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D3.5 Future of Digital Agriculture & Forestry

Horizon Scanning Report (first report)

Work Package 3 - Digital Agriculture & Forestry Uptake – Forecast & Foresight

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Abbreviations

Agrifood	Business system containing all operators along the food supply chain, i.e. primary food production (by farmers, fishers, aquaculture producers), food and drink industry, food retail and wholesale, food services,
AI	Artificial Intelligence
CAP	Common Agricultural Policy, the EU's common policy for all EU Member States, supporting farmers and ensuring Europe's food security.
€	Euro
EU	European Union
NGO	Non-Governmental Organisation
STEEP	Social, Technological, Economical, Environmental and Political
US	United States of America

Introduction and Methodology

Starting Point and Objectives of the Report

The Horizon Europe programme funded 4Growth project[1] analyses the uptake of digital and data-driven solutions in agriculture and forestry in Europe, by documenting the current state and projecting the future evolution of the sector. The project's Foresight Module explores the changing framework conditions of agriculture and forestry and the digital transformation of these sectors, by applying two core foresight methodologies via qualitative analysis: horizon scanning and scenario development. This report focusses on the outcome of the horizon scanning process conducted between January and August 2024.

As an intermediary horizon scanning report, this paper is the first output of the Foresight Module and presents the initial findings, while the horizon scanning processes will continue in the year ahead. Horizon scanning is a foresight process of screening literature, news and a variety of other sources to identify trends, i.e., developments of change. It is a structured bottom-up process, in this case looking at relevant developments documented in the last 5 years. The approach covers a "360-degree" perspective of social, technological, economic, environmental and political spheres, zooming in from more general and global topics to sector-specific topics[2].

Within the context of the 4Growth project, horizon scanning serves to identify current and future changes in the wider environment which are expected to impact on digitalisation in agriculture and forestry in Europe. The analysis is thus focussed on potential trends and their implications for agriculture and forestry in the EU, zooming into implications for the digitalisation transformation of the two sectors (i.e. applying an "outside-in" perspective). For example, the reflection on implications covers aspects such as in how far the trends imply a growing need for specific digital solutions, or new opportunities, or what the potential hurdles could be for the uptake of digital solutions stemming from the trends.

Therefore, the **objective of the report** is to present an overview of trends - identified over the current period - that are relevant for the agriculture and forestry sectors, to feed into and support strategic reflections about their future developments and their effects on the sectors and digitalisation. Beyond this specific objective, the paper also aims at providing insights and inspiration to think about possible futures, which is covered in a section in each trend description indicating possible future developments paths. Each of the trends is also illustrated by three signals, covering developments in different aspects of the trend, aiming to illustrate the breadth of the topic. Furthermore, the report aims to highlight the implications of the trend for the agriculture and forestry sectors and their digital transformation, which is explicitly covered in a respective concluding section of each trend description.

How to read this report: Readers can look at the overview of the topics and select those that pique their interest, or they can read the whole report to get an overarching picture. We invite readers to also think ahead themselves, reflecting on possible futures via e.g., the section on "What if…" at the end of the report, which explores open future questions on each of the trends and is set up in a way that enables readers to reflect on long-term possibilities.

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[1] This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101134855.
[2] For more details on the methodology, see the subsection 'Methodology'.

The Wider Context of Current Change

The world is in a poli-crises mode: wars on multiple continents, the aftermath of the COVID-19 pandemic, the long-term climate crises, geopolitical tensions, social inequality, and other major issues dominate the debate. It is becoming increasingly clear that societies and economies across the world need to actively become more resilient against these crises (Lawrence et al., 2024). The need to increase resilience also applies to the agriculture and forestry sectors (Pfenning-Butterworth et al., 2024; Think Tank EUROPA, 2023). Already today, multiple policy packages at the EU level address these sectors to help them advance in the transformation to sustainable business perspectives and climate neutrality, or to fight the loss of biodiversity. Such policies are the Farm to Fork Strategy as part of the European Green Deal, the reform of the Common Agricultural Policy, the Sustainable Food Systems Framework, the EU Forest Strategy for 2030, the Biodiversity Strategy, the Bioeconomy Strategy, or the Sustainable Finance Taxonomy (which guides investments towards sustainable projects, including into agri-food, forestry and bioeconomy) (von der Leyen, 2023). Beyond that, specific policies address the digitalisation of these sectors: Examples are the Digital Europe Programme (which launches initiatives in the use of digital solutions to improve efficiency and sustainability, and pushes for smart farming and precision agriculture), and the Forest Information System for Europe (aiming to enhance monitoring and management of forests) (European Commission, 2023c). Furthermore, under the Digital Decade, the European strategy for data and its key pillars the Data Governance Act, the Data Act, and the Digital Markets Act provide a framework for digital data sharing services; it also aims at aligning digital platforms with EU values and principles to bring benefits to EU citizens and companies (European Commission, 2020). As regard to today’s situation, research shows that Europe and North America are on par global leaders in the current and planned application of digital tools in agriculture (Fiocca et al., 2023). However, given the challenging overall context, a continuous monitoring of change will be necessary to enable a more proactive stance, and to establish early awareness of existing change – as applied in this horizon scanning process.

Methodology

The core aim of the Foresight Module (T3.2) is to highlight the impacts of fast-changing framework conditions in agriculture and forestry. The Foresight Module screens respective trends that can be expected to (probably or possibly) impact on the future of agriculture and forestry, as well as on the development of sector-specific digital technologies and their uptake in these sectors in Europe until 2040.

Generally, horizon scanning involves the systematic gathering of information and monitoring of trends to provide an early warning function on possible future changes; it is one of the most established methodologies applied in foresight, especially in the EU policy and research system (European Commission & Daheim, 2023; Joint Research Centre, 2024; UNDP, 2018; Cuhls, 2019; EEA & EIONET, 2023). Horizon scanning is crucial in foresight, as it provides the evidence for development trajectories (Dragt, 2023).

Within the context of horizon scanning, trends are defined as emerging patterns of change phenomena that have already led to or are likely to impact on other areas, i.e., on society, economy and politics (European Foresight Platform, 2016). For the approach applied here, we understand trends as clearly observable phenomena of change, underpinned by evidence in the form of signals that point to the respective changes[3]. Thus, the report covers already observable change (drawing from developments today and in the recent past, which can be expected to continue in the future). It does not cover potential future disruptive developments which do not stem from continuous past and present change. Such disruptive issues (often also described as "wild cards or "black swans") may be taken up in the scenario development.

The methodology applied to identify and analyse trends thus draws from a literature review of a broad scope of publications, i.e., academic publications as well as grey literature, newspapers, websites, blogs, press releases, etc. To guide the search process, a "scanning grid" (i.e., a systematic structure for literature identification) was developed, providing a mapping of contextual areas that are expected to play a role for future digitalisation in European agriculture and forestry. This scanning grid is based on the STEEP systematics, a widely used methodology in horizon scanning, which covers developments categorized by the areas of society, technology, economy, (the natural) environment, and politics (including policy) (Nhokovedzo, 2024; Bishop, 2009; Future Impacts & EMCDDA, 2022). To reflect the specific needs within this project, the STEEP categories were adapted to areas that are of relevance for digitalisation in agriculture and forestry in the EU (see table 1)[4].

Table 1. 4Growth Horizon Scanning Grid

Scanning Area (short title)	**Detail on Issues of Interest within the Scope of the Scanning Area**	Underlying **STEEP** category
Geopolitics	Geopolitical power and tensions, including international peace and conflicts that could influence global cooperation, as well as international trade of food, bioeconomy products, and technologies	Politics
Resource scarcity / Biodiversity crisis	Resource scarcity and biodiversity crisis, influencing the food-water-energy nexus, food security issues, role of the climate crises and impacts for agriculture and forestry	Environment
Technological advancements	Technology advancements in areas like digital technology, biotech, and food safety	Technology

[3] Therefore, a trend can be ranging from a recent emerging phenomenon with a relatively high degree of uncertainty about its future significance up to a broader, more established trend which is far-reaching and observable across the EU or even globally (Sitra, 2019). As each trend is based on several signals (i.e., individual scanning hits based on one source) providing evidence of the development trajectory, signals indicate aspects of the observable change within the trend (Hendricks, 2021). Thus, signals can be sources in the form of newspaper articles, or studies covering a scientific analysis of a larger set of observable data. Therefore, signals can also cover recent developments or more long-standing changes. For more detail on terminology and different approaches in horizon scanning, and on e.g., related terms such as drivers of change, megatrends, weak signals etc, see especially Cuhls, 2019, EEA & EIONET 2023, Hines et al., 2019, Wilkinson, 2017.

[4] This adaptation was based on a literature review of f existing foresight studies in the domain of digital farming, and precision farming (comparable broad foresight studies in the domain of smart, digital forestry could not be identified so far). Two studies were particularly influential due to their fit with the 4Growth focus and due to their overarching European regional and policy focus: a study on transformative futures for farmers and rural communities (Barabanova & Krzystofowicz, 20233), as well as the scientific foresight study 'precision agriculture and the future of farming in Europe' (van Woensel et al. 2016).

Scanning Area (short title)	**Detail on Issues of Interest within the Scope of the Scanning Area**	Underlying **STEEP** category
Societal values	Global societal values and consumer preferences	Society
Regulatory framework	Regulatory frameworks in areas of climate, agriculture, bioeconomy policies, financing schemes for agriculture, forestry, and research and innovation, etc.	Politics
EU system	Development and functioning of the European Union and its systems	Politics
Agri-forest industry shifts	Industry shifts in agriculture, agrifood and forestry and related sectors as well as in digital industry, such as changes in business models, industrialisation, globalisation, and developments in the workforce of these sectors	Economy
Open scanning	Open scanning to identify relevant trends outside of the above-mentioned topics, aiming to allow for serendipity and for identifying blind spots which may result from the systematics of other scanning areas	(all categories)

As a result, the search grid allowed for a 360° view over the STEEP categories to identify blind spots as well as to zoom in from the wider general and global context to digital agriculture and forestry in Europe.

The horizon scanning process

The horizon scanning process consisted of six steps[5], which were:

1. **Development of the scanning grid** (See above for more detail)
2. **Identification and selection of studies and other sources to integrate:** Selection of sources and studies to integrate in the scanning; focussed on recent sources published within the last 5 years (i.e., from 2019 onwards)[6].
3. **Review of Sources:** Rigorous review and analysis of the sources to identify signals based on the scanning grid.
4. **Analysis of Results:** Analysis of dominant themes and drafting of identified trends, including the clustering of related individual signals to reach a set of overarching trends.
5. **Collaborative Trend Identification:** Joint review of the proposed trends, realised in workshops with a team of researchers; categorising insights to the search grid and prioritisation of the long list according to a systematic set of criteria (i.e., coverage of

[5] While these steps build on each other and are generally realised consecutively, there is also an element of re-iterative refinement that was realized in the process of horizon scanning. For example, findings from a review of sources in one area of the scanning grid can provide insights into other relevant studies as well as inspiration for further research for more signals on a specific topic.

[6] Concerning the literature covered, the identification of studies and other sources (step 2) included a broad range of mainly European (and some global), foresight and trend reports with a general focus. Furthermore, the focussed scanning along the 4Growth Horizon Scanning grid dimensions provided a specific focus on publications on or related to European agriculture and forestry. Overall, approximately 200 sources were included in the scanning.

the research topic, strategic relevance of the theme, potential strength of impact for agriculture / forestry and their digitalisation, new or surprising themes).

6. **Description of the identified Trends:** Based on the resources identified and further detailed research, each trend was described in a systematic structure covering a summary and key words per trend. Additionally, past and future developments of the trend were brought together alongside recent signals within the scope of the trends, along with potential implications for digitalisation of agriculture and forestry.

To date, ten trends have been identified based on this process (as presented in this report) drawing from approximately 300 signals identified in the scanning (see figure 1 below). As the horizon scanning process is an ongoing, evolving process, the search strategy will also be developed further during the next steps of the project.

