and the average farm size, the pattern of farm specialisation has also evolved. Although EU farms continue to engage in diverse activities, there has been a marked shift towards specialisation. This trend is particularly evident in crop farms, whose share of total farms increased from 43% in 2005 to 58% in 2020[19]. Public policies and the institutional context also play a role, particularly market price support and coupled payments, which have historically encouraged intensification and scale enlargement[20]. Conversely, decoupled direct payments have a more indirect impact on farm structure changes by encouraging farmers to remain in the sector[21].
As the number of farms in the EU has declined over time, so has agricultural employment. While agriculture remains an important sector for employment, with 8.2 million full-time equivalents in the sector in 2020, agriculture's share of employment in the EU fell from 5.6% in 2010 to 4.2% in 2020, with some important differences across EU Member States. In 2020, agriculture accounted for a particularly high share of total employment in Romania, with more than one in every five persons (20.9%) employed in the sector. The share of agriculture in total employment was also relatively high in Bulgaria (15.5%) and Greece (9.9%). By contrast, it accounted for less than 1.0% of total employment in Luxembourg and Malta (both 0.7%). This labour outflow is mainly driven by the shrinking number of farms and the push for economies of scale through investments in machinery and technology, leading to larger farms[22]. The EU agricultural sector also faces the challenge of generational renewal. In 2020, more than half of the farmers in the European Union were at least 55 years old, and between 2005 and 2020, the share of farm managers under the age of 35 decreased from 7.3% to 6.5%. This decline in younger farmers is concerning because young farmers are crucial for embracing research, innovation, and smart agriculture. They tend to be better educated than older farmers and are more likely to adopt new production techniques, as shown by a recent study conducted by the EU Joint Research Centre[23].

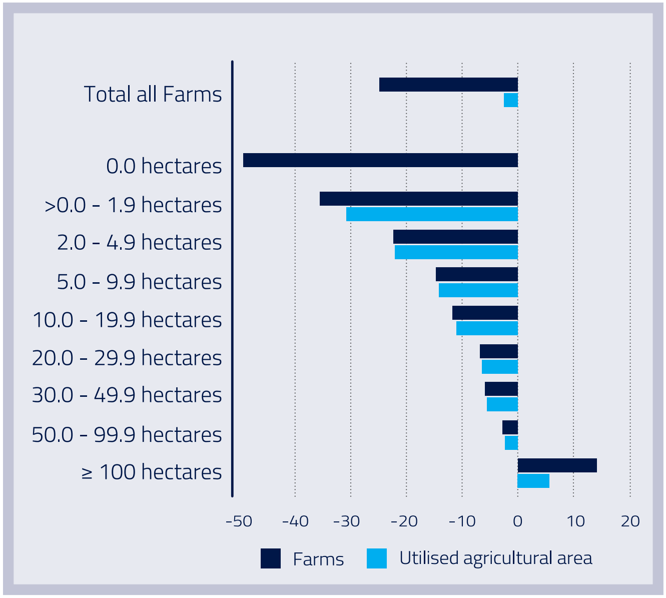

Figure 3 Overall change in farms and farmland by farm size (%), 2010-2020, Source: Eurostat, 2023

Despite these structural changes, the economic size of the EU farming sector has continuously grown in recent years. Agriculture contributes 1.7% to the EU GDP, but the shares for Agro-Food exports and imports are significantly larger. While the contribution of agriculture to EU GDP has remained relatively stable since 2000, the share of agriculture in the EU's exports has grown considerably during this period. The European Union is a net food exporter, with Agri-Food products accounting for 9.3% of all exports and 6.8% of all imports. Since 2013, the European Union has been the world's largest Agro-Food exporter and remains one of its largest importers. In 2023, the total standard output generated by the EU's agricultural industry was estimated at €537.1 billion. A little more than half (51.3%) of the total output value of the EU's agricultural industry in 2023 came from crops, estimated

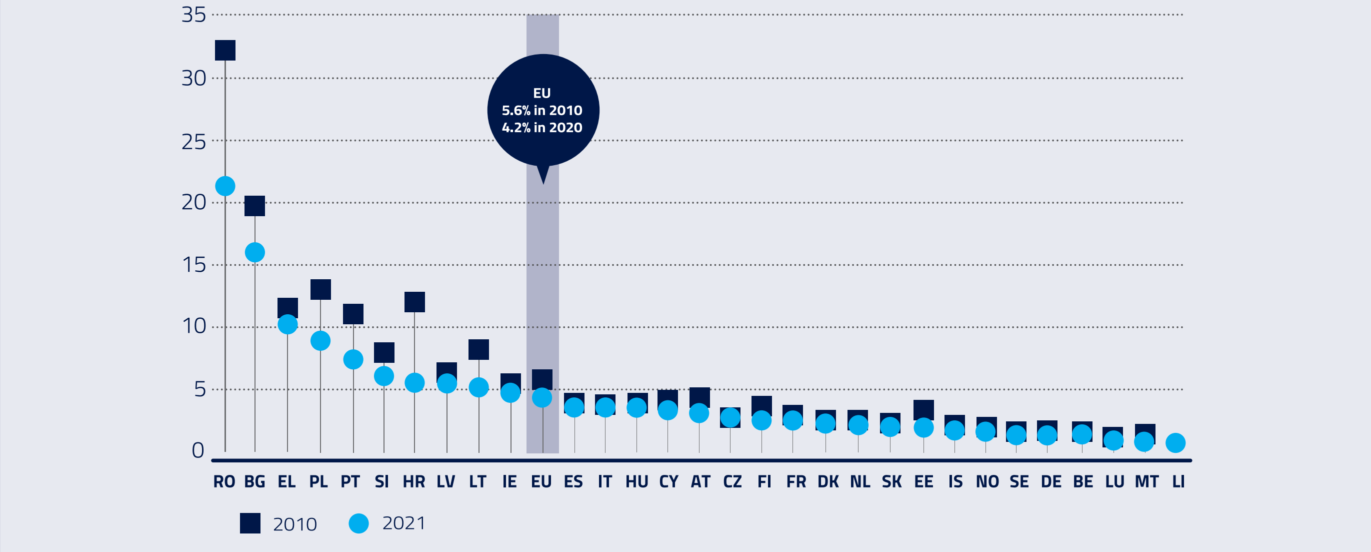

Figure 4 Employment in agriculture (% of total employment), 2010-2021, Source: Eurostat, 2023

at €275.8 billion. Within this category, vegetables, horticultural plants, and cereals were the most valuable crops. Almost two-fifths (39.8%) of the total output came from animals and animal products, estimated at €213.8 billion, with the majority from milk and pigs. Agricultural services, estimated at €24.8 billion, and inseparable non-agricultural activities, estimated at €22.8 billion, contributed the remaining 8.9%.

The gross value added by the EU's agricultural industry, representing the difference between the total value of its production and the costs of goods and services used in production, reached an estimated €225.6 billion in 2023. The gross value added generated by the EU's agricultural industry continued its upward trajectory. Despite a slight decrease (-1.5%) in the estimated value of intermediate goods and services compared to 2022, the unchanged value of agricultural output led to a moderate increase (+2.1%) in gross value added. This trend reflects a consistent rise in

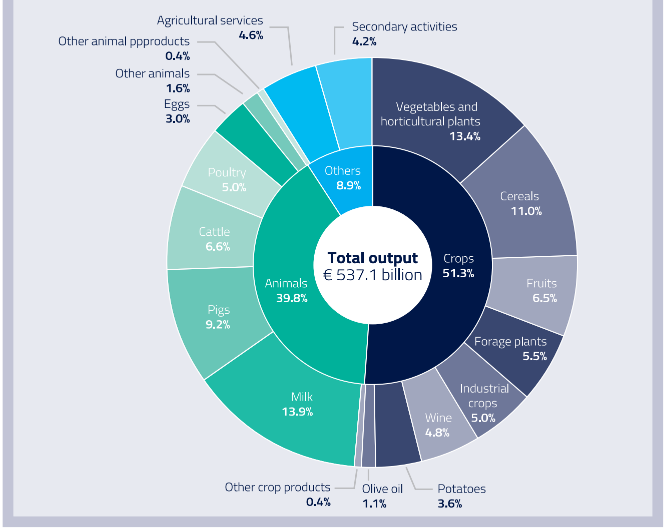

Figure 5 Output of the agricultural industry (% of total output), 2023, Source: Eurostat, 2023

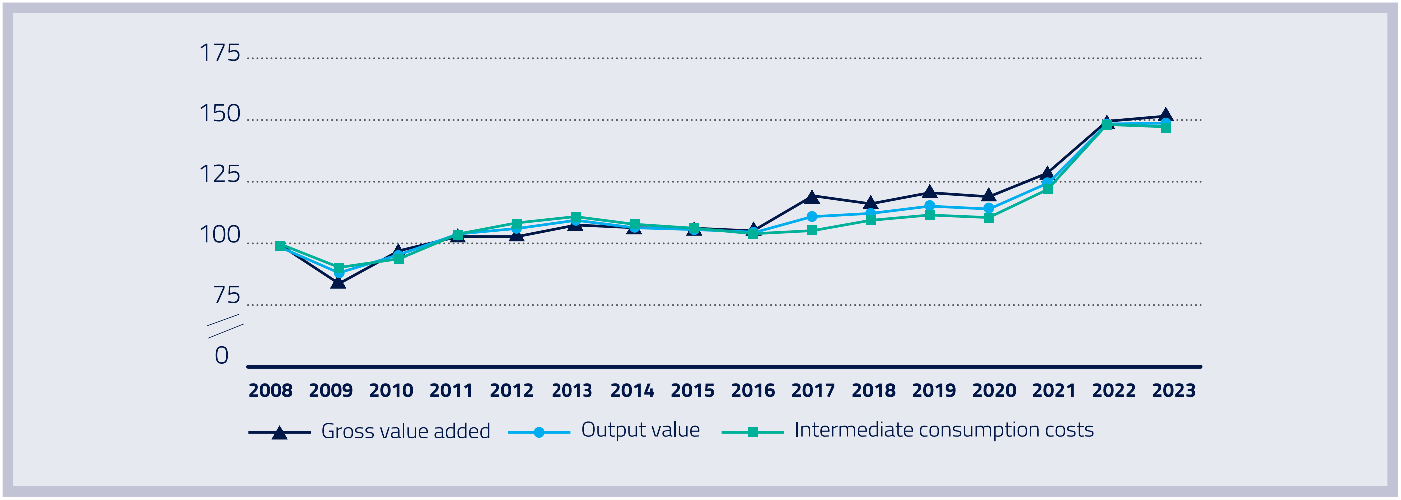

Figure 6 Developments in Gross Value Added, 2008-2023, Source: Eurostat, 2023

gross value added since 2010.

In recent years, as shown by a recent OECD publication[24], agricultural productivity in the EU has increased at a slower pace than in other OECD countries, while the environmental sustainability performance of the sector has not improved in line with expectations. A critical measure of the agricultural sector's efficiency and sustainability is the so-called Total Factor Productivity (TFP), which reflects the sector's ability to maximize output while minimizing negative environmental impacts. Historically, the European Union has shown commendable TFP performance since the 1980s, with annual growth rates ranging from 0.73% to 1.42%. However, between 2011 and 2019, global productivity growth slowed, though the EU's decline was less pronounced, hovering around the OECD average of 0.9% annually, slightly below the global average of 1.3%. Recent academic research2[5] estimates that about a 21% reduction in global agricultural TFP since 1961 is due to climate change, equivalent to losing seven years of productivity growth, highlighting regional disparities. Indeed, climate change poses significant challenges to agriculture, exacerbating climate variability and extreme weather events globally. In Europe, these changes have already impacted crop yields and livestock productivity and are expected to intensify production pressures[26].

Despite these challenges, the EU has managed to increase agricultural output over the past six decades without significantly expanding agricultural land. Continued productivity improvements are crucial to avoid further natural land conversion, offering substantial environmental benefits, particularly in reducing greenhouse gas emissions from land-use changes. However, the EU's long-term output growth has lagged behind other OECD countries and the global average, with modest TFP growth. Most TFP gains in the EU stem from enhanced labour productivity rather than substantial capital investments, unlike countries such as the United States. Despite progress[27], the OECD recent assessment of EU agricultural performance concludes that "Overall, the European Union has not succeeded in decoupling output growth from the use of variable inputs, which is critical in view of the F2F targets to reduce the absolute level of input use"[28].

Agricultural activities contribute significantly to diffuse air, soil, and water pollution, exacerbating the excessive exploitation of natural resources, ecosystem degradation, and biodiversity loss. In 2020, the EU agricultural sector directly emitted 383 million tonnes of CO2-equivalent greenhouse gases (GHGs), accounting for 11% of total GHG emissions in the European Union[29]. Methane emissions from livestock enteric fermentation and manure management constitute the largest share of these emissions (64.8% combined), with nitrous oxide releases from managed soils contributing substantially as well (31.2%). However, from 2000 to 2019, GHG emissions from the EU agricultural sector decreased by 7%, slightly less than the OECD average of 8%. Recent trends indicate slow progress, suggesting emissions levels are stabilizing rather than decreasing. While enhancing agricultural Total Factor Productivity (TFP) can reduce emissions intensity by improving the efficient use of inputs and minimizing emissions from land-use changes, TFP growth alone cannot fully address GHG emissions. The environmental impact of agriculture also depends on the inputs used. Nutrient balances per hectare, which measure the difference between applied nutrients and those absorbed by harvested plants, have shown a declining trend in the EU27 in recent years. Between 2000 and 2015, nitrogen balances decreased by 26%. In contrast, annual pesticide sales volume in the EU27 remained stable at around 360

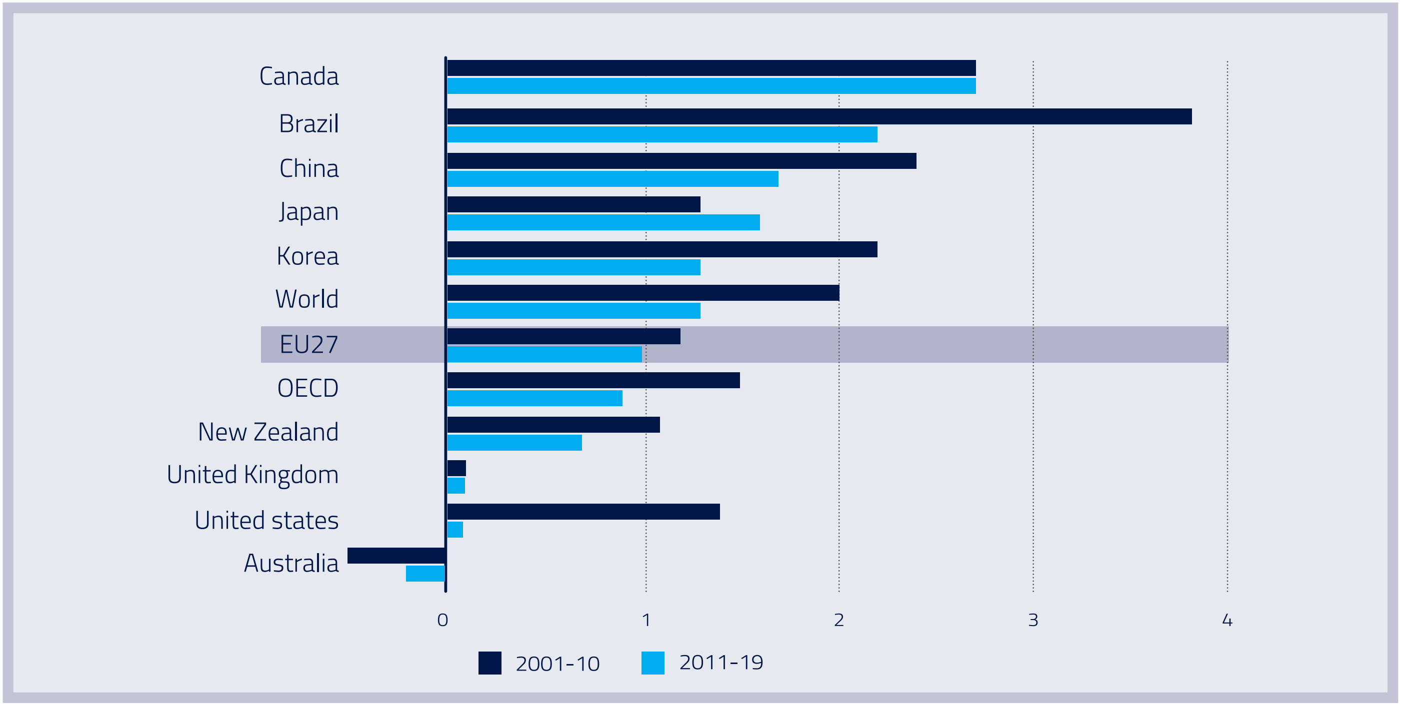

Figure 7 Total factor Productivity (TFP), average annual growth rate, Source: OECD, 2023

million kilograms from 2011 to 2020. Despite a decrease in sales of high-risk substances and progress reported by EFSA 2024 annual report[30], pesticide presence remains a concern for consumers and policymakers in the EU. Factors influencing pesticide sales include climatic conditions, farm profitability, and crop types. Transitioning to more sustainable use of pesticides faces challenges due to socio-technical barriers in high pesticide farming systems, as well as the slow approval process and insufficient farm advisory support for biopesticides and other biocontrol methods.

The trends outlined above show that the Agri-Food sector is navigating a critical phase, addressing the triple challenge of ensuring food security and nutrition, supporting livelihoods throughout the food chain, and enhancing environmental sustainability. Accomplishing these objectives has become increasingly complex amid mounting environmental concerns and successive global crises. Urgency in addressing climate and environmental issues necessitates swift action to transition EU agriculture and food systems. However, measures implemented by EU and national policymakers have sparked discontent within the sector. In early 2024, farmers staged widespread protests across several EU Member States, raising serious questions about the adequacy of EU agricultural policies[31]. Despite farmers accounting only for 4.2% of the EU workforce and contributing just 1.4% to the bloc's GDP, their protests resonated deeply in rural areas where concerns about distant policymakers and

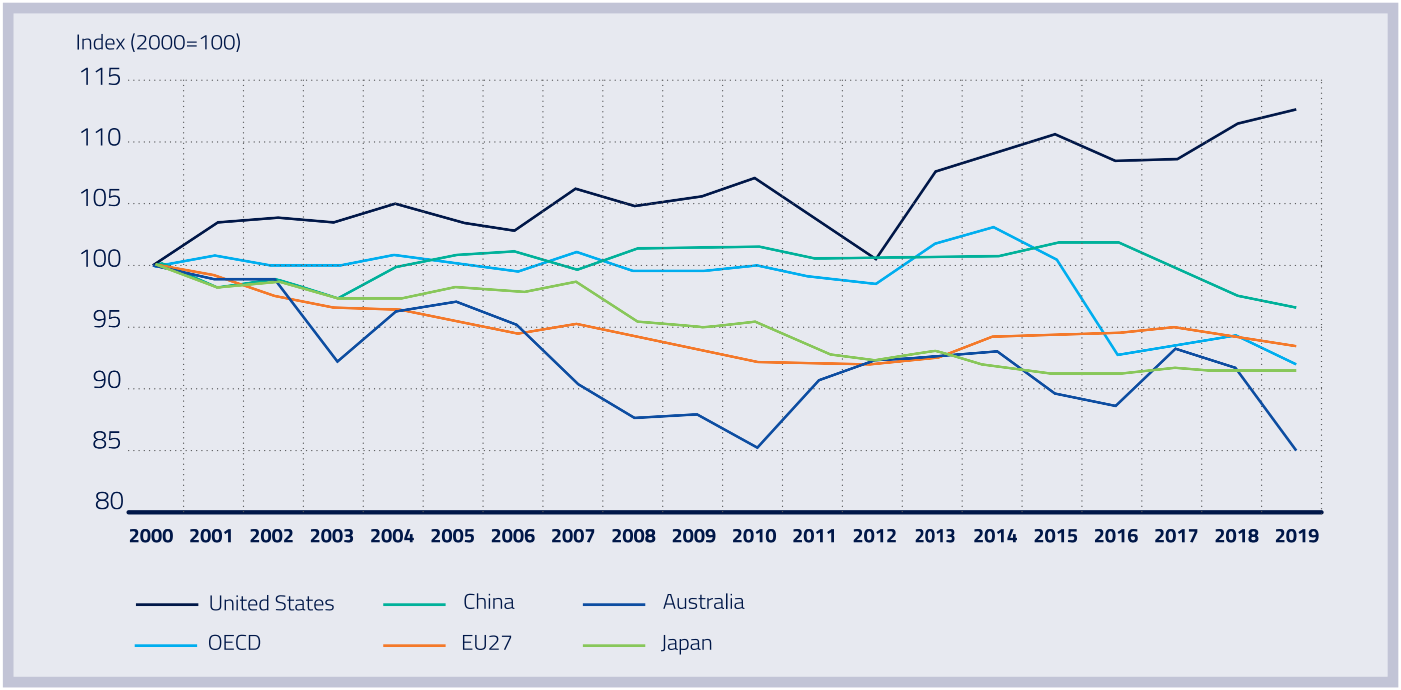

Figure 8 Greenhouse gas emissions trends from the agricultural sector in the EU and selected countries, 2000-2019, Source: OECD, 2022

cultural identity persist. For instance, A survey conducted in January 2024[32] showed that 87% of French citizens supported the farmers' cause. Although each country's protests had unique characteristics, common themes emerged. Farmers expressed dissatisfaction with low farm prices that undermine fair incomes, competition from imports not meeting European standards, and an increasingly burdensome regulatory framework especially with respect to new obligations to ensure environmental sustainability. Moreover, the Russian invasion of Ukraine underscored the critical role of domestic food production in ensuring EU food security, advocating for a rebalancing of priorities between production and environmental objectives.

- **Income.** Despite improvements in agricultural incomes relative to non-farm wages—from around 40% in the mid-2000s to about 60% recently—many farms still struggle. This improvement is largely due to farm consolidation rather than increased productivity. Record farm incomes in 2022, driven by higher output prices due to the Ukraine war, have since declined but remain above pre-war levels. Larger farms, representing 19% of all holdings, account for 77% of output and can sustain viable incomes, unlike many smaller farms. This productivity gap fuels ongoing consolidation, which, despite being necessary, causes frustration and resentment among farmers, exacerbating recent protests.

- **Environment.** The recent farmer protests highlighting the burden of environmental regulations coinciding with the introduction of new Common Agricultural Policy (CAP) regulations in January 2023. Although the CAP is primarily a subsidy policy, farmers receiving CAP payments must meet certain conditions, including legislative requirements and Good Agricultural and Environmental Condition (GAEC) standards. These standards, now more stringent than in the previous CAP, include protecting wetlands and peatlands (GAEC 2), implementing crop rotation (GAEC 7), and setting aside land for biodiversity (GAEC 8). The stricter requirements, combined with a reduction in direct payment support due to budget cuts and redistribution, have intensified farmer grievances.