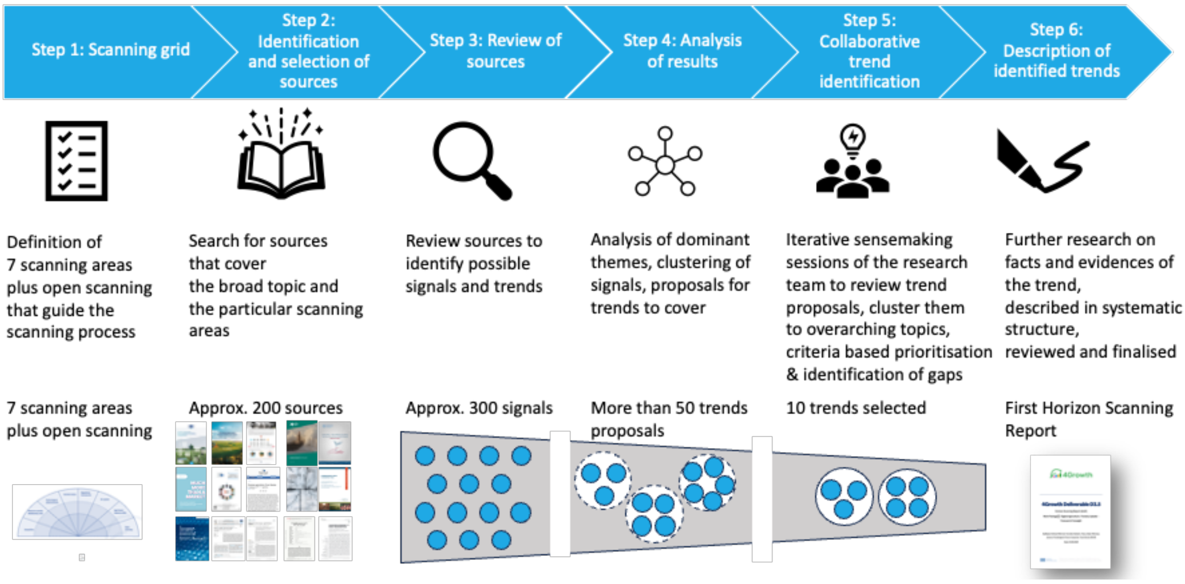

Figure 1. 4Growth Horizon Scanning process overview (version September 2024)

Overview of trends

The trends radar presented below shows the topics covered in the report along the scanning grid. While the impacts of the trends cut across and are relevant for more than one category, the trends as such are mapped to one main category for greater clarity (with attributions as assessed in the collaborative trends identification workshops). Furthermore, the radar shows an indicative timing (as assessed in the workshops), referring to when these issues could likely become strongly relevant for agriculture and forestry in broad terms, visible in the circles from the centre (short-term) to the margin (very long-term, beyond 2035).

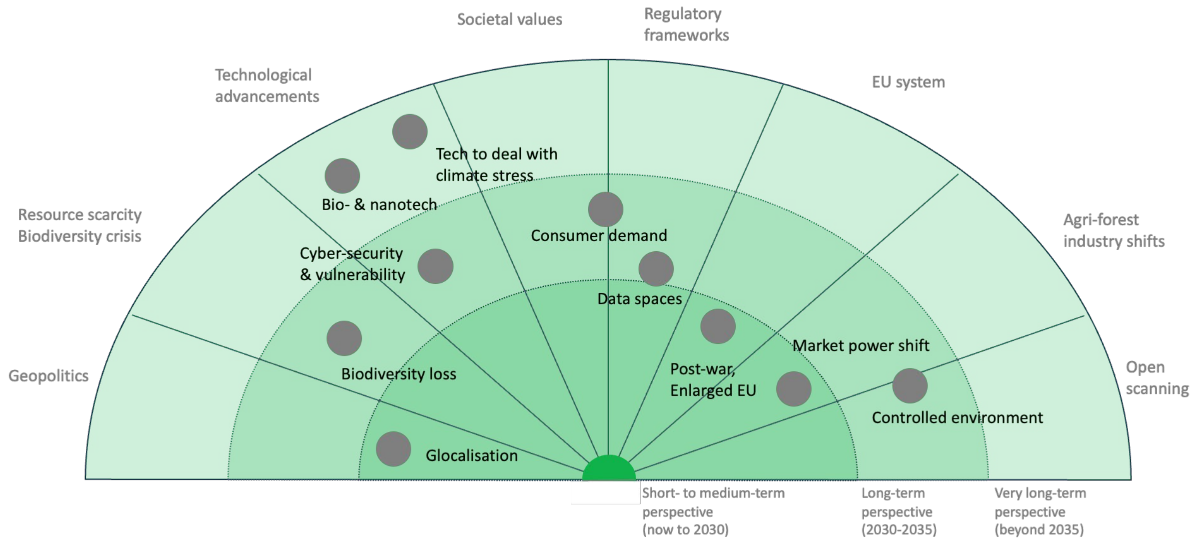

Figure 2. Topics covered in this report: 4Growth Trends Radar[7]

The table below lists all trends with their shortened title, as sometimes used for clarity reasons e.g., in charts and overviews, as well as their complete title.

Table 2. Overview of Trends (with short and long titles)

Trend (short title)	**Trend (complete title)**
Glocalisation	Glocalisation – Pushed by Geopolitical Tensions
Post-war, Enlarged EU	Changed perspectives for agriculture and forestry in a post-war, enlarged European Union that includes Ukraine
Biodiversity loss	Increasing Need to Tackle Biodiversity Loss
Cybersecurity & vulnerability	Cybersecurity Issues and Network Vulnerability Affect Digitalisation in Agriculture and Forestry
Bio- & nanotech	Bio- and Nanotechnologies Can be a Lever for Next Generation Agriculture and Forestry
Tech to deal with climate stress	Technology Solutions for Agriculture and Forestry to Deal with Climate Stress
Controlled environments	Intensification of Biological Resource Production in Controlled Environments
Data spaces	Next Level Decision Making Enabled by Digital Data Management and Spaces
Consumer demand	Rising Regulatory and Consumer Demand for Higher Food Quality, Safety, and Sustainability
Market power shifts	Shift in Market Power in Agri-food and Forest Systems

[7] The figure includes for better readability short titles only, table 2 provides the long-titles as used in the report.

Glocalisation – Pushed by Geopolitical Tensions

Summary and Key Words[8]

Glocalisation is the phenomenon of an increasing relevance of local and regional business activities addressing bottom-up consumers and stakeholder's needs while still being involved in globalised supply chains and production networks. The rise of glocalisation is being driven by stronger geopolitical tensions, thus limiting trade, and affecting agriculture and forestry. Recent examples of impacts on agriculture and forestry are temporary export restrictions on essential agricultural commodities that aim to counteract the fear of domestic shortfalls. For the next decade, more glocalisation is expected inter alia as part of a de-risking strategy, aiming to reduce the vulnerability of supply chains.

Key words: Global trade / resource dependency / open strategic autonomy / technology dependence / supply chain disruptions

Current and Future Developments of the Trend

Geopolitical tensions driven by wars, terrorism and political disputes and conflicts among states and political actors are rising; recent examples include the Russian war in Ukraine, the Israel Hamas conflict, Houthi attacks on ships in the Red Sea, and US-China trade conflicts, among others (Kaya, 2024; Borges et al., 2024). Currently, far right parties with nationalistic programmes that e.g., favour more inward-looking policies and tend to prioritise domestic interests and markets, are gaining ground in many countries in Europe and globally (WTO, 2023). Nationalist policies also lead to growing ideological divisions across ethnic and religious beliefs and values, with some actors using access to resources to add pressure on importing countries.

For the next decade, more glocalisation is expected as part of a de-risking strategy to address supply chain vulnerability and trade conflicts (Demertzis, 2023). Even if the pendulum swings back from nationalism towards multilateralism, glocalisation can be expected to continue as other drivers favour this development. A main push can be expected from climate policies through which more domestic production is favoured to reduce the environmental footprint of consumption; furthermore, automation and digitalisation can be an enabler for competitive national or regional production (compared with purchasing from global markets) (Gong et al., 2022).

Recent Signals within the Scope of the Trend

Export Limitations for Food Products: India's Rice Export Ban

Resource rich countries can actively influence global food availability through their trade policy, e.g., via trade restrictions and other measures. For example, in 2023 India, the world's top rice exporter, temporarily banned the export of relatively cheap white rice, covering around 75% to 80% of Indian rice exports (Glauber & Mamun, 2023). The aim was to drive down rising domestic prices in the period before the next harvest in preparation for an anticipated crop shortfall due to weather anomalies from the El Nino phenomenon. As

[8] The summary parts are written without scientific references, respective citations are available in the Current and Future Developments of the Trend parts.

India's rice exports are crucial to food security in many Asian and African countries, this had strong repercussions (Glauber & Mamun, 2023). For example, the ban led to a spike in global rice prices, severely affecting low-income countries and consumer groups. However, sudden export restrictions can lead to a perception of India as an unreliable supplier of rice, with importing countries potentially searching for alternative supply options (Biswas, 2023).

Europe's Wood Import Independence – a Reaction to High Russian Export Tariffs in 2008

Russia's invasion of Ukraine in February 2022 led to export bans by the EU and like-minded partners on various products from Russia, including on wood (Vos, 2024). However, the EU's wood supply tensions are not new: Already in 2008, Russia imposed trade tariffs on their wood exports. As a result, the EU's total wood consumption from Russian imports dropped by two thirds during the last 15 years, with Russian wood products accounting for only 2% of total EU consumption already before the war (Nabuurs, 2022). Hence, Europe is highly dependent on its own domestic forest resources. The EU has even managed to become a net exporter of (round-)wood to non-EU countries in the last years[9] (Eurostat, 2023). Relying mainly on domestic resources requires good forest management and a balance between biodiversity, carbons sinks and wood production (Nabuurs, 2022). Wood supply management is a challenging long-term process at the interplay of policy, market side and climate-crises related factors, even with a low import dependence (Egger et al., 2024).

Fertilizer Dependency due to Russian War in Ukraine

The Russian war in Ukraine led to fertilizer supply disruptions for agrochemicals from Russia and Belarus, due to sanctions introduced in 2022. Both countries are important producers of mineral fertilizers. Resulting supply shortages affected 136 countries, particularly Estonia, Mongolia, Kazakhstan, Brazil, the US, China, and India, while DR Congo, Ethiopia, Egypt, and Pakistan were most vulnerable to such disruptions (Zhang et al., 2023). In addition, China introduced quotas for phosphate fertilizer exports in 2022, halving their exports (WEF, 2023). On top of this, European domestic fertilizer production is also strongly affected due to record high energy price peaks following the Russia-Ukraine war (IEA, 2024). Spiking natural gas prices affect the agrochemical industry, as natural gas is essential to produce nitrogen fertilizers, accounting for 75 to 90% of manufacturing costs. European fertilizer producers reacted with temporary shutdowns of production sites: In the first half of 2023, 40-50% of the EU ammonia industry was temporally closed, and in the first quarter of 2024, 10-20% remained closed (Fertilizers Europe, 2024). Resulting high costs for agricultural fertilizer have led to a reduction in the use of fertilisers; farmers shifted production to crops that require less mineral supplement (Chopra, 2023). In terms of its impacts, high energy and fertilizer prices have been observed to influence food prices more than reduced food imports (Alexander et al., 2023).

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalization in the sectors could also be expected in the mid- to long-term future.

First and foremost, established and formerly reliable food, feed, fertilizer and energy trade relations, supply chains and routes become more fragile. Therefore, trust in supply providers

[9] Referring to the statistical period 2018-2022.

is reduced, with rising prices affecting poor people the most. Consequently, importing countries tend to seek a greater variety of import sources, try to expand domestic production or attempt to influence consumers to shift their diets and nutrition habits. Digitalisation of farm and forest processes and practices could boom by driving efficiency and productivity of domestic food production through e.g., reducing food waste and wood scrap materials.

With respect to this trend, digitalisation in agriculture and forestry might play out in the following aspects:

- Digitally enabled innovation in agricultural practices can gain relevance by finding ways to boost agricultural and forestry production outputs - while reducing import fertilizer and energy intensive input dependencies.
- Virtual simulations can speed up R&D on substitutes for protein and carbohydrate sources as well as for energy intensive fertilizers.
- Digital food and wood product market modelling might help to identify alternative suppliers and optimise food, feed and other biomaterials imports.
- Tracking of supply chains and food and wood product origins, as well as monitoring of agricultural and forest production is becoming more important for ensuring legality and sustainability of the resources and their origins. Hence, digital tracking and tracing as well as monitoring tools and automated image interpretation are gaining relevance.

Changed Perspectives for Agriculture and Forestry in a Post-war, Enlarged European Union that Includes Ukraine

Summary and Key Words

The Russian war in Ukraine has been significantly affecting global food supplies, due to sanctions, rerouting of trade lanes, land seizures, rising input prices, and destroyed, mined and contaminated land. Additionally, the Russian invasion has accelerated the process of Ukraine joining the European Union (EU). A possible EU enlargement, especially including the envisaged future membership of the agricultural powerhouse Ukraine, would affect the competitive landscape in the agri-food and forestry sectors, with enlargement likely to bring about a shift of large players in EU agriculture and forestry. Also, rebuilding Ukraine agriculture and forestry could be a window of opportunity to reinvent and innovate these sectors. Potentially, Ukraine could become a role model for digital agriculture and forestry innovation in Europe, as well as for green and sustainable agriculture. At the same time, regional disparities in a larger EU will likely become wider, while pre-accession support and cohesion policies can counteract this and drive digital infrastructure expansion in peripheral regions.