- **Trade.** Farm protests have also centred on the issue of trade competition, with two main concerns. Central European countries bordering Ukraine, such as Poland, Hungary, Slovakia, and Romania, have opposed the "autonomous trade measures" introduced in June 2022, which liberalised Ukrainian agricultural imports. These imports, previously subject to tariffs, negatively impacted local prices, leading to unilateral bans by some countries and subsequent EU-imposed safeguard measures. Additionally, farmers across the EU argue that trade agreements favour imports from countries with lower standards, disadvantaging EU producers.

The farmer protests in early 2024 have led to significant political changes at the EU level, including a slowdown of the Green Deal agenda, relaxed environmental regulations in the CAP, and stricter controls on Ukrainian agricultural imports. The EU has responded with measures like temporary exemptions from certain GAEC standards. However, these measures may not satisfy the more militant protestors. The ongoing revisions to the CAP and the introduction of national measures, such as tax reliefs and financial aid, reflect a broader effort to address the agricultural sector's challenges and the administrative burdens faced by farmers.

EU agriculture will face numerous significant challenges in the coming years, including climate change, increasing energy demand, resource shortages, accelerated urbanisation, dietary changes, ageing rural populations, and intensified competition. Simultaneously, agriculture in Europe and other regions stands at a crucial crossroads. In this context, increasing digitalisation of agricultural practices may enable the production of plant and animal products with greater efficiency and reduced environmental impact.

AGRITECH AND FOOD-TECH POTENTIAL CONTRIBUTIONS AND TRENDS

Digitalisation is expected to radically transform everyday life and productive processes in agriculture and associated food, fibre, and bioenergy supply chains and systems, with initial signs of transformation already visible. In the agricultural sector, several concepts have emerged to express different forms of digitalization in agricultural production systems, value chains, and more broadly, food systems. These include Smart Farming, Precision Agriculture or Precision Farming, Decision Agriculture, Digital Agriculture or Agriculture 4.0[33]. Regardless of the exact term used, digitalisation implies that management tasks on-farm and off-farm (in the broader value chain and food system) focus on different sorts of data (on location, weather, behaviour, phytosanitary status, consumption, energy use, prices, and economic information, etc.), using sensors, machines, drones, and satellites to monitor animals, soil, water, plants, and humans. The data obtained is used to interpret the past and predict the future, to make more timely or accurate decisions, through constant monitoring or specific big data science inquiries. Another benefit of digital tools for farmers is the reduction of admin burden, especially via electronic record keeping.

In the several expressions that can be found, for this report it is important to clearly distinguish between AgriTech and FoodTech, as the analysis will focus on the former and the latter will be considered only marginally. AgriTech refers to the use of technology in agriculture, horticulture, and aquaculture to enhance yield, efficiency, and profitability. AgriTech includes a wide range of products, services, or applications designed to improve various input and output processes in farming and food production. These innovations can involve precision farming techniques, the use of drones and sensors for monitoring crops and livestock, automated machinery, and advanced breeding methods. AgriTech aims to optimize resource use, increase productivity, and reduce the environmental footprint of agricultural practices, contributing to more sustainable and resilient food systems. Instead, FoodTech can be defined as the intersection between food and technology, which extends beyond production to focus on processing agricultural products. FoodTech innovations might involve developing new food products, enhancing food safety and quality, optimising food processing methods, and creating sustainable packaging solutions. A commonality among different forms of Agriculture 4.0 and Food 4.0 is that many innovations originate from AgriTech and FoodTech start-ups, collectively referred to as 'AgriFoodTech' start-ups[34]. While technological development has been a constant in agriculture, the term 'Tech' has gained prominence recently, influenced by the ICT and Silicon Valley-related 'Tech revolution' spreading to sectors including agrifood[35]. AgriFoodTech start-ups are seen as new players in broader agricultural or agrifood innovation systems (AIS), aiming to foster new ways of innovating and creating cross-sectoral networks and alliances (e.g., between agriculture and energy, or agriculture and construction). Due to their potentially disruptive technological and economic approaches, they are viewed as catalysts for transforming food systems towards sustainability[36]. Though not the sole sources of innovation, Agriculture 4.0 technologies introduced by start-ups may promote more plant-based diets, reduce food waste, and optimize water, input, and energy use in agri-food systems, thereby contributing to a more sustainable production and consumption.

Proponents suggest that Agriculture 4.0 could have substantial positive sustainability impacts by increasing resource use efficiency, optimising local and global food markets, and preventing negative environmental spillovers, thereby enhancing food security and sustainability. For example, precision agriculture enables more optimal and timely applications of fertilizers and water, increasing resilience to climate change and maintaining yields[37]. Similarly, vertical farming is seen as a way to produce food close to urban populations and reduce food miles[38]. Additionally, alternative proteins such as plant-based or cellular meat offer a more efficient use of available land, enabling sufficient protein production for a growing world population[39]. We will focus on the first two examples: precision agriculture and vertical farming.

Precision Agriculture (PA) or Precision Farming is a modern farming management concept that uses digital techniques to monitor and optimise agricultural production processes. Precision Agriculture (PA) aims to increase the quantity and quality of agricultural output while reducing inputs such as water, energy, fertilisers, and pesticides. The goals are to save costs, minimise environmental impact, and produce more and better food. These methods primarily rely on a combination of new sensor technologies, satellite navigation, positioning technology, and the Internet of Things. Moreover, PA can help measure the environmental footprint of farming, facilitating farmers' compliance with good agricultural management standards, enhancing their role as public goods providers, and supporting fair remuneration for specific efforts. Agricultural data management and precision agriculture can also make farming more transparent by improving the processes of tracking, tracing, and documenting. The EU Joint Research Centre presented a comprehensive categorisation of Precision Agriculture Technologies (PAT), which includes three main types that encompass nearly all agricultural practices [40]:

1. Guidance Technologies: These are hardware and software systems that guide tractors and implements across fields. They include automatic steering and guidance systems for tractors and self-propelled agricultural machinery, such as driver assistance, machine guidance (MG), and controlled traffic farming. The latest RTK technology can provide centimetric precision.

2. Recording Technologies: These are sensors mounted on ground-based stations or mobile platforms like drones, airplanes, or satellites. They gather spatial information such as soil mapping, soil moisture mapping, canopy mapping, and yield mapping.

3. Mapping application Technologies: These include hardware and software that can vary the placement of agricultural inputs in the field. Examples include variable-rate irrigation, and variable-rate application technologies for nutrients, crop protection agents, irrigation, seeding, and precision weeding.

Combining these three categories of PAT aims to maintain or increase yields while improving yield quality and reducing environmental impact. All three categories rely on Global Navigation Satellite System (GNSS) technologies, which provide autonomous geospatial positioning with global coverage, enabling precise location tracking anywhere in the world. The same report empirically assesses the impact of Precision agriculture technology (PAT) on GHG emissions and farm economics [41]. The results of the environmental impact analysis showed that the introduction of PAT might have positive effects on the environment, with reductions in GHG emissions from the fertiliser application, fertiliser production and fuel use. The assessment focuses on two technologies: variable-rate nitrogen application technology (VRNT) and machine guidance (MG). The results show that the mitigation potential for MG ranges from 1513 to 2760 Ktonnes carbon dioxide equivalent (CO2-eq) per year. The mitigation potential range for VRNT varies from 3805 to 6567 Ktonnes CO2-eq per year. These potential GHG emission reductions represent 0.3–1.5 % of the total EU 2015 GHG emissions of the agriculture sector.

Vertical Farming (VF) is also becoming increasingly popular around the world due to its ability to efficiently manage resources and produce high-quality food. Vertical farming involves growing crops within structures such as skyscrapers or old warehouses, rather than in traditional soil. This method saves water and eliminates the need for soil. In a vertical farm, food production is not affected by weather or other natural factors. A wide variety of plant species can achieve optimal growth rates year-round in controlled environments, where light, humidity, and temperature are constantly monitored and adjusted. Closed growing systems prevent chemicals from entering the environment[42]. The concept of vertical farming has united experts in robotics, aeroponics, aquaponics, and hydroponics. It has garnered support from non-profit organisations aiming to improve the environment and boost local economies. For-profit ventures focused on meeting the demand for local produce have also embraced this idea. Additionally, governments seeking to enhance domestic food security have funded these initiatives. In areas where soil and water resources are limited, vertical farming could indeed play a significant role in the production of crops and vegetables. The number of vertical farms in Europe is still relatively small, but the sector is increasing rapidly[43].

Overall, the Global AgriTech market size was worth around USD 23.5 billion in 2022 and is predicted to grow to around USD 79.7 billion by 2030 with a compound annual growth rate (CAGR) of roughly 16.5% between 2023 and 2030[44]. This growth is driven by the widespread adoption of precision farming across various applications, particularly in data management. Internet-connected devices generate vast amounts of data that need analysis, and despite security and privacy concerns, these technologies enhance crop monitoring and harvesting efficiency. Furthermore, urbanization and industrialization are also contributing to market growth by improving connectivity among farmers through digitalisation. Farmers adopting IoT and cloud technologies are more likely to embrace new agricultural ecosystems. As already mentioned, AgriTech encompasses a range of elements, including agribusiness marketplaces, biotechnology, bioenergy & biomaterials, sensing & IoT, farm management software, farm robotics, midstream technologies, and novel farming methods. Significant investments are being made in agricultural biotechnology, new farming and farm management systems, sensing devices, and IoT gadgets. The rise in AgriTech businesses and the increased adoption of sensor-based technologies further drive these investments and contribute to market expansion.

In this sector, innovations generated by start-ups are playing a pivotal role. These start-ups are leveraging cutting-edge technologies to address pressing challenges in agriculture, such as improving crop yields, reducing resource consumption, and enhancing sustainability. Among the top 25 funded European AgriTech start-ups, we have selectively identified some notable cases that exemplify the sector's dynamic and transformative potential.

Over the past decade, countless start-ups have benefited from a venture capital (VC) market that has experienced steady growth in both the amount invested and deals completed. This increased level of funding was particularly transformative within the Agri-tech sector. In fact, approximately 20 times more capital was invested in new Agri-tech ventures in 2021 compared to 2012, while VC investment in the overall market grew approximately 11 times over the same period. However, AgriTech investment saw a sharp decline toward the end of 2021, with the overall VC market following suit shortly thereafter[52]. Although overall investment levels remain significantly higher than they were ten years ago, these recent declines raise several questions for start-ups and investors, especially given the broader market uncertainty.

According to a recently published report by AgFunder[53], in 2024 investment in AgriFoodTech startups has reached its lowest point in six years, plummeting nearly 50% from 2022 to 2023 due to fewer and smaller deals. This decline is more significant than the 35% year-over-year drop seen across venture capital markets. AgriFoodTech funding has decreased as a share of global venture capital, with generalist investors—who previously drove billion-dollar-plus valuations in categories like alternative protein and vertical farming—now exiting the sector. In 2023, AgriFoodTech accounted for just 5.5% of VC dollars across all sectors, compared to 6.7% in 2022 and 7.6% in 2021. The decline is global, particularly for Asia, which did not recover its pre-Covid totals and raised only $3.8 billion, and the US, which saw its share of AgriFoodTech funding drop to just 30% of global funding when it usually accounts for at least 40%.