Key words: EU enlargement / Common Agricultural Policy / Open strategic autonomy / Supply chain disruptions / Post-war Europe.

Current and Future Developments of the Trend

The war in Ukraine continues to significantly impact the country's economy, people and environment. Prior to the war, agriculture represented 41% of Ukraine's exports and the country benefited from an estimated 32.7 million hectares of arable land (Albaladejo Román, 2024)[10]. At the end of 2023, estimates placed the damages and losses to the Ukrainian agricultural sector at around €73 billion, with rebuilding expected to cost around €51 billion and demining an additional €29 billion (Albaladejo Román, 2024; Neyter et al., 2024). These figures will likely continue to rise for as long as the war continues. In addition, the continuing war in Ukraine leads to increasing macroeconomic uncertainties, e.g., concerning energy prices, inflation, and geopolitical challenges for the EU, also impacting strongly on the EU Agricultural Outlook to 2035 (European Commission, 2023a).
Against this backdrop and spurred on by Russia's invasion, Ukraine applied for EU membership in February 2022 and was granted candidate status in June 2022. As of July 2024, EU leaders are welcoming Ukraine's progress in advancing the necessary reforms to fulfil EU membership criteria. By now, the European Council has indicated 2030 as a potential date for Ukraine's membership (European Council, 2023). Reforms to the Common Agricultural Policy (CAP) are likely necessary before Ukraine is admitted to the EU. Both the final shape of the reforms and scale of the war will strongly shape the future of the agricultural sector in an enlarged EU.

Recent Signals within the Scope of the Trend

Militarization and War Alter Biodiversity in Affected Areas

War and military activities have significant consequences for biodiversity, including large-scale habitat alteration, environmental pollution, and contamination (Lawrence et al., 2015). In addition to the environmental consequences of war, the increasing militarization within Europe (including calls for more military training areas to improve defence capabilities) place additional pressure on land available for agriculture and forestry. If such areas are to be converted back to productive farming land once the threat of war has subsided, this will likely require significant investment and time. For example, the costs associated with bringing 80% of the potentially contaminated lands in Ukraine back to normal use are estimated at €29 billion, with the process estimated to take around 10 years (Albaladejo Román, 2024). However, these figures do not take losses in production or human costs into consideration.

Post-War Rebuilding of Ukraine's Agricultural and Forestry Sectors

Next to challenges implied by the sheer scale of the post-war costs associated with rebuilding Ukraine's agricultural sector (estimate assume costs of €80 billion in 2024 for rebuilding and demining (Albaladejo Román, 2024; Neyter et al., 2024)), experts also see a window of opportunity to reinvent the agricultural sector (Adelphi, 2023). They see the potential for Ukraine to become a role model for digital agriculture/forestry innovation in

[10] Current comparisons between Ukraine and the EU agricultural sectors show the size of the potential added value to agriculture of Ukraine joining the EU: The combined 2021 production of the EUs three main crops totalled 30 million tonnes of wheat, 73.5 million tonnes of maize, and 10.3 million tonnes of sunflower. While Ukraine's produced 16.4 million tonnes of sunflower, 10.8 million tonnes of factory sugar beet, 3.5 million tonnes of soya, and 2.9 million tonnes of rapeseed (Albaladejo Román, 2024).

Europe, as well as for green and sustainable agriculture. A 'build back better' approach could modernise Ukrainian agriculture and push the sector to increase its added value, i.e., from predominately low-added-value grains and oilseeds (Albaladejo Román, 2024). The human costs of war, including loss of labour and expertise, could also be a driver for automation and decision support systems, as the skilled workforce will take significantly longer to rebuild.

EU Enlargement to Redefine Common Agricultural Policy

If and when Ukraine joins the EU, significant impacts can be expected for the agricultural and forestry profile of the larger Union. On the one hand, this offers the opportunity to bring Ukraine's legislation into line with EU environmental and agricultural legislation. On the other hand, it brings with it the potential to reform current EU policy, such as the Common Agricultural Policy (CAP). For example, some studies argue that Ukraine's membership would encourage the EU to abrogate area-based agricultural subsides, a move that would favour nature conversation over the current set-up that primarily benefits large landowners and agro-industrial conglomerates (Wolczuk, 2023). Aside from policy implications, with around a third of the world's arable land, Ukraine's accession would strengthen the EU as a dominant agricultural producer and exporter on the world stage, accounting for around 30% of global wheat exports (Albaladejo Román, 2024; Wolczuk, 2023). Furthermore, Ukraine, with a population of over 40 million, would likely become a rapidly growing market for EU agri-food producers and for EU capital and enterprises (Albaladejo Román, 2024).

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

The opportunity to rebuild a better Ukrainian agricultural sector, as well as to redefine the EU's wider agricultural policy (CAP) in the process of accession agreements, has far reaching consequences for Europe's agriculture and forestry sectors, including the possible acceleration of the uptake of digitalisation in relevant areas. With EU enlargement, the EU's agricultural sector would grow significantly, providing ample opportunities to improve productivity and efficiency, as well as to ingrain more sustainable practices, especially as large agricultural enterprises currently dominate the Ukrainian market – with ten companies that cultivate areas of more than 100 000 hectares in control of 71% of the market (Lorenzen & Wetzels, 2023; Albaladejo Román, 2024).

- In newly rebuilt Ukrainian farmland, the digitalisation of farm and forest processes and practices could be implemented on a large scale. This could include, for example, the full automation of agricultural machinery to alleviate effects of probable shortages in workforce.
- Smart and precision farming practices might leapfrog older farming practices, as technology-savvy foreign agricultural players invest in the market, such as the seed conglomerate Bayer-Monsanto or the US grain trader giant Cargill (Lorenzen & Wetzels, 2023).
- Remote sensing could be rapidly adopted to monitor the state of the growth, project yields, identify pest issues, etc. especially in larger farms with access to greater capital.
- Additionally, digitalization could be adopted in environmental monitoring to enable governments and supervisory authorities to control compliance with newly adopted EU environmental regulation in areas such as water quality, air quality, soil quality, etc.

Increasing Need to Tackle Biodiversity Loss

Summary and Key Words

Biodiversity loss is a major global and European challenge, driven by land use change, overexploitation of species, climate change and pollution. Agriculture and forestry are affected by the decline of ecosystem services such as nature-based pollination, pest control, or soil nutrients. Both sectors are also a driver of biodiversity loss, e.g., through large scale monocultures, expansion of intensive land use, and excessive use of agrochemicals. The adaptation of agricultural and forestry practices can help to restore and protect biodiversity.

Key words: Resource scarcity / Biodiversity loss / Climate change / Cultivation practices / Environmental monitoring.

Current and Future Developments of the Trend

Biodiversity is declining around the world due to habitat destruction, overexploitation, pollution and climate change, with one out of eight species threatened with extinction (IPBES, 2019). Many forms of agriculture and commercial forestry are themselves characterized by monocultures and a lack of or adverse effects for biodiversity (Lécuyer et al., 2021). The stress on nature exercised by food production is driven inter alia by growing populations, the economic conditions of farmers, conditions of international trade and a policy environment that rewards intensive farming.

Tackling the biodiversity crises and its conflicts with agriculture requires acknowledging the underlying long-rooted factors under dispute[11], addressing local trade-offs between biodiversity conservation and yield improvement, and implies a need for measurable targets and a new approach of cooperation (Lécuyer et al., 2021). Already today, many global and regional policies are targeting biodiversity loss: For example, the 2022 Kunming-Montreal Global Biodiversity Convention sets out an ambitious pathway for a global vision of living in harmony with nature by 2050 (UNEP, 2022). In Europe, the EU biodiversity strategy for 2030 was transformed into the first continent-wide Nature Restoration Law in June 2024, putting measures in place to restore at least 20% of EU's land and seas by 2030, by requiring EU countries to set up National Restoration Plans (EU, 2024).

Recent Signals within the Scope of the Trend

Spoonbill Population Threatened by Agricultural Activity

The Eurasian spoonbill all but disappeared from France in the 1500s, only to reappear in the 1970s in Loire Atlantique (European Environment Agency, 2020). The wading bird requires wetlands and is an indicator of the overall health of wetland ecosystems (Padmakumar & Shanthakumar 2024). Despite French conservation measures, the status of the protected spoonbill in France is still fragile due to agricultural activity in key sites for the bird. The bird's feeding areas are drained by farmers as well as by power companies, and intensive farming contributes to water pollution that affects wetland habitats. The survival of the bird depends strongly on an effective control of water levels, the protection of flood plains and a continuous monitoring of the vegetation and situation in the wetlands (European

[11] Respective factors are for example land sparing (landscapes specially for food production or biodiversity conservation) and land sharing (integration of conservation into human land-use) (IPBES, 2019).

Environment Agency, 2020). Digital tools for remote sensing could also support in monitoring and tracking harmful behaviour affecting wetland and the bird population.

Farmers Could Grow a Larger Variety of Crops on their Land, Supporting Biodiversity

Although 6,000 food crops are available worldwide, two thirds of our diets depend on only nine crops, with these crops using 90% of all available agricultural land globally (FAO, 2019). To increase the diversity of food crops on the land, researchers and farmers are testing the implementation of strip cultivation by adjusting their production practices (WUR, 2024). Instead of large monocultures, land is sub-divided into smaller strips where a composition of crops is produced side-by-side to raise the diversity of crops. Main benefits are inter alia reduced soil erosion, increased soil fertility, and improved biodiversity (Earthhow, 2024). However, strip farming requires the selection of appropriate crops and different harvesting, storage and processing techniques. This example shows that new cultivation methods can utilize positive ecosystem interactions, increase the variety of crops and contribute to biodiversity.

China's Ties to Foreign Agricultural Land are Affecting Biodiversity

China undertakes various activities, nationally and abroad, to safeguard its food security (Donnellon-May, 2023). This is driven by concerns about the impact of water scarcity, of droughts and of floodings on its domestic and imported food supply, which is also related to the spread of diseases such as African swine fever (Chang, 2019). To safeguard imports, China rents and buys farmland in Latin America, Central Asia, Eastern Europe, Africa, and even the US (Donnellon-May, 2023). In addition, China concludes free trade and agricultural cooperation agreements mainly with Belt and Road Initiative countries as part of China's Food Silk Road (Tortajada & Zhang, 2021). Such foreign large scale capital-intensive farming has been criticized for its negative impacts including deforestation, erosion, and loss of biodiversity due to monoculture plantations (Gironde, 2020). Concerning future perspectives, China for example plans to build 25 large scale industrial pig plants in Argentina that produce meat only for export to China, three of which are already in construction (Euromeat, 2023). Here, Argentinean NGOs have raised concerns about possible consequences of deforestation, soil and water pollution, water depletion from plants, and monoculture farming of soy and corn for feed provision, which would heavily affect biodiversity (Koop, 2020).

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

Strip farming is shown as an example of improving biodiversity in agricultural practices. For large applications, specific machineries are needed. It requires innovations in precision agriculture technologies that can manage small but diverse plots for crop production. In contrast to large scale monocultures, precision agriculture machines must perform activities per square meter or per individual animal (WUR, 2024).

- Respective plant-specific farming includes GPS, sensor technology, ICT and robotics, with sensors recording data on crops and soil, while software identifies

deficiencies and needs and can propose location-specific treatments; other software programs define nitrogen application per area (e.g., a strip).
- New types of cultivation approaches can increase the variety of tasks for machines, with e.g., strip farming requiring different machines.
- Robotics, in particular, will rely on cutting edge sensing cameras and adaptive learning and an "understanding" of the high variety of conditions on the field.

Monitoring of the state of biodiversity and understanding what this means for the resilience of the ecosystem, requires strong advancements in remote sensing and automation to assess the degree of vulnerability and to provide information for the prioritisation of conservation activities.

- Remote sensing and monitoring data are needed to control compliance of agriculture and forestry player's actions with respect to environmental regulation and beyond by public authorities. Documented evidence could help to overcome law enforcement deficits to control big and small players (as shown here with Chinese agriculture actors or French farmers activities in bird reserves).
- Specific Biodiversity Data Spaces might be required – beside Agriculture Data Spaces or Forestry ones – for enabling a safe exchange of respective data between various data producers.
- Already today, digital monitoring techniques are used in forestry and agriculture to detect diseases or wildfires at an early stage (Brunori et al. 2021) and to trace food and wood throughout the supply chain. The main reason for monitoring is often economic: to preserve yields in both forestry and agriculture.
- Assessing and interpreting monitoring results requires strong expertise as results in biodiversity are very context sensitive and trade-offs need to be expertly assessed. For example, preventing wildfires and diseases may be beneficial for biodiversity, even though wildfire and disease have a function in the long-term preservation of ecosystems. Hence data analytics need to undergo a steep learning curve and gain critical expert support.
- There are also other monitoring programmes such as Global Forest Watch (Hedberg and Sipka, 2020), in which the European Space Agency ESA launched Φ-sat-1 to collect data on the state of the earth, including the state of vegetation and water quality. Other private-sector initiatives include Google Earth and Microsoft's AI for Earth (ibid.).