However, the most recent VC data highlights a few bright spots. While funding to most categories declined, two sectors—Bioenergy & Biomaterials and Farm Robotics, Mechanization & Equipment—

Start-up	Location	Total funding [45]	Description
Infarm [46]	Germany	$ 604,5M	The largest vertical farming company in Europe, Infarm builds and distributes efficient vertical farms throughout cities. Infarm combines efficient vertical farms with IoT technologies and Machine Learning, to offer an alternative food system that is resilient, transparent, and affordable. The company distributes its smart modular farms throughout the urban environment to grow fresh produce for the city's inhabitants.
Ecorobotix[47]	Switzerland	$ 81,1M	ecoRobotix develops autonomous robots for ecological weeding of row crops, meadows, and intercropping cultures. The robot covers the ground by getting its bearings and positioning itself with the help of its camera, GPS RTK, and sensors. Its system of vision enables it to follow crop rows and to detect the presence and position of weeds in and between the rows. Two robotic arms then apply a microdose of herbicide, systematically targeting the weeds that have been detected.
Biotalys [48]	Belgium	$ 77,6M	Biotalys is a company protecting crops and food with proprietary protein-based biocontrol solutions and aiming to provide alternatives to conventional chemical pesticides for a more sustainable and safer food supply. Based on its novel AGROBODY™ technology platform, Biotalys is developing a strong and diverse pipeline of effective product candidates with a favorable safety profile that aim to address key crop pests and diseases across the whole value chain, from soil to plate.
Agreena[49]	Denmark	$ 77,4M	Agreena is the creator of a soil carbon platform with the goal of scaling regenerative agriculture through finance and technology. The company verifies, mints, and sells carbon credits generated by farmers, issues third-party verified carbon certificates, and develops software that uses ground-truth data, satellites, artificial intelligence, anddeep tech to enable scalable detection of key metrics, including regenerative agriculture principles, providing clients with both finance and scientific technology solutions to accelerate the global transition to regenerative agriculture and allowing farmers to increase their yields.
Robovision[50]	Belgium	$ 60,7M	Robovision serves as the adaptive engine and central platform for image-to-action AI solutions, allowing seamless AI integration into dynamic environments without the need for specialized AI expertise. It operates both in the cloud and on the edge, offering users a comprehensive control center for their AI vision technology. The initial traction Robovision gained was in agtech, which represents most of its activities. The company focuses on what it describes as "impact agrifood."
Solynta [51]	Netherlands	$ 39,6M	Solynta is a breeding and biotechnology company based in Wageningen, the Netherlands – the hometown of one of the leading agricultural research institutions in the world. The company develops and applies new breeding technologies to convert potatoes into a hybrid crop. Hybrid potato varieties with superior traits and performance are being generated at a speed that is vastly greater than what can be achieved by traditional breeding. In addition, hybrid potatoes will allow sexual seed propagation, greatly enhancing the speed of product developments and providing tremendous logistical and phytosanitary advantages to the potato industry.

Table 1 Selection of successful European AgriTech startups

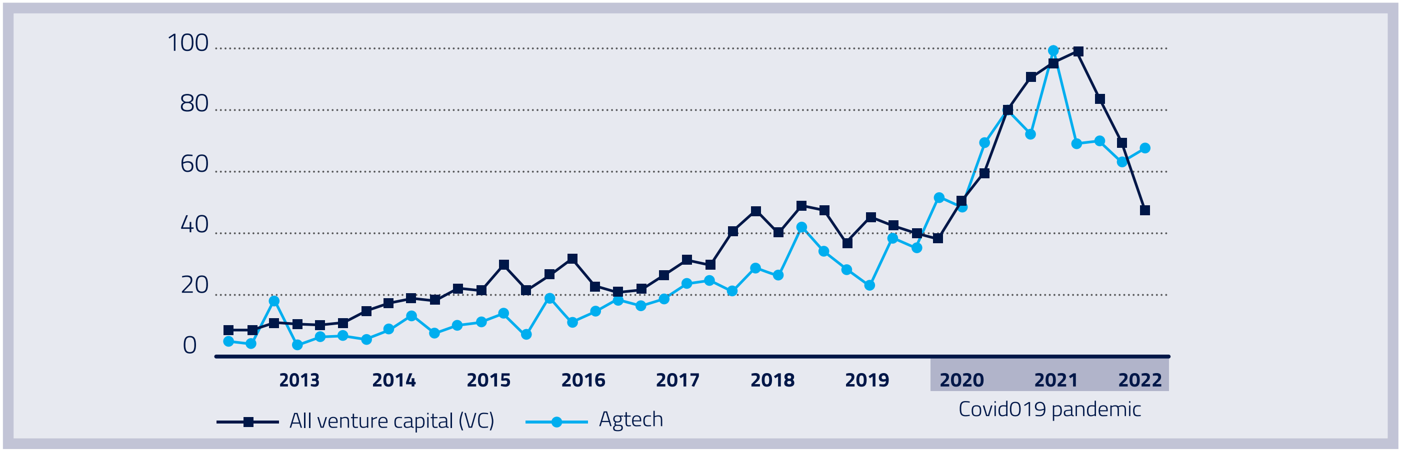

Figure 9 Quarterly investment activity normalized (%) to maximum quarterly value observed, Source: McKinsey, 2022

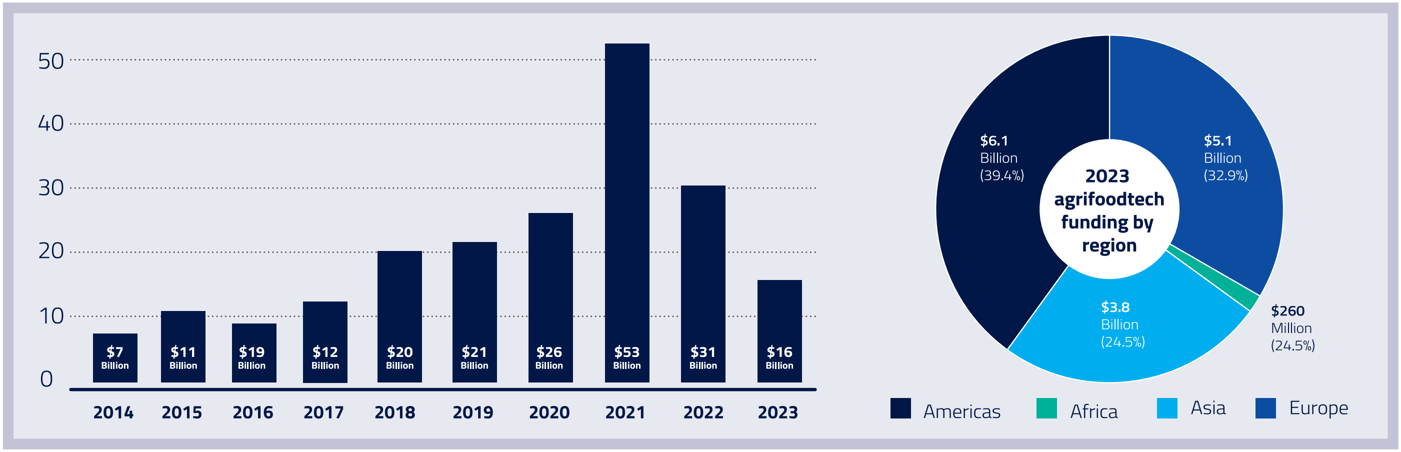

Figure 10 Global trends in AgriFoodTech investments , Source: Crunchbase.com

saw increases. Notably, funding to upstream startups, which operate on the farm or in food production, rose significantly, accounting for 62% of overall investment dollars in 2023, up from 51% in 2022 and 30% in 2021. This is significant because upstream sectors are often at the forefront of innovations tackling climate change, metabolic illnesses, food insecurity, and agrifood system inequalities. Additionally, the Farm Robotics, Mechanization & Equipment category, which includes more than just weeding robots and autonomous tractors, grew in 2023, continuing its steady upward trajectory with a 9% year-over-year increase to $769 million.

Despite the growth of the AgriTech sector, driven by innovations in precision agriculture, biotechnology, IoT, and robotics, in the EU advancement, applicability and acceptance of these technologies is fragmented and varies considerably[54]. It suffices to consider the issue of connectivity (and the related one of digital skills) to grasp how technological adoption in agriculture is very diverse and find barriers. The earlier cited Commission Communication on a long-term vision for rural areas, underscores how digital connectivity is one of the key elements for balanced development and economic prosperity of such areas [55]. But the same communication stresses that despite recent efforts in high-speed broadband connectivity, only 59% of households in rural regions have access to next generation access (NGA) broadband (>30Mbps), compared to 87% of the households in the EU[56]. To close the gap there is the need to mobilise private-sector investments[57].

More generally, there are still several challenges and barriers to widespread adoption. These challenges span technical, financial, legal, and societal dimensions, affecting various technologies within the AgriTech industry.

1. Financial Challenges

- High Costs of Equipment: precision agriculture involves the use of expensive machinery and equipment, representing significant up-front investment costs for farmers. Financial constraints and limited access to credit make it difficult for many farmers to invest in precision agriculture technologies.
- Return on Investment: uncertainty around the potential positive economic effects and the possibility of recovering this investment creates a significant barrier to adoption, especially for those farmers with lower incomes, who are less able to afford the technology.
- Small farm size: larger farms have a greater capacity to adopt these technologies, because they might be looking for increasing economies of scale. Larger farm size tends to be related to greater production potential and control of resources and therefore those farmers who own larger farms might be better situated to bear the risk of adopting PAT.

2. Legal and Data Ownership Challenges

- Data Ownership and Privacy: ensuring effective data ownership and addressing privacy concerns in the context of big data are critical challenges. In 2018 the EU Code of Conduct of Agricultural Data Sharing by Contractual Agreement (EUCC) was signed by several association and published. According to this voluntary initiative farmers own the data generated on their fields. A recent review article[58] pointed out that, however, there is still limited evidence as to how this document has been received and implemented and it is yet to be seen what the implications of the Data Act (DA, adopted in 2024) will be. The DA regulation does not address data ownership but rather rights to access and share data. Importantly, as put by the authors of the cited article: "It is thus essential to determine if the EUCC may still play a significant role to address sector-specific issues in line with the horizontal rules of the Data Act"[59]. So, the increasing volume of data still necessitates a clear understanding of data ownership and privacy issues.
- Legal Compliance: in the EU, a major legal challenge involves processing large volumes of agronomic data and using decision algorithms, which is crucial for farmers and farm organizations.

3. Societal and Market Challenges

- One of the most relevant barrier for technology adoption is the educational challenge, as many farmers do not possess the required digital skills to manage IT solutions. This is closely linked to the ageing of European farmers and the lack of young graduates joining the agricultural sector.
- Food Security and Employment: The impact of precision agriculture on food security and agricultural employment needs careful consideration. While these technologies can improve efficiency, they may also reduce the need for labour. Digitalisation could alter occupational roles and identities

of agricultural stakeholders who are heavily governed by agricultural policy (such as farmers)[60].

- Market Consolidation: the growing consolidation of companies delivering precision agriculture technologies is a significant societal challenge. As these companies become larger and fewer in number, monopolies may emerge, concentrating data and control in the hands of a few big players. This limits price negotiation for technologies and services, and dependency, control, and unfair practices could threaten farmers' viability.

4. Technical Challenges

- Data Management and Quality: precision agriculture generates vast amounts of data, including field-specific information on planting, crop-input choices, management strategies, and harvesting practices. Managing this data, ensuring its quality, and processing it intelligently are challenging due to the volume and heterogeneity of the data.
- Interoperability: the lack of interoperability standards and technical protocols that allow communication between machinery and tools poses a significant challenge. The inability of different systems to exchange data seamlessly limits the effectiveness of precision agriculture technologies.
- Broadband and Connectivity: Rural areas often lack the necessary broadband infrastructure, leading to connectivity issues with devices such as tractors, computers, and satellite photography equipment.

Among the various challenges reviewed, two are worth considering a bit further, the risk of concentration and the issue of data ownership. Digital farming is suited for large-scale production and run the risk of excluding small- and medium-scale farmers, together with increased automation, this could further erode the autonomy of peasants and small-scale producers[61]. This is the more relevant when one considers that the market for farm machinery is dominated by 5 major players: CNH Industrial (UK/ Netherlands), Claas (Germany), Deere & Co (USA), AGCO (USA) and Kubota (Japan)[62]. As expected, all are active proponents of digital farming in Europe and use their market power to lobby for EU support[63] . They are also all active in the European Agriculture Machinery Association (CEMA). CEMA has called for direct CAP support measures and wider EU research funding for digital and precision technologies, as well as investments in rural broadband and digital training for farmers and advisors[64]. CEMA is also pushing for deregulation of the sector, claiming that regulatory costs are a significant barrier to providing cheaper technologies[65]. Yara is the dominant player in the EU fertiliser market. They have invested significantly in digital farming devices and are now teaming up with ICT giant IBM to develop a digital farming platform[66] . In 2017, they also acquired Adapt-N, a precision software fully integrated with John Deere equipment[67]. Asset management firms, financial institutions, commodity traders, and seed and agrochemical giants, as well as new players such as Google[68] and Microsoft[69], are all keen to cash in on what is essentially a new revenue stream. They thus play a key role in pushing the big data-driven digital farming agenda in Europe.

Digital farming has the potential to produce large amount of data, data produced by many single farmers could be aggregated and analysed by advanced machine learning and other types of algorithms. The risk is that the emerging data platforms will be typically owned and controlled by large corporations, or potentially governments[70]. This brings us back to one statement made in the introduction on how digitalisation of farming could be beneficial to policy making and, in particular, policy monitoring. It emerges that remote sensing and integration of digital databases can improve policy monitoring making it simpler. Using existing EU satellite services, such as Copernicus and Galileo, Member States could monitor farmers' compliance with income support conditions remotely[71]. The European Union (EU), for example, already uses satellite-based earth observation for agricultural area and subsidy monitoring to reduce costly on-the-spot controls, which artificial intelligence can complement[72]. Because the aggregation of data allows it to be transformed into a valuable commodity, agribusinesses, IT companies and financial institutions all find the emergence of big data in agriculture an attractive prospect. Big data services are being set up so that farmers lose ownership rights over their data once it is aggregated, allowing corporations alone to reap the profits[73]. This has left many farmers sceptical about the benefits they can gain by signing up to such platforms[74]. Once data is privatised in this way, it is known as proprietary data or data exploitation. Therefore, issues concerning data ethics[75] and data sharing[76] are potentially problematic in digital farming, making it unattractive for farmers if they totally lose control over their own data.

Overall, the benefits and downsides of digitalisation for agricultural policy seem highly contingent on technologies and institutions and the capabilities of the actors involved[77]. Addressing these challenges requires a concerted effort from stakeholders across the AgriTech sector, including farmers, technology providers, policymakers, and researchers, to ensure the sustainable and equitable growth of precision agriculture and other AgriTech innovations.

However, it should be noted that that the promises of the AgriTech sector to make farms more profitable, efficient, safe, and environmentally friendly are not without caveats. Indeed, precision agriculture and digitisation are not panaceas for all farming challenges. Precision farming's gradual application should not replace measures to protect and foster biodiversity. While PA might indirectly influence land parcels and landscapes, measures to protect biodiversity through agro-ecological principles must continue or even be enhanced. Furthermore, critics argue that AgriTech may perpetuate reliance on fossil fuels and non-renewable resources, concentrating supply chains in a few powerful firms[78]. Alternatives like agroecology, focusing on holistic and regenerative approaches, and promoting plant-based diets not based on industrialised alternatives, such as vegetarianism and veganism, are advocated by some[79]. In this context, increasing hybrid forms like 'digital agroecology' are being proposed, combining digital agriculture with agroecology. For instance, specialised manufacturers, such as Pixelfarming Robotics[80] and the Small Robot Company[81], are targeting small-scale farmers and digital agroecology. In this respect it must be noted that Digital and precision tools can be used by all types of production models, such as conventional, organic, regenerative, agroecology etc.[82].

THE POLICY LANDSCAPE

Digitalisation, particularly the twin transitions towards a digital and green economy, is a priority on the EU agenda. This is evident across various strategic documents under the European Green Deal and the European Commission's initiative "A Europe Fit for the Digital Age." Multiple policy instruments across different governance levels promote the adoption and effective deployment of digital technologies in agriculture and rural areas. This includes, for instance, the Farm to Fork (F2F) Strategy, the Organic Action Plan, the European Strategy for Data, and the Long-term Vision for Rural Areas, which includes a flagship on "rural digital futures" and actions to continue supporting digitalisation of agriculture in its action plan. The Common Agricultural Policy (CAP) includes tools to harness digital technologies to enhance sustainability, competitiveness, and quality of life. Other EU programmes like the Digital Europe Programme (DIGITAL) aim to bring digital technology to businesses, citizens, and public administrations. Horizon Europe supports research for digitalisation of agriculture, forestry and rural areas[83], and through the Soil mission it funded additional initiatives to support digital and data technology in agriculture[84]. The European Innovation Council (EIC) as launched the "EIC Accelerator Challenge: Novel technologies for resilient agriculture"[85].

Moreover, a cross-sectoral approach to digital transformation is supported by legal initiatives to improve data use and reuse, such as the EU Data Governance Act. Other significant data-related initiatives include the stakeholder code of conduct on agricultural data sharing[86], which provides guidance on data use, defines roles in data sharing, and sets principles for privacy, security, and liability. Additionally, Horizon Europe may support further data-related initiatives. The European Commission emphasises that data and digital tools in agriculture are interdependent. Effective implementation of digital tools relies on improved data collection, harmonisation, and management. Enhancing digital components within Agricultural Knowledge and Innovation Systems (AKIS) can improve farmers' ability to analyse business models and performance, increasing their willingness to provide data crucial for maximising technology effectiveness.

Among the several initiatives mentioned, the most relevant one is the Common Agricultural Policy (CAP), which has been the European Union's agricultural policy framework since its institution in 1962. Since then, the Common Market has become larger and more diversified, but environmental and societal concerns around agricultural production practices and food processes have become more prominent in the policy debate. The CAP is organised into two pillars. Pillar 1 finances direct payments to farmers as income support as well as some market measures and is fully funded by the European Union through the European Agricultural Guarantee Fund (EAGF). Pillar 2 finances rural development activities, including structural measures and agri-environment-climate schemes through the European Agricultural Fund for Rural

Area	Activity	Ambition 2030
Climate	▪ Total greenhouse gas emissions reduction (European Climate Law) ▪ Carbon farming initiative (Farm to Fork [F2F]Strategy)	▪ 50-55% emissions reduction compared with1990 levels ▪ Regulatory framework to be developed to certify carbon removals
Waters, soil and air quality	Reduce nutrient loss and fertiliser use (F2F Strategy)	Reduce fertiliser use by at least 20% and reduce losses of nitrogen and phosphorus by at least 50%
Biodiversity	▪ Increase organic farming(Biodiversity Strategy) ▪ Restore habitat (Biodiversity Strategy)	▪ At least 25% of agricultural land under organic farming by 2030 ▪ At least10% of agricultural area under high diversityl andscape features
Health and pollution	▪ Reduce antimicrobial use (F2F Strategy) ▪ Reduce pesticide use and related risks(F2F Strategy)	▪ Reduce overall EU sales of antimicrobials for farmed animals by 50% ▪ Reduce the overall use and risk of chemical pesticides by 50% and the use of more hazardous pesticides by 50% by 2030
Animal welfare	Improve animal welfare standards (F2F Strategy)	Evaluate and revise existing animal welfare legislation
Resource use	▪ Reduce food waste (Circular Economy and F2F Strategies) ▪ Encourage water reuse in agriculture (Circular Economy) ▪ Develop an Integrated Nutrient Management Plan (Circular Economy and F2F Strategies)	▪ Existing target to halve per capita food waste at retail and consumer levels by 2030. The new proposal will cover food waste along the entire food value chain ▪ Water Reuse Regulations setting minimum requirements for water reuse in agricultural irrigation will enter into force in June 2023 ▪ Ensure more sustainable application of nutrients and stimulating the markets for recovered nutrients, linked to the objective of reduced chemical fertiliser use

Table 2 Main targets and actions relevant to farming in the European Green Deal, Source: OECD, 2022

Development (EAFRD), but requires co-financing by Member States. The current CAP for 2023-2027 was negotiated under a restrictive budget context, partly due to the departure of the UK, and partly due to the increasing importance of other priorities the EU aimed to fund. During these negotiations, the Commission published the Communication on the European Green Deal in 2019. The implications for agriculture were detailed in the Farm to Fork (F2F) Strategy, released in the spring of 2020, which aims to accelerate the transition to a fair, healthy, and environmentally friendly food system. This was accompanied by a Biodiversity Strategy, addressing agricultural land use and environmental impact. Additionally, agriculture is impacted by other EU legislative initiatives linked to the European Green Deal, including the European Climate Law, the new Circular Economy Action Plan, and the updated EU Bioeconomy Strategy. These ambitions and new targets have been integrated into the reformed CAP.

A key objective of the CAP 2023-27 is to modernise agriculture and rural areas through fostering and sharing knowledge, innovation, and digitalisation. The CAP promotes a comprehensive approach towards digitalisation for agriculture and rural areas, not only at the farm level but also for the modernisation of the administration. For the first time, EU countries have designed digitalisation strategies as part of their CAP Strategic Plans, facilitating the advancement of digitalisation in agriculture and rural areas. Building on the portfolio of CAP measures at their disposal, EU countries strategically promote digitalisation, focusing on critical areas such as infrastructure, training, skills development, and the uptake of advanced technologies, including precision farming. The CAP tools for digitalisation include investments in broadband and digital technologies for agriculture, forestry, and rural areas, such as precision farming and smart villages[87]:

- Investments, for instance for broadband or the installation of digital technologies in agriculture, forestry, and rural areas, such as investments in precision farming, smart villages, rural businesses, and information and communications technology infrastructures like broadband.
- Eco-schemes and agri-environment-climate commitments to support precision farming technologies optimising input use.
- Sectoral interventions to purchase digital technologies at any stage of the supply chain, including knowledge exchange or monitoring of products' quality.
- Farm advisory services on digital aspects in agriculture and rural areas, including the use of a Farm Sustainability Tool for Nutrients.
- Cooperation to prepare and implement EIP operational groups, local development, and Smart Village strategies, as determined by EU countries.
- Knowledge exchange and information: support training for digital skills, increase awareness and knowledge on digital technologies, and promote exchange of experiences with digital technologies (e.g. demonstration farms).

Overall, more than 274 000 farms are to be supported by digital farming technology to better adapt to new technical developments[88]. Eco-schemes and agri-environment-climate commitments support precision farming technologies to optimise input use[89]. Sectoral interventions facilitate purchasing digital technologies across the supply chain, including knowledge exchange and product quality monitoring. Farm advisory services provide guidance on digital aspects, including the Farm Sustainability Tool for Nutrients. Cooperation efforts focus on implementing EIP operational groups, local development, and Smart Village strategies[90]. Additionally, the CAP promotes knowledge exchange and training for digital skills, aiming to support over 274,000 farms in adapting to new technical developments.