Cybersecurity Issues and Network Vulnerability Affect Digitalisation in Agriculture and Forestry

Summary and Key Words

Digital technologies with their sensing, communication and information gathering devices and fixed as well as mobile network infrastructure can be potentially misused as a means of surveillance, espionage, and sabotage. Digital tools in agriculture and forest technologies could become the next frontier in cyberwarfare. The increase in hacking and rising risks of infrastructure failure or malicious attacks of digital agriculture and forestry systems (for the processing industry and for supply chains) also increase the risks for food and biomaterial supply security and safety, which in turn can e.g., increase market prices due to rising costs.

Key words: Vulnerability / Digital divide / Data security / Hacking / Espionage / Sabotage

Current and Future Developments of the Trend

While the expansion of digital infrastructure in Europe is progressing overall, there are still gaps, particularly in rural areas. In 2023, only 56% of households in Europe had fibre-optic connection, and in rural areas this figure was only 41% (European Commission, 2024). Furthermore, the rollout of mobile 5G networks is falling short in terms of quality and coverage, due to limited investments (European Commission, 2024). Hence, telecommunication networks are subject to age-related failure and are lacking interoperability and scale for the application of the Internet of Things (IoT) in industry, agriculture and forestry (European Commission, 2024). At the same time, there are risks posed by the dependency on non-EU providers for components in digital infrastructure, farming and forestry devices and systems, e.g., concerning hacking, espionage and sabotage from various actors (which can be hostile foreign countries, malicious business competitors, terrorists, or activists). However, domestically sourced components are also not immune to such risks. A review of disclosed cybersecurity incidents between mid-2011 and April 2023 showed a rising frequency of cybersecurity threats to the food and agriculture sector globally (Kulkarni et al., 2024).

With the growing numbers and types of digitally connected industry applications and possible entry ways to hacking, incidents of espionage and sabotage are rapidly rising. For example, the IoT platform market alone is expected to grow annually by 29% globally until 2030 (Precision Reports, 2024). The EU is aware of the risks and in February 2024 proposed a collection of measures to address connectivity targets and the resilience of digital systems (European Commission, 2024c; NIS Cooperation Group, 2024).

Recent Signals within the Scope of the Trend

Espionage Enabling Equipment in Machines and Infrastructure

The involvement of Chinese technology providers in US and European data infrastructure projects in areas such as telecommunication are assessed as high-risk for security threats (European Commission, 2023b). There are allegations of spying and espionage or possible backdoors, and fears of Chinese state connections with the respective technology providers. Hence, since 2018, Chinese suppliers (including major actors such as Huawei and ZTE) have been banned as technology suppliers to 5G network infrastructure build-up in Japan, the US as well as in several EU countries (Kroet, 2024). A cross-sectoral perspective on evidence for cybersecurity risks appearing in various fields can also sensitise agriculture and forestry actors to widen their risk radar: For example, in early 2024, an investigation by the US Homeland Security on critical infrastructure vulnerabilities raised concerns about espionage and sabotages. Homeland Security identified cellular modems, firewall and networking equipment at several Chinese supplied giant ship-to-shore harbour cranes at US seaports that were not part of the contract nor functional for the machine (Homeland Security, 2024). As military equipment is also handled by these cranes, the US wants to spend €18 billion in replacing the respective cranes (Kuś, 2024). (Semi-)Autonomous machines like self-driving or assisted cars or smart and precision farming devices also include dozens of sensors and can be used as a ubiquitous interface for spies (Eliot, 2021).

Cyberattack on Food Processing Company Exemplifies the Vulnerability of Smart Farming Devices

Data security is a growing concern in the agri-food system, and it can create global repercussions in highly interconnected multinational companies. For example, a ransomware attack in 2021 on the Brazilian meat processing giant (JBS Foods) led to a 5-day production shut down in facilities in the US, Canada, and Australia, causing temporary record-high meat prices (Claughton & Beilharz, 2021). Beside food processing, agricultural and forestry AI also comes with systemic risks for farms, farmers and food security that are often poorly understood and underappreciated (Tzachor et al., 2022): Automatic farm and forestry machines like ag-bots[12], crop sprayers, drones and robotic harvesters and decision support systems can be hacked, data can be stolen, and data and machines can be manipulated. As such, various technical dimensions of Smart Farming and Precision Agriculture can also be attacked: hardware, network and related equipment, data, code and applications, support chains, and other entities like people or institutions (Yazidinejad et al. 2021). These issues can lead to potentially dire implications for global food prices, among other issues.

Connectivity Risks Due to Reliance on Single Networks and Providers

The provision of digital connectivity through infrastructure is at risk to accidents, sabotage, and business interruption. Beside cyber risks, physical threats are particularly pertinent for network infrastructures that are not able to be fully monitored or protected. For example, an incident in April 2024 involving a sinking ship led to severe damage to four undersea fibre-optic cables in the Red Sea that carry 97% of the global internet traffic, requiring global rerouting and affecting transmission speed in huge parts of the world (Folk, 2024). Connectivity is further at risk of becoming commercially unviable for infrastructure providers to invest into infrastructure built-up or maintain services in rural areas and the periphery due to low population and business density and long distances to cover. This causes installation costs with relatively low return on invest (CORA, 2021). Furthermore, dependency on regional monopolies can drive service costs up as well as increase the risk of regions being left behind in terms of infrastructure provision. Overall, the rural digital connectivity gap is constantly declining but persists in Europe – user density and high infrastructure investment costs in rural areas requires public funding for new installations (Arcuri, 2023; de Clercq et al. 2023). Reliability and service continuity of network infrastructure are at stake; however, they are the precondition for using digital agri -and forestry technologies.

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

The reliability of digital infrastructure is a precondition for the functioning of smart and precision farming and forestry applications.

- Digital farmers and forest owners might need back-up solutions or to set-up local data networks to ensure the reliable functioning of digital technologies in their business. Low data solutions that do not need 24/7 internet connectivity and local area data networks might be required here.

[12] Autonomous agricultural robots.

- Agri- and forest-technologies could become the next strategic area for espionage. Modern smart farming and forestry machinery, agricultural and forest data spaces, as well as agri-food supply chains and Industry 4.0 food processing plants are possibly subject to hacking, sabotage and espionage. For example, as China increases its activity in the field of green technologies, its influence could strengthen in the European digital agriculture and forestry domain.
- Other respective security threats could be posed by other foreign players, non-state actors and terrorists. Such risks include, for example, the estimation of yields to influence market prices or to gain competitive advantage, the manipulation of sensitive data to influence carbon pricing, fake due diligence by influencing regulatory monitoring, or the sabotage of connected machinery to influence food and bioeconomy product provision and hence influence food and bioeconomy security and safety (Demestichas et al., 2020).

Bio- and Nanotechnologies Can be a Lever for Next Generation Agriculture and Forestry

Summary and Key Words

Technological advancements in bio- and nanotechnologies, omics, and their conversion could help to discover innovative ways for agriculture and forestry to manage challenges like new and invasive pests and the need for climate resistant crops and livestock. Such technologies enable the development of new types of nano-bio-fertilizer which could be highly efficient and have less negative environmental side-effects. Bio-sensors can offer near-real time in-depth understanding of the state of soil, plants, livestock, etc. enabling precision farming that suits the micro-local needs.

Key words: Biotechnology / Nanotechnology / Biomanufacturing / Genetics / Biosensors / Nano-fertiliser

Current and Future Developments of the Trend

The climate crises drive unknown stress factors for plant and livestock growth, such as weather conditions and new diseases and pests, that can lead to decreasing yields and more crop losses. Some agricultural practices, such as forms of factory farming, have in the past led to the resistance of plants and livestock against veterinary pharmaceuticals including antibiotics, pesticides, and herbicides, etc. (Mann et al., 2021; Policy Horizons Canada, 2024). By now, engineering biology, biotechnology and the integration of multiple disciplines have enabled the development of biotechnological approaches and interdisciplinary tools, including genetic engineering, genome sequencing, and genome editing technologies. Use cases are, for example, helping to predict the robustness of species in changing environmental conditions, as well as creating crop cultivars and breeds that meet food and bioeconomy product demands (Aurand et al., 2024; Munaweera et al., 2022; Anderson & Song, 2020). Furthermore, the agricultural biotechnology sector also includes molecular diagnostics, vaccine and veterinary pharmaceuticals, bio-pesticides and bio-fertilizers developments, biofuels developments, etc.

The global market size for agricultural biotechnologies was €110 billion in 2023 and is expected to grow to €270 billion by 2034 (PMI, 2024); and the global market size of agricultural nanotechnologies in 2024 is estimated at €350 billion and may get to €1080 billion by 2034 (PMI, 2024). Despite high public awareness and strong regulation of genetically modified organisms, the EU market is strong in this area, drawing on an innovative and competitive biotech industry. In the next years, Artificial Intelligence is expected to further drive biotech innovations. Concerning future policy conditions, the European Commission has announced a more coordinated approach for biotechnology and biomanufacturing to strengthen the competitiveness of European players and further realise their potential (European Commission, 2024a).

Recent Signals within the Scope of the Trend

Bio- and Nano Tech for Cultivation of Climate Adaptive Plants and Animals

Numerous efforts are ongoing to advance research around biodesign and gene editing to cultivate plants and animals which are adapted for the ongoing and expected change in climate conditions. Affordable gene sequencing is the basis for compiling a huge gene pool of varieties and breeds from different climate zones, with specific robustness or yield characteristics, and for different eras using natural museum archives and prehistoric finds (Munaweera et al, 2022). The wide gene pool allows researchers to predict the adaptive potential of plants and livestock and to combine and develop possible biodesigns that potentially contain various characteristics and performances (Andersen & Song, 2020). In addition, new genomics approaches in gene editing, RNA interference to regulate gene expression, the application of nanotechnology to genetic manipulation and new interdisciplinary collaboration of ecology, system biology, molecular genetics and conservation agriculture, can help to more systematically cultivate new sorts and breeds for food, feed, biomaterials as well as for biodiversity conservation that are less vulnerable to climate change impacts, diseases and pests (Alexandrova-Stefanova et al., 2023; Munaweera et al, 2022; Aurand et al., 2024; Anderson & Song, 2020). For example, the company Colossal successfully reconstructed the chromosomes structure of a mammoth living 52 000 years ago, that was excavated in 2018 (Leatham, 2024). This is part of a “moonshot mission” to repopulate the Siberian tundra with cold-adapted elephants that involves the ancient genome to contribute to landscape conservation and indirectly prevent melting of the permafrost (Doxzen, 2021).

Biosensor Technologies Enable Real-time Understanding of the State of the Local Environment

New sensor approaches using biosensing based on enzymes, whole cells, antibodies, or DNA offers a new detection principle for on-site monitoring of environmental conditions and developments (Gavrilas, et al. 2022; Huang et al, 2022). Bioelectronic sensing to achieve nearly real-time data about environment and health situation is required for applications like precision farming. For example, by combining synthetic biology and materials engineering, researchers programmed coli bacteria to produce electrical current output within minutes when detecting chemicals like endocrine disruptors[13]. This approach provides a platform for miniature, low-power bioelectronic sensing of various chemicals (Aktinson et al., 2022). Various nano-biosensors offer portable low-cost solutions for assessing plant and soil health, nutritional status, hazardous chemicals, and stress levels of plants in the field. They sense physiological signals at low detection limits and translate them into standardized detectable

[13] chemicals that interfere with human hormones already in extremely small doses in a harmful way.

signals (Mondal et al. 2022). While most of these new sensor types are not yet commercially available, they have a huge potential in sustainable smart and precision agriculture and forestry, environmental monitoring, next generation biomanufacturing and precision medicine (Mondal et al. 2022; Dixon et al. 2021).

Novel Nanomaterials Revolutionise Fertilizers with More Efficiency and Less Negative Side-effects

Today, chemical fertilizers are dominant in global agricultural practices to deliver the necessary nutrients for plant growth. However, their excessive use has negative side effects on soil microflora, environmental contamination, and human health. In contrast, the emerging application of nano and nano-biofertilizers promises high-quality and high-yield food production while limiting ecosystem damage. This new type of nanotechnology enabled biogenic fertilizers increases the efficiency of nutrients uptake. For example, nanoparticles enter plant cells and penetrate leaf interiors at a much higher degree compared to conventional fertilizers (Iha et al., 2023; Basavegowda & Baek, 2021). In another case, MIT chemical engineers developed a coating for bacterial cells that make them applicable in large scale agricultural use. The underlying bacteria convert nitrogen gas to ammonia, thus providing nutrients as microbial fertilizer to the plants with the possibility to replace chemical fertilizers (Trafton, 2023).

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

The impacts of novel respective materials for the agriculture and forestry sectors are numerous. Digitalisation plays a major role in the development of resilient organisms, better fertilizers and pesticides, by using repositories of material and gene data, and by using insights from new sensor types for next level precision farming and forestry:

- Digitalisation will enable and enhance the potential of synthetic biology as an approach to redesign and engineer organisms that have the potential to make plants and livestock more resilient; this also opens new opportunities for the bioeconomy by replacing fossil-based products and processes (World Economic Forum, 2024).
- Advances in deep learning can enable the virtual simulation of cultivation and breeding experiments, as well as the development of new gene based veterinary drugs, fertilisers and pesticides.
- AI-enabled biodesign factories (biofoundaries) could scale up pilot experimentation in biomanufacturing, supporting interdisciplinary research and developments (European Commission et al., 2024; European Commission, 2024).
- Building up a genomic data infrastructure of gene banks could be used as a pool for genetic variations, with such repositories containing flora and fauna characteristics in standardised passport data type (Munaweera et al., 2022).
- Digital museums and herbarium collections can open new ways of understanding biological responses to climate change in an historical context (Anderson et al., 2020).
- The European Commission (2024) communication “Building future with nature” highlights the role of AI for biotechnology and biomanufacturing. This includes human health focused action like the 1+ Million Genome initiative and the Virtual Human

Twin which could both potentially be applied for environment, plants and livestock gene data infrastructure and to create a 'Virtual Environment Twin'.
- In the future, new types of digitally connected sensors and deep learning on successful growth conditions and vulnerabilities could be the basis to build up a Digital Twin of the field, forest or environment.
- Hence, it could facilitate new forms of smart and precision farming and forestry as well as new ways of providing agriculture, forestry, and environmental policies.

Technology Solutions for Agriculture and Forestry to Deal with Climate Stress

Summary and Key Words

In the open land, geoengineering and microclimate management measures are discussed and tested to mitigate negative impacts of climate change and to manipulate climate and weather at the microlevel, or regionally. Geoengineering includes measures such as atmospheric sulphur spraying that mimic volcano eruptions, or the storage of carbon as greenhouse gas. Also, next generation desalination and irrigation technologies that are extremely energy efficient could overcome water scarcity in coastal regions. These advancements could turn formerly unutilized or abandoned land into areas fit for food production or afforestation. In this context, digitalisation (with e.g., water demand and soil condition monitoring) could enable more efficient use of irrigation, avoiding side-effects like soil salinisation.

Key words: Agricultural practices / Geoengineering / Carbon sequestration / Microclimate management / Water desalination

Current and Future Developments of the Trend

According to the EEA (2024), Europe is not adequately prepared for rapidly growing climate risks, with food production and natural ecosystems including forests both likely to be affected. Respective developments are expected to lead to cascading effects on food security, human and animal health, rural and coastal livelihoods, vulnerable populations, and the wider economy (EEA, 2024). Already today, agriculture and forestry as well as parts of the natural ecosystems are suffering from water stress, in particular in the Mediterranean; in the whole of the EU, 29% of the territory was affected during at least one season in 2019 (EEA, 2023). Climate change, water supply and consumption for populations, energy supply, industry as well as for tourism and agriculture all play a major role for European water resources, with the situation expected to worsen until 2050 (Bisselink et al., 2020).

To mitigate climate change, geoengineering approaches[14] are already being analysed and tested, and forms of agricultural practices are being developed that allow animals, plants and soil to better deal with changing climate and weather conditions. However, according to EEA (2022), the EU food systems policy is not yet strong enough to phase out unsustainable modes of production such as using harmful technologies, substances, and practices. Hence, a growing variety of adaptation methods in agriculture and forestry can be assumed:

[14] like reducing solar radiation or binding CO_2 so that it is not released into the atmosphere

including conventional practices beside a growing number of innovative sustainability-oriented practices.

Recent Signals within the Scope of the Trend

Geoengineering: Agriculture and Forestry Contributes to e.g. Carbon Storage

Solar geoengineering in the form of solar radiation management is based on the idea of mimicking a volcanic eruption's stratospheric sulphate aerosol emissions that reflect sunlight and hence has cooling effects. Some authors assess that cooling benefits for agricultural productivity might be neutralized by scattered solar radiation (Proctor et al., 2018), others estimate an increase in global crop yield by about 10% (Fan et al., 2021). Other types of geoengineering aim at removing CO_2 from the atmosphere to limit global warming. Here, carbon capture and storage (or utilization) are widely discussed and beginning to scale up and gain momentum with 41 projects in operation and 351 in development globally (Global CCS Institute, 2023). Beside these industrial size installations, agriculture and forestry play a crucial role in carbon sequestration or carbon farming. Here, soil carbon sequestration and biochar are methods to bind CO_2 in the soil that improve soil quality and promote food availability (McDonald et al., 2021; Kortetmäki & Oksanen, 2023; Wani et al., 2021). Also, reafforestation is a natural way of binding carbon in trees and drives the expansion of forests[15]. These types of carbon farming in agriculture and forestry are seen by the European Commission as a business model for healthier ecosystems, providing revenues for land managers e.g., by selling carbon credits (European Commission, 2021a and 2021b).

Microclimate Management: Using Nature-based Solutions to Adapt to the Climate Crisis

Global and regional geoengineering can provide quick fixes to the climate crises, while local microclimate management can manipulate local climatic conditions to optimize agriculture and forest production (Cach-Pérez et al., 2021; Menge et al., 2023). Practices like shading, mulching, applying covers, windbreaks, insect nets, and irrigation systems offer mostly nature-based solutions to improve yields and quality, control pests and diseases, enhance water use efficiency, improve soil health and support climate change adaptation and even increase carbon uptake and storage (Biswas et al. 2023). The European Union supports sustainable practices through its Common Agricultural Policy, and the LULUCUF Regulation (OECD, 2023).

Leaps in Low Energy Consuming Water Desalination Could Open New Opportunities for Agriculture and Land Use

Today, water desalination plays only a minor role in Europe, providing about 3 billion m^3 of desalted water each year (Adamovic et al., 2019). Desalination plants are usually heavily energy consuming; hence, several alternative concepts are under development to find low energy consuming desalted water provision. For example, MIT researchers developed a system of solar powered evaporation and thermohaline convection that provides freshwater cheaper than tap water. However, it is so far just a lab experiment and designed for household size applications (Chu, 2023). Innovative large scale low energy desalination pilots use, for example, forward osmosis filtering that requires less pressure than the dominant reverse osmosis concept (McKee, 2023). Access to clean desalinated water could

[15] In contrast, using land for bioenergy carbon capture and storage (BECCS) is seen as problematic as large scale biomass production competes with land and water for food, forests and nature (Kortetmäki & Oksanen, 2023).

help to expand agricultural production in coastal areas with irrigation systems without harming groundwater bodies.

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

- Carbon farming as a business model requires proofing of the climate service provided. Digitalisation can support reliable monitoring, data analysis and reporting processes. Digital sensors could improve the accuracy of measuring carbon uptake and the verification of its long-term carbon sequestration benefits.
- Digital farm administration helps to document cost shares attributed to carbon farming. Market platforms can provide access to clients who want to buy carbon credits (McDonald et al., 2021).
- Smart agriculture devices can support microclimate management. Through using ground sensors and remote sensing data, real-time monitoring can improve microclimate management strategies.
- Irrigation systems that draw on low-cost desalinated water require proper irrigation and humidity monitoring to find ways to manage good crop growth and soil quality, similar to microclimate management.
- Crop simulation models, as well as a Digital Twin of the microclimate conditions on the field, can help to choose the adequate crops and livestock.
- For cultivation strategies and daily management, AI based on the crop simulation models can provide respective decision support systems to farmers and forest owners, helping to mainstream good microclimate management practices that can be shared with others with less experience.
- Using autonomous agriculture robots in microclimate farming requires innovative machines that better adapt to the variety of cultures on the field.

As such, digitalisation can help climate-smart agriculture applications and practices (Gupta et al., 2022; Pedersen et a., 2024). For example, the Horizon 2020 project Stargate project links microclimate management with climate-smart agriculture approaches and advances respective digital technology solutions (Stargate, 2024).

Intensification of Biological Resource Production in Controlled Environments

Summary and Key Words

The expansion of food production in controlled environments[16] is driven by numerous factors, among them increasingly harsh environmental conditions, increasing safety requirements for food production, a growing need for efficiency improvements and a growing competition for land. Concerning respective solutions, a variety of different approaches exist

[16] such as greenhouses, vertical farms, or bioreactors

already, and others are currently in development. Examples include hydroponics in greenhouses or vertical farms, aquaponics that aim at closed nutrient cycles, or the production of food, feed and biomaterials in industrial processes and bioreactors. However, as of today, the application of respective solutions remains limited to certain plants, cells and species, ranging from leafy greens to algae, insects to lab grown meat. With respect to their impact, e.g., algae, insects and other sources produced in controlled environments are regarded as a potential solution for providing novel protein sources for the growing global population, with much lower resource use than protein sources which are currently commonly consumed.

Key words: Controlled agricultural environment / Vertical farming / Algae farming / Artificial meat / Insects as a protein base

Current and Future Developments of the Trend

For decades, farming in controlled environments, such as greenhouses, has been used to extend the season and to grow plants that would otherwise not grow in outdoor climate conditions. For example, through the extensive use of controlled environments for food production, the Netherlands has become the world's second largest food exporter after the US (Walsh, 2020). In broad terms, the controlled environment agriculture concept covers various areas such as stacked layered vertical farms, aquaponics that integrate fish farming in the nutrient cycle, or production of organisms and cells in bioreactors. This approach works for leafy greens, herbs, certain fruits and vegetables, insects, algae, animal and plant cells, but not for bulk commodities like grain, legume or root vegetables such as potatoes and carrots. For the past 10 years, the innovation rate in this area has been especially high, with respect to new architectural approaches such as vertically stacked layers, or in high tech applications in lighting systems, intra-logistics automation, nutrient recycling, etc. (Wiklund, 2023). Hence, the input of resources can be optimised through an increase in control of the living organisms in the farm, the dosage of pesticides, nutrients, water and light, and the circular recovery of resources. Open-field farming is increasingly under pressure from weather stress, water scarcity and new pests, farmers must take growing efforts to reduce the negative impacts of intensive farming including fertilizer and pesticide washout into water bodies (Devot et al., 2023; Schürings et al., 2024). By reducing external influences and better controlling the flow of nutrients, controlled environment agriculture is becoming one solution for parts of farming, and to a certain amount to forestry (cultivation of seedlings). In addition, consumers request fresh, healthy, and local produce, driving urban farming initiatives including vertical farms (Khan, 2024).

The market for controlled environment agriculture is expected to more than double between 2022 and 2029 to nearly € 200 billion globally (Petruk, 2024). However, the start-up market that rose over the last 10 years is currently in a highly competitive transition phase in what is called "the valley of disillusion" with some start-ups filing bankruptcy (Wiklund, 2023). Nevertheless, controlled environment agriculture is regarded as being at the verge of a new upswing through innovations in energy solutions, circularity, and integration in urban planning (Gordon-Smith, 2024). Countries with limited agricultural space, like Singapore, are strategically deploying vertical farming to achieve local food production of 30% by 2030 and to reduce foreign dependency on food supply (Gordon-Smith, 2024), while the European Union aims at strategically exploiting algae as bioeconomy resource (European Commission, 2022b).

Recent Signals within the Scope of the Trend

Giant Vertical Farm Project GigaFarms in Construction in Dubai

In 2024, the construction of the world's largest vertical farm began in the United Arabic Emirates. Dubbed 'GigaFarm', it operates as a closed loop circular waste-to-value system. Starting at a size of 80 000 m^2 and 12-meters high, it aims to grow 3 million kilograms of leafy greens, herbs, and vegetables by 2026 and to reduce the UAEs food imports (ReFarm TM, 2023). The project is also expected to limit freshwater and external pesticide use in its controlled environment, and to replace fertilizer by onsite compost and nutrients from wastewater recycling, thus also contributing to national decarbonization efforts. GigaFarm plans to also grow mangrove seedlings for reforestation efforts (IGS, 2023). Other comparable concepts integrate fish tanks into the farm to produce food integrated in the nutrient cycle (Santosh et al., 2024). Large scale vertical farms are ideal for data-driven farming practices, and AI driven automation; however, the technology learning curve needs to cut down costs for automation solutions for their application in smaller farms (Campbell, 2024).

Advancements in Controlled Environment Production of Alternative Proteins

Meat and dairy production accounts for at least 11% of global greenhouse gas emissions[17] (Blaustein-Rejto & Gambino, 2023). Today, several plant-based substitutes for meat-based protein are already available on the mass market, while insect-based proteins are used mainly for feedstock, with a small quantity marketed for human consumption for a mainly Asian food market. However, global insect production – carried out in partly innovative vertical farms[18] – is expected to grow from an estimated 100 kilotons in 2024 to 700 kilotons annually by 2030 (Schafer, 2024); insect farms are scaling up, with big players located in Europe (Fantom, 2022).