An important development is the integration of the agricultural knowledge and innovation systems (AKIS) into the CAP Strategic Plans (CSP) as from 2023[91], although The resources devoted to agricultural knowledge and innovation systems (AKIS) - through Horizon Europe and the CAP - are limited compared to the total support provided to the sector. Although the European Innovation

Partnership for Agricultural Productivity and Sustainability is an important initiative and investment in AKIS and digital technologies has high potential to make enhanced productivity and environmental sustainability mutually compatible, investment in and adoption of innovation remains a challenge. The complexity of the EU AKIS is partly due to the existence of 27 national AKIS and their regional AKISs, with their set of actors and initiatives operating at the EU level within a single European common knowledge and innovation area. Each EU Member State has developed an individual AKIS that corresponds to its particular situation, actors and needs and is embedded in national laws, institutions and cultures.

The new delivery model for the CAP 2023-2027 introduces significant governance changes, aligning with the European Green Deal's environmental goals. CAP 2023-2027 aims to help the agriculture sector meet the EU's sustainability targets, but its success depends on Member States' efforts. A key change is the shift of policy design and implementation responsibility to Member States, who must present CAP National Strategic Plans (CSP). The EU sets basic policy parameters, while Member States are accountable for achieving targets, moving from a compliance-based to a performance-based CAP. The main challenge is ensuring effective implementation at the farm level, depending on governance structures, improved monitoring, evaluation systems, and data availability. Farm-level data is crucial for policy impact assessment but is hindered by confidentiality and a lack of harmonized definitions. The European Commission publishes extensive CAP data on the Agri-food Portal with interactive tools. Challenges persist in data availability and regulatory obstacles like the General Data Protection Regulation, complicate data sharing.

The European Commission approaches both data and digital tools in agriculture in parallel, highlighting that the former relies on the latter. The development and implementation of these digital tools depend on improved data collection, harmonization, and management. Enhancing digital components can empower farmers to analyse business models and performance more effectively, thereby increasing their willingness to supply the necessary data to optimize these technologies. The vast amount of data generated by digital activities holds significant potential for economic growth and addressing societal challenges. The European data strategy aims to create a single market for data, promoting competitiveness and data sovereignty. It encourages data altruism, especially for Internet-of-Things-generated data, which is key for advanced farming technologies like precision farming. In this context, the Data Governance Act and the Data Act propose regulations to determine data usage and access rules, aimed at increasing data availability. By stimulating competition and innovation, this Act opens new avenues for services reliant on data access and enhances access to device-generated data. Furthermore, the Data Governance Act addresses information asymmetry in the EU farming sector. It aims to regulate the transfer of data from farm machinery to manufacturers, ensuring fair use of farm performance data to prevent any disadvantages to farmers.

As part of the European Data Strategy, the European Commission announced plans for a common European agricultural data space to facilitate trustworthy data pooling and sharing between private stakeholders and public authorities. This data space aims to create a secure and trusted environment for the farming sector to share and access data, enhancing economic and environmental performance. By integrating production data with publicly held data, this initiative opens up new opportunities for monitoring and optimizing the use of natural resources, aligning with the objectives of the Green Deal and the Common Agricultural Policy. The AgriDataSpace project[92] aims to establish a European data space for agriculture that supports data sharing, processing, and analysis. The project consortium comprises experts from research institutes, agriculture data intermediaries, and industry associations across 10 countries. These experts will collaborate with stakeholders to map the current data-sharing landscape, analyse governance and business models, and define a technical reference architecture for implementing the EU agricultural data space.

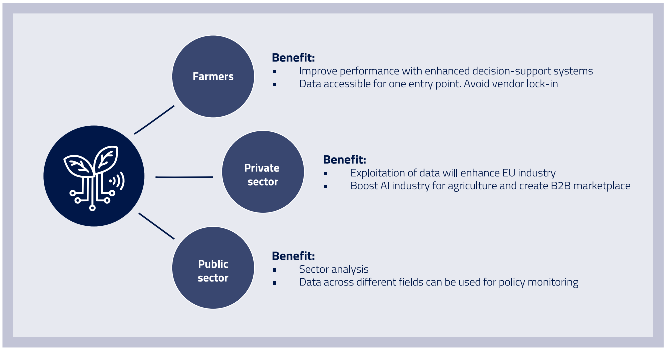

Figure 11 The common European agricultural data space, Source: European Commission

As anticipated, the EU supports research and innovation on agricultural and rural digital transformation also through Horizon Europe and the Digital Europe Programme, which are pivotal in providing innovative digital solutions while also empowering farmers to effectively utilise these technologies. These ongoing research projects and initiatives collectively form the cornerstone of the EU's digital agricultural transition, driving sustainability, competitiveness, and progress in the sector. Other relevant initiatives are the AgrifoodTEF[93], the Digital innovation hubs, and the 'European Innovation Partnership for Agricultural productivity and sustainability' (EIP-AGRI)[94]. Partnerships and EU missions also help maximise the adoption and development of digital transformation in agriculture and rural areas. Funding from Horizon Europe and the Digital Programme with example of projects are reported in the AgriResearch Factsheet[95]. The future of farming is being shaped by ongoing research, innovation, and capacity building in the agri-food sector, supported by various EU funding initiatives. These efforts are crucial for developing and implementing cutting-edge technologies such as AI, IoT, robotics, and digital platforms, which are transforming agriculture and fostering a more sustainable and efficient food system. Horizon Europe plays a pivotal role in advancing sustainable and inclusive food systems, as substantial funding is allocated to projects focusing on food, bioeconomy, natural resources, agriculture, fisheries, aquaculture, and the environment. This includes initiatives under the topics of data sharing, big data effects, and real-time sensor data upscaling for EU-wide monitoring of production and agri-environmental conditions. Through Horizon 2020, more than €200 million for Research and Innovation (R&I) were allocated to the deployment of digital technologies for the agricultural sector. The specific activities supported under Horizon 2020 included the development of smart farming systems, digital solutions for precision agriculture, and the integration of digital technologies into the entire agricultural value chain. Furthermore, the Digital Europe Programme (DIGITAL) provides a comprehensive approach to fostering innovation and digital transformation in agriculture. It aims to enhance the economic and environmental performance of the sector while optimising natural resource utilisation and contributing to Green Deal and CAP objectives. Other instruments include:

- The TEF (Testing and Experimentation Facility), an example of which is AgriFoodTEF[96] a network of test and validation infrastructures in Europe that supports Agri-Food technology companies to do near product development of their AI and Robotics solutions in real-world facilities.
- The EDHI (European Digital Innovation Hubs Network) that, for instance, support the project DigiAgriFood, which aims to empower the digital and green transformation of the entire spectrum of the Agri-Food value chain with immediate benefits for citizens, SMEs and public sector. It specializes in Artificial Intelligence technologies, Advanced Digital Skills, High Performance Computing and Digital Transformation and Interoperability and contributes directly to the missions and objectives of the "Digital Europe 2021-2027" program[97].
- The EDIC (European Digital Infrastructure Consortium)[98], which is an instrument made available to Member States under the Digital Decade Policy Programme 2030 to speed up and simplify the setup and implementation of multi-country projects.

In her speech to the European Parliament before the vote of confirmation for her second mandate on July 18, 2024, Ursula von der Leyen announced that her Commission will stick to the target of the Green Deal and that in the first 100 days she will present a new 'a new Clean Industrial Deal'[99].

Yet, the future implementation by the new Commission of this policy and of the others reviewed in this section, and in particular of the CAP in general and of its digital transformation components will have to deal with several challenges to which we come back in the conclusions of this report.

SCENARIOS

MAIN AREAS OF UNCERTAINTIES

To identify and select the main dimensions of uncertainty, from which we derive the axes of the proposed scenarios, we start reviewing briefly three studies, two of which focus on the possible future of farming as a result of broadly defined digitalisation[100], and one looks more broadly at the future of farming listing the mega-drivers of change by 2040[101].

The first contribution (a report from the European Parliament), which does not have a time horizon, identify two key sources of uncertainty[102]. The first concerns whether digitalisation of agriculture will be mainly driven by purely economic and efficiency objectives under a context of free trade, or rather the attention will be more on global sustainable development with a strong supra-national push (i.e., EU) on environmental sustainability. If higher efficiency is the main driver, digital farming will develop fully, leading to robotization and automation with the loss of jobs, with policy and regulation intervening little in the free market dynamics. The report presents a table[103] with concerns and opportunities across the four scenarios identified. The opportunities of digital and precision tools identified by this report coincide to a large extent with the potential benefits illustrated earlier in section 2.2. The concerns identified by this report are, amongst others, 'Neglect of environmental issues, loss of biodiversity and therefore potentially even higher risk of natural disasters', 'Social unrest because of high inequality, either between people or between regions' and 'concentration of data in the hands of big companies'. If sustainability is the main driver, policy and regulation will set rigid sustainability frameworks and targets, and digitalisation of farming will develop at a medium pace toward semi-autonomy systems reducing the loss of job. The possible draw backs include, for instance, resistance to new technologies that may slow down uptake, too much bureaucracy that may slow down the innovation rate. The second dimension of uncertainty concerns the possibility that groups of countries, countries or regions within countries take over and lead to fragmentation within the EU. In this case the draw-backs include, among others, little trust in government and institutions, smaller farmers not being able to keep up with new technologies because of lack of knowledge or investment capital, large digital divide between big and small farmers. It must be noted, however, that the conclusions of this report are overall positive on the potential benefits deriving from precision agriculture that, according to the authors, can contribute to food security, sustainable farming, although they also note that uptake is still low, that new skills are required and that it remains unclear how increased uptake may trigger societal challenges.

The second contribution (a scientific article)[104], without a time horizon, also identifies two dimensions of uncertainty. The first concerns whether the context is conducive (high acceptance, high digital literacy, high innovation rates) or unconducive for digitalisation (low acceptance, unequal knowledge and skills, low innovation rate). The other dimension concerns whether many players (cooperation, open systems) or few players are active (government and business dominate, controlled systems). The authors when considering these two dimensions of uncertainty focus particularly on the impact that they may have on data sharing and data concentration or distribution, which is reflected on the landscape that can be open with many players engaged in digital farming and data sharing or can be dominated either by big corporation or by governments. The article also stresses the uneven distribution of knowledge, skills and acceptance of digitalisation in shaping the future of farming.

The third contribution (a report from the JRC) focus broadly on the future of farming in 2040 without focusing only on digitalisation but listing several mega-drivers of future development (see figure in next page)[105]. From the various drivers the report extracted five themes that will characterize agriculture in 2040, of which we briefly summarise here the three most relevant. First, by 2040 digitalisation will be in full swing and the farmers will need technological and managerial skills. Second, the impacts of climate change will be felt all across Europe, leading to volatile weather conditions, more frequent floods and droughts and more extremes in terms of temperatures. Accordingly, climate change adaptation and mitigation measures are expected to be mainstreamed throughout the entire food chain. Third, consumers will be more demanding, they will require knowing the origin of food, which may be a driver for community supported agriculture offering direct contact between producers and consumers.