In a related technology field, bioreactors are closed systems for cell growth in a controlled environment. Here, the market viability of lab grown or cultivated meat is progressing. In 2023, the first company applied for authorization to sell lab grown meat in Europe, while the market of less than 20 companies across Europe is currently in its infancy (Stummer, 2024). Although lab-based cell growth is a standard process in the pharmaceutical industry, the challenge here lies in scaling-up production sizes to large quantities, requiring reactors that are 10-times larger than today's largest reactor in the pharma sector (Alwahaidi, 2024; Ching et al., 2022). The other major challenge is finding animal free substitutes for the required nutrient base for muscle growth. Today, cost-intensive bovine serum from calf foetuses is the major nutrient base for cell cultivation, making up 50% to 95% of the production costs of nearly all artificial meat products. Cell meat start-ups and biotech companies are searching for alternative proteins that can stimulate the division of the cultivated muscle cells (TransGen, 2024).

[17] Other studies estimate the share up to 19.6% (Blaustein-Rejto & Gambino, 2023).
[18] Vertical insects farms follow similar design principles and processes like vertical farms for plants.

European Commission Highlights the Role of Algae as Underexplored Bioeconomy Resource

Algae grow around 10 times faster than traditional crops, they do not compete with other crops for land, do not require freshwater, and require much less fertilizer (Kite-Powell, 2018). They can be used for multiple purposes, for example as a resource for biofuels, as feed for livestock farming, directly as food or nutritional supplements, as a biostimulant in support of the uptake of fertilizer by plants, or as an additive to construction materials (European Commission, 2022b; Transparency Market Research, 2022). In 2022, the European Commission highlighted the role of algae as an alternative but relatively untapped protein source and identified action needs to upscale algae cultivation and production (European Commission, 2022b). Research also confirmed that about 20 million km^2 (about twice the area of Canada) of the ocean is suitable for macroalgae or seaweed farming, and that there is a rich farming potential in the North Sea (Liu et al., 2023). While macroalgae grow in open oceans and in off- and onshore aquacultures, micro-algae can also be mass-cultivated in photobioreactors in industrial processes (European Commission, 2022b); aquacultures and bioreactors are both form of controlled environment farming practices.

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

- A controlled environment allows relatively easy digitalisation and automation, as external influences (as are present in the natural environment) are limited. This makes it easier for automated machines to treat and harvest plants and to manage processes like watering, fertilizer supply, etc.
- Digitalization is a key prerequisite for implementing more controlled environments and drives innovation through continuous real-time learnings, e.g., on improving growing conditions by regulating light, temperature, wind, etc., adjusting robotics for harvesting, understanding impacts of plant maintenance, improving circular nutrition and waste cycles, etc. (Wiklund, 2023).
- Specifically, highly automated vertical plant and insect farms are strongly dependent on automated internal logistics processes as well as on monitoring and maintaining growth conditions and the state of the plants.
- Concerning the production of cultivated meat and microalgae in bioreactors, this is comparable to pharmaceutical and food chemical processes. Industry 4.0 approaches[19] based on digitalization can help to improve these processes and their efficiency, enable supply chain transparency, etc. (Kamalapuram & Choudhury, 2024; Wydra et al., 2023).
- For algae farming in the open ocean, digitalisation can play a crucial role as well, especially concerning monitoring algae stocks and their growth, or to enable transparency of sourcing, for managing sustainable harvesting approaches, etc. Furthermore, controlled environment agriculture could be seen as a "sandbox" for digital and automated agricultural technologies to gain experiences with complex outdoor applications.

[19] Industry 4.0 refers to the Industrial Internet of Things. It integrates intelligent digital technologies into physical manufacturing processes and goods and in agriculture biological realms enabling digital automation in systems, processes (Kamalapuram & Choudhury, 2024).

Next Level Decision Making Enabled by Digital Data Management and Spaces

Summary and Key Words

The global data base from agricultural and forestry machines, remote sensing, sensors, market data, etc. is massively growing. In addition, expected advancements in AI enabled data analytics will make the use of data management in farms and in forestry management simpler and more meaningful for the user by providing hands-on support for business processes. Thereby, agricultural data spaces provide platforms, infrastructure, and tools for safe use of data for farmers and forest owners. Internal and external farm and forestry data are used for increasingly automated analysis for decision support, for communication with business partners, consumers, public authorities, and others. However, trust and clear added value is important to engage in data sharing. Public authorities are increasingly using data spaces to combine data to get an overview on the state of agriculture and forestry and to inform policymaking and execute legislation. Agricultural data spaces are part of investments of the EU into European Data Spaces.

Key words: EU Data Act / Agricultural Data Spaces / Smart farming / Precision farming / Decision support systems

Current and Future Developments of the Trend

Beside skills, experience and traded knowledge (e.g., about land, crops and livestock), farm and forest businesses need systematic data collection for planning, resource management, sales, certifications, and for gaining access to CAP subsidies and taxes. Agricultural and forestry machinery can provide information on field data, machine data, and executed tasks (crop care, milking, tree harvesting). However, these domains are often not connected, lack interoperability, and are isolated in several (sub-)ecosystems of different machines and service providers (Kalmar et al., 2022). Data Spaces are an ecosystem of data repositories and software to share, exchange, access and generate knowledge for the user to understand the status quo. Through the combination of multiple data sources and advancements in data analytics as well as in generative AI, data can be translated into decision support systems output, providing advice to farmers and forestry managers or directly to autonomous agri- or forestry robots (Rose et al., 2016; Iakovidis, et al. 2024). Already today, the EU is investing in the development of European data spaces in several sectors, including agriculture, to improve the industry's competitiveness based on a vibrant data market and enable better decisions based on a sound evidence base (European Commission, 2024b). In addition, the EU is currently leading in data policies and contributes to improved regulation of data spaces with regulations such as the EU Data Act (EU, 2023). These policy frameworks are important as they increase trust in the market players that share their data and ensure cross-border and cross-system interoperability.

Overall, the field of data spaces is developing dynamically, as visible in increases in the number of different data sources, partners, and application fields (European Commission, 2024). With the European partnership of 'Agriculture of Data' providing research and development funding for tools to enhance sustainable production, the resilience and competitiveness of the sector as well as strengthen policy monitoring, the European data spaces and decision support tools will further develop innovative solutions and improve their uptake (European Partnership 'Agriculture of Data', 2023).

Recent Signals within the Scope of the Trend

On-Farm Data Spaces for Decision Making and Automation

On-farm agricultural data spaces are advanced farm management systems that gather data from various sources such as machinery, sensors, and external sources like marketplaces and weather data. Farmers can choose which data to share (Kalmar et al., 2022). This data can be used for decision support, moving from understanding current events to predicting future outcomes and enabling self-optimization (Fraunhofer, 2020). This integrated knowledge supports smart and precision farming, considering factors like market conditions and quality requirements. Digital Twins, representing the farm's state and activities in real-time, can enable remote control and simulation testing for better decision-making in the future (Verdouw et al., 2021, see in another sector Empson, 2023).

Corporate Companies Driving Agricultural Data Spaces

Big agricultural suppliers like Bayer, Syngenta, Claas, and John Deere are heavily involved in digital farming solutions: they offer software and platforms that integrate field data, provide crop analyses, and offer suggestions for optimizing planting and fertility management. These include software like Climate FieldView or Cropwise that incorporate field data and interactions with crops and soil, real-time data integration for field activities, and platforms for carbon quantification and agronomic advice using generative AI expert systems (Climate, 2024; Claas, 2024; Syngenta, 2024; Bayer, 2024). The goal is to optimise planting, fertility management, and precision farming practices. Critics raise concerns about the potential monopoly power of these companies in controlling farm data, dominating digital tools, and driving sales of their own products (Atik, 2022; Davidson, 2018; van Woensel, 2016).

Data Spaces for Policymaking and Reduction of Bureaucratic Burden

Governments use farm and forestry data to inform policy making, monitor policy effectiveness, and enforce regulations. In this processes, digital data can streamline procedures for authorities, farmers, and forest owners (Finck & Mueller, 2023; Kotsev et al., 2021). Recently, nine EU Member States joined forces to realise an integrated administration and control system for CAP governance (European Commission, 2021d). One prime use case of the joint action simplifies the control of specific CAP requirements for environmental sustainability in the agriculture sector (here specifically to maintain the land in good environmental conditions through defined mowing practices): In Estonia, companies developed the SATIKAS system using Copernicus satellite-based information to monitor mowing practices on agricultural grasslands, which reduced the need for field inspections (Copernicus, 2024; NEREUS et al, 2018). Hence, digital data spaces have the potential to reduce the bureaucratic burden on farmers and public authorities.

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalization in the sectors could also be expected in the mid- to long-term future.

- Functioning agricultural data spaces that use the full potential of gathering intelligence and learning across the sector require an increasing number of actors to participate in data sharing initiatives. Here, trust-building among partners that are exchanging potentially sensitive company information is crucial.

- In agricultural data spaces, traditional suppliers representing industrial agricultural practices are the leading actors in providing data platforms, software and decision support systems. The risk of data lock-in with a decision for a farm software and data space are driving lack of trust by farmers (Atik, 2022). It is important that decision support systems promoting sustainability in agriculture and forestry are not controlled solely by big agricultural companies but by organisations with more neutral or balanced interests.
- To promote collaboration, business models need to be developed that are attractive for all partners (Deero et al., 2023). With farm suppliers that are already dominant in agrochemicals, seeds or machinery domain providing data management solutions, the fairness of business models for data software and platforms are key to avoid one-sided dependencies.
- The EU Data Act aims to regulate the data economy to create a fair data market and support compatible European data spaces, specifically in the agriculture sector (EU, 2023). However, building trust relies on functioning law enforcement and the experience of individuals and organisations.
- Several EU projects had been carried out recently, including AgriDataSpace and Demeter[20] that both aim to build a framework for the digital transformation of the EU's agri-food sector by collecting experience with various concepts and approaches to learn from good (and bad) practice.
- The EU is acknowledged by a recent OECD study as leading the way in the digital traceability of food supply chains, enabled under alia by agricultural data spaces (Charlebois et al., 2024; Tay, 2024).

Rising Regulatory and Consumer Demand for Higher Food Quality, Safety, and Sustainability

Summary and Key Words

Food safety, quality, and sustainability are key concerns in European agri- and aquaculture. The EU's Farm to Fork Strategy as well as new consumption patterns further drive this trend, with consumers increasingly demanding high food safety and quality – which in turn promotes sustainable, local, and transparent farming practices. In this context, the way food is produced and consumed is becoming increasingly relevant to one's social status. At the same time, individualized nutrition that addresses specific health needs and value criteria, is playing an increasingly significant role for some consumer groups. This leads to rising requirements for more transparent and traceable food chain controls and more comprehensive information on quality, health, and value dimensions.

Key words: Food safety, quality and sustainability / Supply chain transparency / Individualized nutrition

Current and Future Developments of the Trend

High-quality, safe and sustainable food are core concerns of the EU and its citizens. Poor food quality and unhealthy diets significantly impact public health, contributing to illnesses, such as obesity, non-communicable diseases, and deaths (Hau & Lange, 2023).

[20] See https://agridataspace-csa.eu and https://h2020-demeter.eu

Furthermore, a growing public awareness of sustainability, environmental issues and of animal welfare leads to demands for increasingly higher standards, including organic food and fair-trade products (Chiripuci et al. 2022). In response to these concerns, the EU's 2020 Farm to Fork Strategy seeks to develop a sustainable food architecture by minimizing environmental impact, ensuring food security, and encouraging healthy eating habits. The strategy also links to the EU's Green Deal, CAP, and the biodiversity strategy, and it is related to the 2021-2027 Organic Action Plan, which aims to promote organic production and demand. This initiative, amongst others, has led to an expansion of over 0.8 million hectares of organic farmland in the EU from 2021 to 2022, resulting in organic agriculture covering 10.4% of the agricultural area within the EU by 2022 (IFOAM, 2024).

Recent Signals within the Scope of the Trend

Healthy, Organic, Home-cooked Food Trending on Social Media

Food has long been a prominent topic on social media, significantly shaping users' shopping, eating, and cooking behaviours. A variety of platforms offer extensive information on diets, nutrition, and recipes, with a notable impact on younger, digitally native audiences (Simeone & Scarpato, 2020). The trend towards healthy, organic, and home-cooked food is particularly pronounced (Pilar et al., 2021). An analysis of the #healthyfood hashtag on Twitter (now X) from 2019 to 2020 reveals that users link healthy food with a balanced lifestyle, diet, fitness, and concepts such as veganism, homemade, and organic options (Pilar et al., 2021). Similarly, social media has increasingly elevated food to a status symbol and lifestyle indicator (Simeone & Scarpato, 2020). From YouTuber 'Freelee the Banana Girl' gaining fame in the 2010s with her raw vegan diet to TikTok star Nara Smith's rise in late 2023 with her "home cooking from scratch" content, food choices are increasingly seen as reflections of lifestyle and personal values (Butler, 2024; Lundhal, 2018). Hence, healthy, organic, and partially home-cooked content is likely to shape future food preferences, mirroring broader trends in individual approaches to diet and well-being.