As seen, there are several possible ways to define the main uncertainties for the future, although for the sake of producing our traditional 2x2 scenarios we must select only two dimensions. Considering the state of play described in chapter 2 and the policy and regulatory challenges presented there (section 2.3), one of our dimensions of uncertainty (see infra for its operationalisation) will be about what direction regulation (governance) will take. It must be stressed that this dimension does not include the support policies that will be used to characterise the scenario storylines. The second dimension will be that of the socio-dynamics of the

Demographic developments	Size of world population ,ageing EU population, generational shift of farmers and consumers, urbanisation, migration, dietary shifts
Shifting values of EU society	Values placed on rural areas, tradition and culture , landscapes as public goods and multi-functionality of farming , counter-urbanisation (in migration), sustainability and ethical aspects , diversification of lifestyles and diets, work-related aspirations
Inequality & trust	Social cohesion, consumer trust, influence on community values and activities, and implications on attitudes and lifestyle, influences food choice, consumer engagement in the food chain
Digitalisation	Precision agriculture (Internet of Things), automation & robots, connectivity, virtual services and servitisation
Biotechnology	New breeding technologies/synthetic biology, alternative protein sources, food design, bioeconomy
Climate change	Volatile, harsher weather conditions, changing transboundary pests and diseases
Natural resources	Expected increasing scarcity and competition for access(water, lands, oil, minerals, fertilisers), environmental degradations such as air and water pollution, habitat loss, decline of biodiversity, soil quality
Economic growth and globalisation	Framework conditions for policy, public budget, trade, rise of emerging economies, developments in agricultural markets, access to land and capital, financialisation of commodity markets
Structure of the agrofood sector	Power distribution within the sector, structural change of farm holdings, relative importance of agriculture in rural economies& diversification, increased competition
International situation	Conflicts & crises, competition, access to energy and other resources, implications for standard setting, trade, sanitary measures
Policies & regulatory frameworks	Set framework conditions for farming and food production in the EU and elsewhere, urban-rural relationship, climate, energy and environmental targets

Table 3 Main drivers for the future of agriculture, Source: Bock et al (2020, p. 14)

ecosystem and the structure that it will take. This dimension (see also infra for its operationalisation) resonate with the concerns about excessive concentration and the future of small farms sustainability in Europe, as well as with issue of level of employments. Several other dimensions emerge from the three contributions reviewed, and these will be used to characterise the different scenarios. We will certainly touch on the issue of environmental sustainability, on digital skill and technology acceptance, as well as with the question of potential inequality, and of farmers reaction to different regulatory approach.

THE PROPOSED SCENARIOS

As anticipated, we selected as the two dimensions of uncertainties representing the axes of the scenarios depicted below: 'the socioeconomic dynamics' and 'regulation'. The technology itself, the extent to which only efficiency or also sustainability will be the driver of digitalisation, whether the context will be conducive or unconducive to technology adoption, the potential divides and inequalities will all impact both the regulatory process and the socioeconomic dynamics and, thus, will be included inside the scenarios storylines.

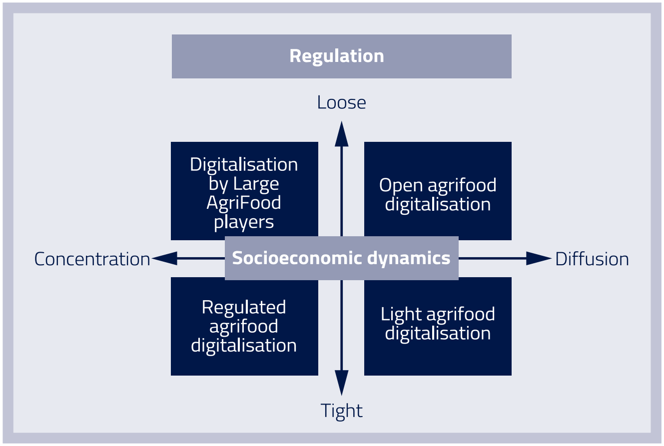

Figure 13 Proposed scenarios, Source: Authors' elaboration

Regulation varies from tight to loose, to reflect not only the extent of the regulation itself but also the possibility of fragmentation at national level given that the new CAP gives more responsibility to Member States. Tight regulation is a situation with clear mandatory targets and a strong supra-national push for using digitalisation to meet the Green Deal objectives. Loose regulation is a situation whereby there might be fragmentation and national level with little intervention to 'correct' the free market dynamics. The socioeconomic dynamics can either lead to concentration (consolidating a trend we have discussed in chapter 2) with small farms left behind and increased inequality or to diffusion with many players involved in digitalisation including to some extent also small farms. Whether concentration or diffusion prevails is related to whether the context will be unconducive or conducive to technology adoption. This, in turn, depends on whether or not existing digital divides are attenuated (increased access to broadband and increased digital skills also among small farmers).

SCENARIOS' STORYLINES

We present the scenario storylines starting from the two in the upper part of the picture, and then moving to the two scenarios in the lower part.

Open Agrifood Digitalisation (OAD). Under this scenario, a loose regulatory approach favours the free and widespread adoption of technological innovation mainly for the pursuit of economic and efficiency gains. Digitalisation will develop fast with robotisation and AI applications controlling farms. Algorithms that solve use of inputs, food safety and animal health and welfare issues become dominant in the farming sector. They include robots and algorithms replacing work and providing predictive support for decision-making on farms. (especially the use of inputs). On the other hand, as a result of other support policies and developments, the digital divide is reduced and funds to help invest in technology allow to a large extent also small firms to be part of this new game. Within the agrifood ecosystems data are widely shared between farms, tech and food companies, governments, and consumers.

This contributes to changing to some extent the balance of power and the market structure, reducing the dominance of big businesses and opening the way for small farms to catch up and for start-ups and scale-ups to gain importance. Open data sharing allows companies to link consumer data to farming technologies. Open data and transparent value chains level the playing field for businesses and increase innovation rates, also because the structure opportunities open a space for startups and scaleups. The availability of data also enables algorithm-driven policy-making and monitoring. On the other hand, the loose regulatory and governance regime may result in sharp differences between countries and also within countries at regional level, with persisting divide and inequalities. With the main drives being economic and focused on efficiency, there would be a clear risk that environmental issues are neglected leading to loss of biodiversity and higher risks of natural disasters. This scenario is also characterised by gradual disappearance of human labour from farms with sizeable loss of jobs. Another risk is that of lock-in and dependency on few providers of technological system, some of which may not be European. Finally, full digitalisation and open data sharing bring also potential loss of privacy and, especially, vulnerability to cyber-attacks and hacking the food system.

Digitalisation by Large AgriFood players (LAFP). As in the case of the OAD scenario, a loose regulatory framework favours the fast and full deployment of digital technologies with robotisation and AI applications controlling farms. This produces substantial economic and efficiency gains, but also large loss of jobs. The main and big difference is that this leads to strong concentration of market power and data control. Support policies are not sufficient for small farms to catch up as they continue to suffer from digital divides and lack of needed financial resources to invest in technology. Therefore, under this scenario, the trend of disappearance of small farms and dominance of large farms and agrifood business intensify. In addition to Large AgriFood players, a large role is played by the providers of farm machinery (i.e., CNH Industrial, Claas, Deere & Co AGCO, and Kubota and potentially also by big tech new entrants such as Google and Microsoft. While technological deployment is fast, because of concentration the rate of innovation is not as high as in the OAD scenario. Inequalities increase and environmental targets are neglected. Digital business models of dominating agrifood and technology companies driven by consumer data control farm data to the extent it matches their consumer orientation. farmers become mere executers of capital-driven algorithms that use their data. Governmental data access regulation is limited, because the food tech companies are stronger players. Power distribution is clearly skewed towards Large AgriFood players and big technology companies that dictate distribution of added value. Governments greatly depend on them. Agricultural policy focuses less on farm activities than on big businesses. The drawbacks of this scenario are very clear and include: a) monopolies, because all data is in the hands of big companies and production is focused on efficiency and economic gain; b) uneven access to technology because of high investments being necessary; c) smaller farmers not being able to keep up with new technologies because of lack of knowledge or investment capital.

Light Agrifood Digitalisation (LAD). Under this scenario there is a strong supranational push and governance with little fragmentation across countries. The EU sets mandatory sustainability frameworks and targets, with increased regulation intensity. The subsidies of the CAP are tightly linked to environmental targets, and support for digital technologies breakthroughs aims to increase agrifood sustainability and to reduce divides and inequalities. Sustainability, equality and justice are at the core. Adoption of digital technologies contributing to these targets will be supported, also with attempts to produce behavioural change. For instance, Precision Agriculture is pushed where it clearly drives sustainability of agriculture forward and is strongly regulated. Support policies enable also small farms to be part of the game, and there is space also for starts-up and scale-ups, as regulation also try to avoid concentration. On the other hand, the take up of digital technologies is not as fast and as full as in the previous scenario, because regulation creates constraints and bureaucratic burden, which slow down changes and technological breakthroughs. There is some level of automation and substitution of human labour, but to a lesser extent compared to the previous scenarios. Divides and inequalities are to some extent reduced. Tensions can still arise between farmers and governments /EU given the tight regulatory framework on environmental targets and obligations. Data sharing remains limited. Farms control data and supply it to government and business when it is beneficial to them or linked to incentives. Incentives to farms are needed for them to disclose data that supports agricultural policy. So, governments still need to use remote sensing and environmental monitoring data acquired from outside farms. Because technology adoption is slower and less widespread than in the previous scenario, the risks of lock-in on technology and of cybersecurity are lower.

Regulated Agrifood Digitalisation (RAD). Under this scenario we have a tight regulatory and governance regime as in the previous one, and a socioeconomic dynamic leading to concentration with the dominance of Large AgriFood players and big technological company as in the LAFP scenario. Digital technology is used extensively, but it is government-controlled. Because the regulatory regime is tight and not fragmented, the EU and national governments manage to control and guide big business toward the policy objectives of sustainability, equality, and justice. Governments reduce and equalize the power of all actors to engage in agricultural policy, because it controls digital technology used for agricultural policy. The technocratic policy approach implies that agricultural policy needs to conform the digital technologies of governments, and that policy change only comes from government. This approach to some extent limits the disappearance of small farms and ensure that concentration does not further increase existing divides and inequalities. Big Businesses and farmers are forced to supply data of relevance to agricultural policy to governments, which uses these data extensively. Consumer data is mainly held by big agrifood and big technology businesses, although government controls the governance of data. Hence, government also defines and implements data access in its favour. While farms have low willingness to share their data, government enforces data sharing against their will. It uses data analytics and algorithms for decision making where they support its agricultural policy interests, reaching deeply into farms to make them transparent. Again, this is the source of potential tensions between farmers and governments. Because of the tight regulatory control and the consequent administrative burden, the rate of innovation is reduced.

SCENARIOS ASSESSMENT AND CONCLUSIONS

The picture below provides a qualitative assessment of the four scenarios along five dimensions. Efficiency, Innovation, and Sustainability (environmental) are straightforward and do not require comments. Under Social Cohesion we group the equality/inequality impacts together with the potential differentiation between countries or within countries, and with the potentials tensions between farmers and governments. Because in the various sources reviewed in chapter 2 it emerges that the existence of small farms is a value and policy objective, we added as a dimension of assessment the extent to which different scenarios affect this aspect.

As clearly visible from the picture no single scenario is ideal and fully satisfactory. All the scenarios excel in a few dimensions but are very low in others. To refer to the different scenarios we use the abbreviation introduced earlier and included in the picture. The OAD and the LAFP scenarios score well in terms of efficiency but score very low on sustainability. The OAD scores high on innovation, whereas the LAFP score lower. The LAFP scenario has very negative impacts both in terms of social cohesion and of small farms survival, whereas the OAD scenario scores a bit better in these dimensions, but not very high given the risk of fragmentation. Both the LAD and the RAD scenarios scores high in sustainability, and in terms of small farms survival. On the other hand, they score well but not too high with respect to social cohesion since strong regulation may cause again tensions between farmers and governments as we have seen in the spring of 2024. They do not score very high in terms of efficiency and innovation.