Rising Number of Food Supply Chain Management Start-ups

A rising number of tech start-ups are enhancing transparency in supply chain management by enabling real-time monitoring and digitising food information from farm to fork (StartUs Insights, 2021). Key technologies driving these advancements include IoT and blockchain, that provide information to producers, retailers, consumers, and other stakeholders across various industries from crop and animal farming to seafood (StartUs Insights, 2021). For example, the French start-up Connecting Food uses blockchain to trace supply chains and provides solutions for a range of stakeholders, including consumers, by sharing production information through QR codes on packaging (Connecting Foods, 2024). Another example is Clear Farm, which employs smart farming technology to improve animal welfare in pig and dairy cattle production chains, offering data on welfare, economic, and environmental sustainability (Clear Farm, 2024). As another example, the Canadian start-up Sedna Technologies offers a seafood traceability ecosystem using IoT sensors, radio-frequency identification, and back-office digitization to enhance transparency in seafood manufacturing (Sedna Technologies, 2024). Consequently, these digital innovations enable food processors, retailers, consumers and other stakeholders to make informed decisions along the supply chain based on reliable and traceable information.

Food Watch Demands EU-wide Mandatory Front-of-pack Nutrition Labelling "Nutri-Score"

The NGO Food Watch advocates for the EU-wide adoption of a standardized nutrition label called Nutri-Score, aiming to help consumers make more informed decisions and improve their dietary habits and health (Food Watch, 2024). Currently, eight European countries have voluntarily adopted the Nutri-Score label (Hau & Lange, 2023). In an open letter to the European Commission, Food Watch has called for its mandatory implementation across the EU (Food Watch, 2024). While the effectiveness of the Nutri-Score once harmonized and adopted remains to be seen, it could be a relatively straightforward initial step towards enabling improved consumer decision-making (Hau & Lange, 2023). The advocacy around the Nutri-Score reflects both growing consumer concern over nutrition data and personalized nutrition (Chaudhary et al., 2021) as well as the powerful opposition of the agri-food industry in the European political arena over the past two decades (FoodWatch, 2024b). Enabled by digital supply chain traceability and transparency, food-related consumer information systems are generally expected to continue to increase and evolve. However, already traditional package labelling – like highlighted here with the example of Nutri-Score – shows the difficulties and hurdles faced, such as the different interests of the food industry and consumer protection representatives, varying assessment of health, environmental impacts and their integration into one simple label design. These hurdles need to be overcome for a successful market dissemination of new food quality and health related product information that may come with digitally enabled supply chain transparency and increased traceability.

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

- Digital solutions increasingly enable higher standards through innovative methods, from enhancing traceability in supply chains to optimising various aspects of production.
- Digital tools and platforms can provide comprehensive insights into food production processes from farm to fork, enabling more effective communication with business partners and end customers.
- Advances in technology allow for the collection, utilization, and analysis of vast amounts of data across the entire value chain, potentially disrupting traditional business models and significantly reducing transaction costs (Schroeder et al., 2021).
- For instance, it is expected that by 2050, an average farm will generate around 4.1 million data points per day, up from 190,000 data points per day in 2014 (Schroeder et al., 2021). Agrifood producers may increasingly be urged by the food processing industry or by retail partners to adopt tracking technologies along the supply chain to gain a competitive edge.
- Solutions from digital platforms dedicated to providing detailed supply chain data, such as the start-up Connecting Foods, may also be complemented by social media as a marketing tool for farmers and agribusinesses (Jurado et al., 2019).

Shift in Market Power in Agri-food and Forest Systems

Summary and Key Words

The market structure in agri-food systems is driven by market concentration in agribusinesses and in farms. In agriculture, small farms are decreasing, and the number and size of large farms are increasing. Consequently, new business models are required for small players, with rewards for environmental and climate services being one option. While in the forest sector the market structure has been relatively stable, the sector is also characterized by a high degree of diversity of players, which can make dissemination of innovation difficult. Recent developments also show that large farms and forests are more prone to integrate digital tech options, and that powerful supply chain partners and transparency and traceability requirements are driving digitalisation in farms and forests.

Key words: Agriculture market concentration / Market power balance / Carbon farming

Current and Future Developments of the Trend

The market structure in European farms is changing, while in forestry structures are more stable. Since 2005, the number of farms in Europe has decreased by 37% amounting to a loss of more the 5 million – mainly small – farms. In parallel, the largest farms (more than 100-hectare size) have been growing through land acquisition and mergers (Eurostat, 2022). This development is expected to continue, by 2040 the EU could potentially lose an estimated further 6 million farms (Schuh et al., 2022). Generational changes and operational handover play a role, as well as higher market pressure from concentration in the agribusiness and food industry. The ownership structure of European forests is different: these are owned by 16 million private (60%) and public (40%) entities with a wide variety of property sizes, almost 90% of private forests have a size of less than 10 hectares. The EU forestry ownership structure is more stable compared to farms, only the restitution of nationalised land to its former owner in some Eastern European countries is an ongoing change. Perseverance in the ownership structures is expected to continue largely unchanged. State and industrial owners actively manage their forest in line with political and business objectives, while private small-scale forests vary from altruistic motives to active management. European forests resources are growing, only 75% of annual growth is felled (Mauser, 2022).

Recent Signals within the Scope of the Trend

Concentrated Agribusiness Sector Limiting Farm Supply Choices and Sale Options – Small Farms Decline

The European Parliament sees the need to strengthen farmers' bargaining power with wholesale and retail companies, and to rebalance power in the food system (European Parliament, 2021). Corporate concentrations in the global agri-seed and pesticide market led to only four big players (ChemChina/Syngenta Group, Bayer, Corteva Agriscience, BASF) controlling 62% of the global agricultural seed segment and 51% of the agrochemical market in 2022 (ETC Group, 2022; Omar & Thorsøe, 2023). By offering digital data platforms and expert advice systems, these corporations can potentially directly influence farmer's strategies and purchasing decisions. Also, on the downstream side of buyers of farm products, medium to high concentration in the food industry and retail sector is accelerating. Therefore, the market power of farmers is often limited (Hernandez et al., 2023). Thus, farmers are often under pressure to follow the food industry and retail partner's sales price, quality, certification, and other criteria. In addition, the key agribusiness actors maintain close relationships with governments, possibly allowing them to influence policymaking: the Farm to Fork strategy could manifest their market power according to Omar & Thorsøe (2023) – in contrast to the European Parliament's claims (European Parliament, 2021). With small farms under pressure, both upstream and downstream, large-scale farms are likely to further grow as market structures favour intensive production and accelerate farm concentration processes (Schuh et al., 2022). Economic pressure, consumer focus on sustainability and changing business models thus drive the need for European farmers to adopt digital technologies, particularly those with large farms (i.e., larger than 800-hectares) (Fiocco et al., 2023).

Vertically Integrated Forest Companies are Lead Appliers and Developers of Digital Precision Solutions

Companies with vertically integrated operations spanning forestry to secondary wood-based products are unique, as they are large forest owners with a direct impact on forest management, and they integrate forestry into a complex value chain. Three such European companies are Stora Enso, a Finnish timber company that is one of the world's largest private forest owners, Holmen and Svenska Cellulosa, both Swedish timber companies that together own around 3 million hectares of forests in Sweden (Charrey, 2023). Their integrated value chains cover downstream activities, including the manufacturing of wood products for construction and paper and packaging. Hence, they are well-positioned to measure the carbon flows across their value chain, from carbon sequestration in their forests to product storage, providing insights into the net carbon impact of their diversified businesses in forestry (Charrey, 2023). In addition, these large integrated companies can more easily adopt digital solutions: they use digitalisation strategically in their industry manufacturing processes and must manage vast forest land; therefore, they often are more open, more capable and have a high need to use technology and digitalisation in their forest management (Holmström, 2020; Feng & Audy, 2020). For example, Stora Enso uses satellite imagery, drones, LiDAR[21] and on-ground sensing to have detailed insights into the health of their forests; furthermore, they use forest's Digital Twin for precision forestry and co-develop specific solutions for forest management (Stora Enso, 2023).

Increasing Influence of Food Companies and Fossil Fuel Energy Companies on Farms through Carbon Markets

Carbon farming is seen by the EU as a business model for farmers and land managers for implementing defined land management options (European Commission, 2021a). On the one hand, farmers and forest owners can receive area-based CAP payments for climate commitments, on the other hand they can receive results-based incentives for carbon stored in the soil and in plants by earning marketable carbon credits (European Commission, 2021a and 2021b). In recent years, there is increasing competition for carbon credits among different sectors, particularly between agriculture and fossil fuel industries, and agribusinesses are advocating for preferential access to agriculture and forestry carbon

[21] LiDAR is Light Detection and Ranging is an active remote sensing technology like radar, but using light and laser technology instead of radio or microwaves. It allows detailed 3D mapping of forest structure and height, tracking health. It can be used on the ground and in the air, e.g. using drones as well as on satellites.

farming credits, aiming to ensure they can meet their emissions reduction targets without being outbid by other industries (Scherger, 2022). Energy utilities, particularly those in fossil fuel sectors, have already been strategically investing in carbon farming projects as part of their corporate social responsibility (CSR) strategies or sustainability initiatives and to offset their carbon emissions from their core business. Energy utilities often collaborate with agribusinesses and other stakeholders to develop carbon farming initiatives (Scherger, 2022).[22] Hence, farmers and forestry owners can benefit from cooperation with big corporations, like monetising climate mitigation outcomes, or getting access to carbon certification schemes, but can also be put under pressure regarding how and what to do on their land.

Implications for Digitalisation of Agriculture and Forestry in Europe

What impacts do these developments and signals have on the agriculture and forestry sectors and their digital transformation? Drawing from past experiences, the following implications for agriculture and forestry and digitalisation in the sectors could also be expected in the mid- to long-term future.

- With large farms and forests, there is a higher need to use digital tools in farm management to enable a better overview of the health of crops, livestock and forests (Fiocco et al., 2023). Furthermore, large farms tend to have a higher degree of specialization in the workforce and can employ highly trained specialists in charge of introducing and maintaining digital technologies and training colleagues (McFadden et al., 2022).
- While Europe and North America are leaders in digital agriculture technologies adoption (Fiocco et al., 2023), in Europe, 62% of farmers are currently using or planning to use digital agriculture technologies in the next two years[23], according to a McKinsey survey from 2022 (Fiocco et al., 2023).
- The strong market pressure from up- and downstream agribusiness market partners – upstream suppliers offer digital data sensing and software in their products and services, and downstream customers demand specific information that defines the criteria for traceability and transparency of products – can drive the application of digital technologies to provide supply chain transparency, provide certification requirements for specific farming practices or quality standards, and enter market platforms to increase customer relationships.
- Small farms need to be highly innovative and diversify their business model to survive the market shakeout. Digital tools can help to communicate and sell directly to consumers and offer non-food products and services.

[22] For example, The World Economic Forum launched in 2021 its 'Carbon+ Farming Coalition' – which is no more visible in 2024 – advocating for climate-smart farming with partners from agribusiness, energy and insurance corporations and some others (World Economic Forum, 2022; DeSmog, 2022).
[23] mainly farm management software and remote sensing

What, if … ? Food for thought on long-term perspectives

The 4Growth Foresight Module is about understanding the fast-developing framework conditions of agriculture and forestry and their digital transition. That the future is unknown, with multiple alternative futures being possible, is one of the guiding principles of foresight – implying the need for future-oriented action aimed at enabling change towards desirable futures (Inayatullah, 2013; Störmer et al., 2020; Barrett et al. 2021). To enable such action, opening the horizon of knowledge and imagination is necessary (to more alternative futures which are often not included in most of the discourse on the future). Here, it is helpful to systematically apply the question of “what, if...”, to anticipate possible consequences of various potential future developments.

While this principle of identifying possible alternative futures will be the focus of the next foresight element (i.e., the development of scenarios), this section already serves as a bridge to these perspectives. For all trends identified, it includes two prompts in the form of “what, if...” questions, drawing from the evidence presented in the trend description. The purpose of this section is thus to already inspire and enable thinking about long-term developments. It also contains a blank space open to further “what, if...” questions that are hopefully prompted by the whole report, and which is open to be filled in the process of the overall project.