The fact that all scenarios have some drawbacks is an indication that the prospects and effects of digitalisation in the agri-food sector and in agricultural policymaking are uncertain. In this context political choices and policy will play a crucial role may face challenging trade-offs. Political choices may have radical effects if they go openly in one direction (i.e., prioritise only sustainability) or in another (i.e., let the market dynamic plays itself out, which may prioritise efficiency).

First, in view of the farmers' protest of March 2024, policy and regulation will face a dilemma between farmers demands and the current policy objectives and regulation, both for what concerns income support and trade policies and for the obligations deriving from the Green Deal objectives. Under a regime of loose regulation, which includes two scenarios (Open Agrifood digitalisation, and Digitalisation by Large AgriFood players, environmental issue may be neglected, whereas with a tight regulation tensions with the farmers may resurface.

Second, digital farming should avoid exacerbating concentration and leaving small farms behind. Despite the advantages of digitalisation, it also has the potential to exacerbate a digital divide, segregating those who have access to cutting-edge technologies from those who do not. This divide may create a division between connected and disconnected farms, as well as between small and large agricultural enterprises. To ensure that digitalisation is inclusive and accessible to all, collaboration among policymakers, industry leaders, and technology providers is crucial. It is essential to promote the benefits of digitalisation and provide support to farmers through training, resources, and incentives to adopt new

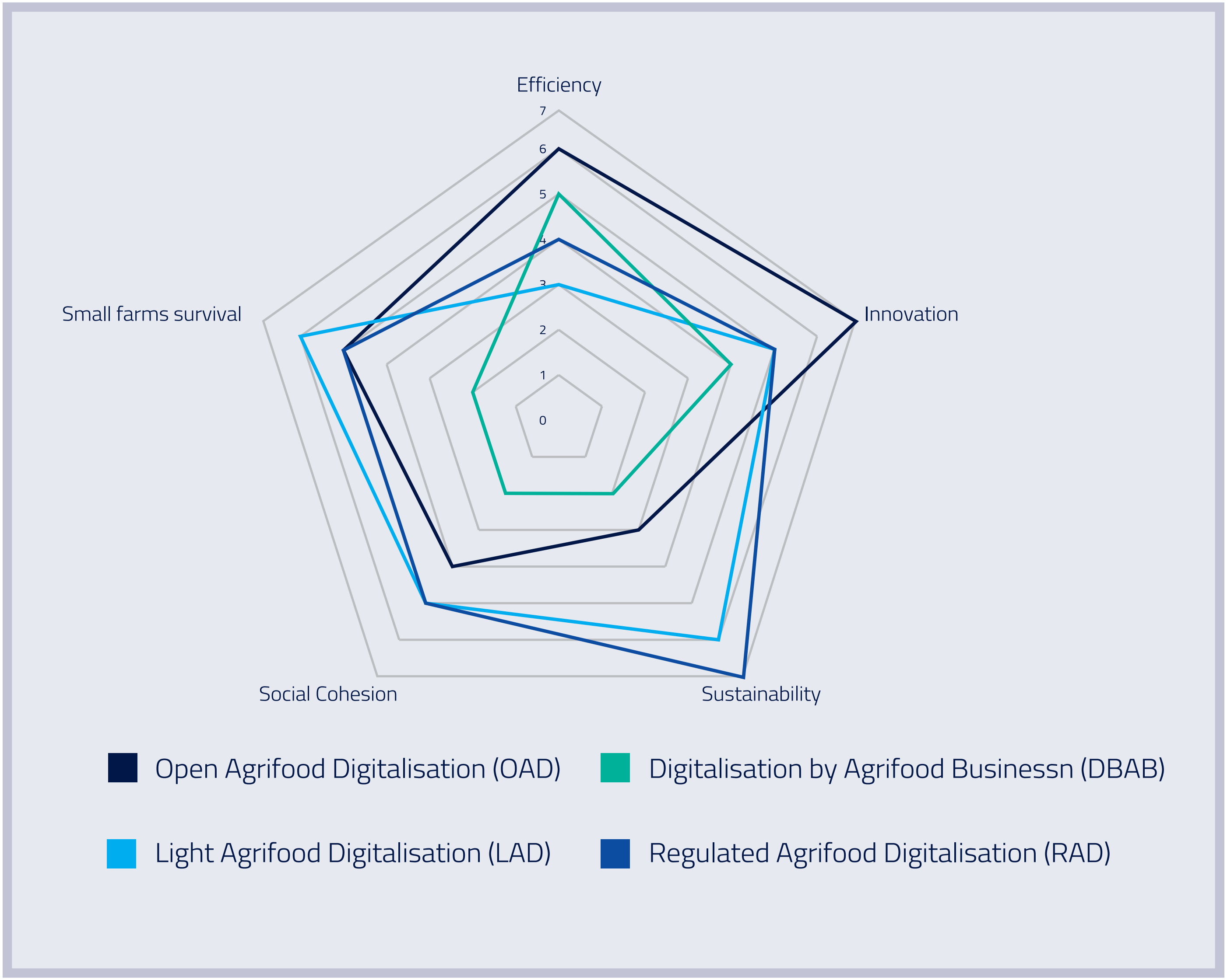

Figure 13 Radar diagram assessment, Source: Authors' elaboration

technologies. In the scenario of Digitalisation by Large AgriFood players there is a clear risk of exacerbating inequalities and little chance of small farms survival, which mean political choices and policies should as much as possibly try to avoid such concentration trend.

Third, in addressing the landscape of data-sharing platforms and ecosystems necessary for a common European agricultural data space, there is a pressing need to develop cohesive frameworks. These frameworks should facilitate seamless data sharing and interoperability across diverse applications and stakeholders within the agricultural sector. Again, the risk of monopolies and data concentration is high in the scenario dominated by Big Business, but to some extent also in the Digital Regulation scenario.

From the discussion above we draw the following conclusions:

1. **Future ownership of data is crucial.** Data exchange is at the core of AgriTech and more generally of digitalisation of agriculture and may lead to the development of data platforms. There is the risk of data monopolies by big companies. The Code of Conduct on Agri Data Sharing, a voluntary initiatives signed by 10 agricultural associations to address the issue of data sharing represent a good starting point, to be integrated with existing and new legislative acts. Legislators and policy makers should develop common international standard for creating and sharing data, avoiding data centralisation. It will thus be critical to create respective policies and legislation that ensure that data ownership and benefit from digitalisation of agriculture are directed according to political/ policy goals. In this context it is very important to create the conditions for the emergences of agricultural data spaces to facilitate trustworthy data pooling and sharing between private stakeholders and public authorities. Policy makers should pre-empt the emergence of dominant platforms in the agricultural data exchange, as they would fall outside existing legislation (DMA, DSA, and AI Act). Big Business and Big Tech dominance must be avoided.
2. **A balanced digital transformation that includes environmental issues and sustainability.** As illustrated in the introduction there is agreement that agrifood requires a radical transformation where digitalisation and technological innovation have potentially an important role to play. Such digital transformation should be comprehensive and try to combine different dimensions of impact. It should aim at increasing efficiency and productivity, at the same time as tackling environmental issues, biodiversity, and the risks of natural disasters. Policy makers should devise smart incentives that substitute top-down regulation/targets to entice a use of technology that combines environmental and economic/efficiency objectives.
3. **Suggestion for future CAP:**
    - Enticing farmers to invest in technologies and a renewed greening scheme. It could take the form of a ‘sustainability bonus’ linked to investment in technologies with a proven benefit for the environment.
    - Strengthen the efforts related to environment and sustainability, especially through the use of efficiency-producing technologies.
    - Incentivise and support the digital transformation of agriculture to reduce environmental impact.
4. **Moderate inequalities and support small farms.** The full digitalisation of agriculture can exacerbate existing divides and inequalities, thus, undermining social cohesion. Small farmers may not be able to keep up with new technologies because of lack of knowledge or investment capital, and technology uptake might lead to a rapidly growing digital divide between small and big farmers. Digitalisation of agriculture will affect employment , with human labour potentially being increasingly replaced by robots and computer (see Annex), although in different ways depending on the regions. Support policies should be adopted that cross-cut the boundaries of agricultural and social policies.

ANNEX: BRIEF NOTE ON AUTOMATION AND EMPLOYMENT

The extent to which the new wave of technological innovation entailing automation (i.e. computerization, digitalisation, AI, robotics, etc.) will reduce jobs has been debated in the past decade. In other reports of the Makers and Shapers series this topic has been discussed at length. This brief note is a brief explanatory summary in general and with some specific consideration on agriculture, as to substantiate some of the scenarios and their assessment.

The available estimates on potential job losses from automation are still very uncertain and differ widely both in academic and non-academic reports They range from the risk of computerisation of 47% jobs in the US estimated by Frey and Osborne[106] to only 9% of job loss in OECD countries projected by Arntz et a[107]. Or from 57% of job losses in OECD countries according to Citi Bank and Oxford University,[108] to the 14% estimated by OECD researchers.[109] Recent compilations[110] of estimates on the effects of automation on jobs renders this variability very clearly, with differences of several orders of magnitude. For example, worldwide estimated jobs losses by 2030 range from between 400 and 800 million according to McKinsey[111] up to the 2 billion projected by futurist Thomas Frey[112].

According to the Skill Biased Technological Change (SBTC) hypothesis, computerisation will substitute low skills jobs, meaning that the risk of job being automated will mainly regard low-skilled and low-income individuals. This hypothesis has not found strong empirical corroboration and has left space to the alternative Routine Biased Technological Change (RBTC) hypothesis. According to this hypothesis, that the amount of routine involved by a job will determine the possibility that is automated and substituted by machine (being computer or robot). One of the main proponents of the RBTC hypothesis, David Autor, has recently presented a more realistic approach to the problem of automation asking the question why there are still so many jobs[113]. According to Autor, one of the effects of automation on labour market is also that of increasing the value of the tasks that workers uniquely supply. So, there is both substitution and complementarity between labour and machines and the current polarisation of the labour market may not continue in the future. Along the same line of reasoning, the model proposed by Acemoglu and Restrepo envisage both substitution and complementarity[114]. According to these authors, technological innovation can either directly displace workers from tasks that are fully automated (displacement effect) or indirectly increasing labour demand industry or jobs arising as a result of technological progress (productivity effect). Only if the long-run rental rate of capital relative to the wage is sufficiently low, then the equilibrium involves automation of all tasks. Otherwise, the two types of innovations will go hand-in-hand. Yet, they also recognise that in the transitional period polarisation and inequality may increase driven by faster automation and introduction of new tasks.

The impact of automation on employment can have three effects: the productivity effect, the new task creation effect, and the displacement effect. If there is a productivity, automation increase the efficiency and productivity of workers, and this can be positive for employment, as it increases the demand for goods and services. Automation creates new tasks and this can also be positive for employment for it creates new job opportunities in complementary tasks. Finally, automation can replace human workers in certain tasks, leading to job losses. The net effects on employment, then, depends on which effect is predominant. It must be said, however, that replacement tend to lead to losses of repetitive and low skilled jobs, so affecting the weaker segment of the labour force.

According to a recent article empirically comparing the effect of automation in agriculture, industry, and services sectors[115], in the agriculture sector the negative impact of automation on employment tend to be relatively higher. More precisely, the authors show that only high productivity countries benefit in terms of employment. In other words, in countries with low or medium productivity levels, increased automation results in a decrease in agricultural employment. As the majority of EU countries are not high-productivity, although our are just scenarios, it seem plausible to point out the risk of job losses.

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