Glocalisation

What if ....
... agriculture and forestry in Europe become much more autonomous – and digital technologies help to increase domestic productivity while ensuring food quality and sustainability requirements?
... the suppliers of European food and of other bioeconomy products could be easily replaced by competitors from other regions and / or domestic production?

Post Ukraine war, enlarged EU

What if …
... permanent demilitarised zones as no-go areas are established in the EU and its neighbourhood on sites of previously arable land?
... the accession of Ukraine boosts EU food production and exports resulting in a new global agricultural order?

Biodiversity loss

What if ....
... The European Union is no longer able to import biological resources from other parts of the world because China and other countries have already secured sole access?
... many natural resources are no longer available due to biodiversity loss or even the collapse of ecosystems?

Cybersecurity & vulnerability

What if ....
... malicious deep fakes of agricultural and forestry data lead to flawed decision making by farmers and forest owners, or to automated decision routines in machines, sabotaging the whole sector?
… a clear transparency of food and biomaterial products with their social, environmental and economic footprint enables value driven consumption?

Bio- & nanotech

What if ....
... biotechnologies enable production of high-performance biomaterials that outperform fossil-based plastics, steel and concrete for all types of applications?
… a full Digital Twin of a farm and forest, based on detailed real-time field information, allows the simulation of different applications of agricultural and forestry practices and hence provides the "perfect" decision support for an autonomous management of farms and forests?

Tech to deal with climate stress

What if ....
… multibillionaires take geoengineering into their own hands and execute solar radiation management by spraying sulphate aerosols in the atmosphere, without first seeking permission?
… super low energy consuming water desalination could make previously unviable coastal areas suitable for agriculture?

Data spaces

What if ....
... a digital twin of European agriculture and forestry would make the bioeconomy production fully transparent and would allow farmers and forestry owners to anticipate upcoming yields?
… digital data spaces specifically for alternative sustainable agriculture and forestry practices (like agroecology or sustainable forestry drawing on e.g., nature-based solutions) can provide clear decision support for farmers and forest businesses?

Controlled environment farming

What if ....
... global protein consumption would be provided by alternative sources, e.g., from insects and algae, hence replacing huge areas of livestock and open field farming?
… food production processes would be integrated into the food processing chain, carried out in the same factory, replacing farming by industrial processes?

Consumer demand

What if ....
... ethically produced food that is not labelled as such (i.e., without any information on ethical production criteria) is rejected by consumers who base their purchasing and eating decisions almost exclusively on recorded criteria such as animal welfare or climate compatibility?

... farmers and agribusinesses became major social media influencers with large followings, so that their food products are associated with the producers rather than the other way around?

Market power shifts

What if ....
... farms and forest business grow to become such large organisations that they are “too big to fail”?
… vertically integrated agri-food industry and forestry conglomerates run land like factories?

Place for further questions

What if ....

Conclusions and Outlook

The report presents ten trends that are expected to shape the future of agriculture and forestry concerning the uptake of digitalisation in the next decade and beyond. This set of trends covers a wide spectrum of developments from shifts in globalisation and the role of geopolitical tensions, impacts of climate and biodiversity crises, changes in the EU system, development of enabling technologies for agriculture and forestry, emerging farming practices, market power shifts in the sectors, to evolving consumer demands. The table below summarizes main keywords per trend as well as the recent signals within the scope of the trend, as presented in more detail in the sections above.

Table 3. Overview of Trends, key words and signals

Trend (short title)	Keywords	Recent signals within the scope of the trend
Glocalisation	Global trade / resource dependency / open strategic autonomy / technology dependence / supply chain disruptions	• Export Limitations for Food Products: India's rice export ban • Europe's Wood Import Independence – a Reaction to High Russian Export Tariffs in 2008 • Fertilizer Dependency due to Russian War in Ukraine
Post-war, Enlarged EU	EU enlargement / Common Agricultural Policy / open strategic autonomy / supply chain disruptions / Post-war Europe	• Militarization and War Alter Biodiversity in Affected Areas • Post-War Rebuilding of Ukraine's Agricultural and Forestry Sectors • EU Enlargement to Redefine Common Agricultural Policy
Biodiversity loss	Resource scarcity / Biodiversity loss / Climate change / Cultivation practices / Environmental monitoring	• Spoonbill Population Threatened by Agricultural Activity • Farmers Could Grow a Larger Variety of Crops on their Land, Supporting Biodiversity • China's Ties to Foreign Agricultural Land are Affecting Biodiversity
Cybersecurity & vulnerability	Vulnerability / Digital divide / Data security / Hacking / Espionage / Sabotage	• Espionage Enabling Equipment in Machines and Infrastructure • Cyberattack on Food Processing Company Exemplifies the Vulnerability of Smart Farming Devices • Connectivity Risks Due to Reliance on Single Networks and Providers
Bio- & nanotech	Biotechnology / Nanotechnology / Biomanufacturing / Genetics / Biosensors / Nano-fertiliser	• Bio- and Nano Tech for Cultivation of Climate Adaptive Plants and Animals • Biosensor Technologies Enable Real-time Understanding of the State of the Local Environment • Novel Nanomaterials Revolutionise Fertilizers with More Efficiency and Less Negative Side-effects
Tech to deal with climate stress	Agricultural practices / Geoengineering / Carbon sequestration / Microclimate management / Water desalination	• Geoengineering: Agriculture and Forestry Contributes to e.g. Carbon Storage • Microclimate Management: Using Nature-based Solutions to Adapt to the Climate Crisis • Leaps in Low Energy Consuming Water Desalination Could Open New Opportunities for Agriculture and Land Use

Trend (short title)	Keywords	Recent signals within the scope of the trend
Controlled environments	Controlled agricultural environment / Vertical farming / Algae farming / Artificial meat / Insects as protein base	• Giant Vertical Farm Project GigaFarms in Construction in Dubai • Advancements in Controlled Environment Production of Alternative Proteins • European Commission Highlights the Role of Algae as Underexplored Bioeconomy Resource
Data spaces	EU Data Act / Agricultural Data Spaces / Smart farming / precision farming / Decision support systems	• On-Farm Data Spaces of Decision Making and Automation • Corporate Companies Driving Agricultural Data Spaces • Data Spaces for Policymaking and Reduction of Bureaucratic Burden
Consumer demand	Food safety, quality and sustainability / Supply chain transparency / Individualized nutrition	• Healthy, Organic, Home-cooked Food Trending on Social Media • Rising Number of Food Supply Chain Management Start-ups • Food Watch Demands EU-wide Mandatory Front-of-pack Nutrition Labelling “Nutri-Score”
Market power shifts	Agriculture market concentration / Market power balance / Carbon farming	• Concentrated Agribusiness Sector Limiting Farm Supply Choices and Sale Options – Small Farms Decline • Vertically Integrated Forest Companies are Lead Appliers and Developers of Digital Precision Solutions • Increasing Influence of Food Companies and Fossil Fuel Energy Companies on Farms through Carbon Markets

Looking across the ten trends and their implications for the digital transformation of agriculture and forestry, preliminary cross-cutting findings[24] can be identified regarding the development and role of digitalisation and data driven solutions in these sectors. With these findings, the trend analysis provides an understanding of push and pull factors and related hurdles for the digital transformation, as well as insights into the role of key actors and stakeholders in the process. The cross-cutting findings are:

- Digitalization is seen as a major driver for current and future innovation and efficiency in agriculture and forestry, e.g., through the speeding-up of R&D to identify substitutes for imported goods (see trend: glocalisation), to the cultivation of more climate-resistant plants (see trends: tech to deal with climate stress, bio- & nanotech) and to speed-up learning to improve production (see trend: controlled environment).
- Data management is expected to improve and strongly influence decision-making processes and to optimize production in these sectors, e.g., through generative AI-driven advice systems (see trend: data spaces). It can also enable improved market relationships and supply chain management to tackle supply and sales dependencies (see trends: glocalisation, market power shifts; data spaces), as well as be a key lever for Industry 4.0-like automation in controlled environment farms for leavy greens, vegetables and fruits, insects, algae, etc. (see trend: controlled environment).
- Data management and digitalization can both enable increased supply chain transparency and traceability (see trend: market power shifts), serving consumer and intermediary needs, and possibly even creating (more) consumer trust (see trend: consumer demands).

[24] I.e., findings that play a role in two or more trends.

- Digitalisation requires high investment in digital solutions and reliable infrastructure, particularly in rural areas (see trend: cybersecurity & vulnerability). Benefits for farmers and forest owners need to be based on solid business models, with trust between actors in data sharing networks being central (see trend: market power shifts).
- Growing cybersecurity risks and the vulnerability of digital infrastructure, as well as dependencies on major players in agriculture and forestry business ecosystems[25] are issues that need to be addressed to ensure the successful uptake of digital infrastructure (see trends: cybersecurity & vulnerability, market power shifts, consumer demands).
- The foreseen enlargement of the EU through the integration of Ukraine (with its small number of farm giants and many medium-sized farms[26]) might become a push for innovation in agriculture across the EU. A rebuilt, post-war, farm sector in Ukraine could use the latest technologies and innovations, with European agriculture and forestry players in other countries as fast followers of this innovation example (see trend: Post-war, Enlarged EU, data spaces, market power shifts).
- With the increasingly urgent need to stop biodiversity loss, governments are using digital means of analysing remote sensing data to identify priority areas for action and to simplify controls of environmentally friendly farming and forestry practices. Linked to climate policies, public authorities also use digital monitoring to measure the outcomes of carbon farming activities (see trends: biodiversity loss, data spaces, market power shifts). In this context, digitalisation could also be a major lever to decrease the administrative burden for farmers, forestry owners and public authorities.

Many of the trends as well as their implications for agriculture and forestry are also influenced, shaped and co-driven by major EU policy initiatives and discussions (such as the EU Green Deal, the Farm to Fork Strategy, the EU Forest Strategy for 2030, the EU Biodiversity Strategy for 2030, or the EU's net zero emissions target and related climate policies). Furthermore, the Digital Decade and the advancing regulation around the EU Digital Markets Act, the Digital Data Act, and the ambitions in shaping and regulating Agricultural Data Spaces are highly influential. The EU is regarded as being at the forefront of digital regulation, as this is seen as a precondition to ensure the necessary trust among partners for sharing data (see trend: data spaces). Specific EU initiatives such as the Once Only Principle[27], the Data Governance Act as well as AI-enabled analysis of environmental remote sensing data will be critical for using digitalisation as a lever to reduce the administrative burden of market participants and to simplify bureaucracy. This is true also in the agriculture and forestry sectors, for example, with respect to nature conservation measures and environmental due diligence (see trends: data spaces, biodiversity loss,

[25] The risk of power dependencies through digital platforms and services might be even higher in the agriculture and forestry sectors than in digital consumer platforms, as the powerful entrepreneurs behind several agri-data platforms are global agrobusiness giants that dominate physical markets of seeds and agrochemicals supply. However, European data market regulation applies, and the sector is still young and emerging.

[26] In pre-war Ukraine, key actors were 8600 medium-sized farms cultivating 200 to 2000 hectares of land (Albaladejo Román, 2024), while 10 companies dominate about 70% of the agricultural market, operating more than 100 000 hectars of land (Lorenzen & Wetzel, 2023).

[27] The Once Only principle refers to the EU Single Digital Gateway Regulation, that citizens and businesses must provide their data only once to public administrations that will share them if needed with their counterparts in other Member States through a secure data space in line with EU's data protection laws.

consumer demands). Concerning future (policy) developments, the discourse on the twin transition at the EU-level is strongly related to the 4Growth project's focus, i.e., using digital technologies as enablers for the green transition. For example, the 2022 Strategic Foresight Report of the European Commission (European Commission, 2022a; Muench et al., 2022) focused on the domains of agriculture, forestry, and nature conservation among others. Prior to the 2022 report, the 2021 Strategic Foresight Report (European Commission, 2021c; Cagnin et al. 2021) addressed shaping and securing the EU's capacity and freedom to e.g., tackle food security and supply chain related risks (see trend: glocalisation) as well as risks of external interference into European agriculture and forestry (see trends: cybersecurity & vulnerability, market power shifts, EU Enlargement, post-war Ukraine). Hence, already today EU policies and initiatives strongly drive and influence digitalization in agriculture and forestry and will continue to shape how it develops in the future, with major impacts also expected from the new Commission's policy priorities. While this report does not analyse needs for future EU policies, these aspects will be explored in more detail in the upcoming steps of the 4Growth project.

Throughout the duration of the project, the Foresight Module will continue to undertake horizon scanning, with new developments being analysed as they emerge. A second horizon scanning report will be finalized in autumn, 2025. In addition, a set of scenarios will be developed that describe possible future development paths for agriculture and forestry in the EU, zooming in on different perspectives of digitalization uptake and practices. For the development of the scenarios, horizon scanning insights will also serve as a basis and starting point, with the first draft scenario report to be finalized in spring, 2025.

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