Pathways towards a fair, inclusive and innovative Data Economy for Sustainable Food Systems

D5.1: Analysis of Trends: Identifying technological and societal challenges with impact on the DE4FS

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Glossary of terms and abbreviations used

List of Abbreviations and Acronyms	
AI	Artificial Intelligence
AWU	Annual Working Unit
B2G	Business-to-Government
CAP	Common Agricultural Policy
DAT	Digital Agricultural Technologies
DE4FS	Data Economy for Food Systems
EC	European Commission
EEA	European Environment Agency
EU	European Union
FLW	Food Waste and Loss
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
genAI	Generative AI
GHG	Greenhouse Gas
ICT	Information and Communication Technologies
IoT	Internet of Things
LCA	Life Cycle Assessment
ML	Machine Learning
OECD	Organisation for Economic Co-operation and Development
SME	Small and Medium-sized Enterprises

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Executive summary

The deliverable 5.1 "Analysis of Trends: Identifying technological and societal challenges with impact on the DE4FS" reflects the outputs of the activities hitherto carried out under the Task 5.1 "Analysis of trends" of the Data4Food2030 project. Task 5.1 seeks to identify future societal and technological changes and trends influencing and shaping the data value propositions for food system in Europe. Specifically, the task aims to tackle the recent and upcoming technologies (potentially) relevant for the food sector (including developments in other sectors), societal expectations for the food sector and new economic and non-economic value proposition including corresponding new societal, environmental and policy challenges and solutions. In this sense, the present document includes the preliminary identification such trends and how they may create an impact, which will be later used for further development of the project deliverables D5.2 Identifying technological and societal challenges with impact on the DE4FS and D5.3 Recommendations & roadmap for improving the DE4FS.

Overall, the report aims to present a comprehensive analysis of the trends influencing the data economy for food systems in Europe, focusing on the intersection of digitalisation, societal expectations, economic shifts, environmental challenges and policy developments. As digital technologies continue to reshape the economy and society, the report highlights the significant opportunities and challenges that arise within the agricultural sector, particularly in the context of increasing data volumes and the demand for transparency and sustainability. It is also important to outline that, given the nature of the research, the definition of the direct impacts in data economy and in food systems follows an inductive method due to the limited availability of official and grey literature studies in the matter.

Key findings indicate that the integration of digital technologies into food systems enhances efficiency, market access and resource management. However, it also raises concerns regarding data monopolisation and job displacement, necessitating equitable access to resources and information across the entire food value chain. The report emphasises the importance of regulatory frameworks that govern data usage, promote innovation and ensure compliance with privacy standards, thereby fostering trust among stakeholders.

The technological trends look into the digitalisation effects and considers various types of technologies, such as advanced connectivity, generative and applied artificial intelligence, big data and cloud / edge computing, smart sensors and Internet of Thinks, and blockchain and digital platforms. Overall, digital technologies present significant opportunities to enhance food systems by improving efficiency, transparency and sustainability. They can support better decision-making through enhanced data accessibility, facilitating the improvement of inventory management from farm to fork. Blockchain technology streamlines transactions and regulatory processes via smart contracts, fostering trust among supply chain actors. Digital platforms enable collaboration among stakeholders, empowering farmers with knowledge about best practices and innovations, while also enhancing market access and operational efficiency. Despite these opportunities, the data economy for food systems faces challenges that need to be addressed. Fragmented data complicates access and interoperability, especially in rural areas with inadequate connectivity, limiting the effectiveness of smart sensors and IoT devices. Additionally, the financial burden of deploying new technologies, alongside concerns about data privacy and security, poses obstacles for small-scale farmers. The concentration of power among a few dominant digital platforms raises equity concerns and may lead to job losses, while uncertain business models and the need for new skills require comprehensive training initiatives. Addressing these issues is essential for ensuring equitable benefits across the food value chain.

The societal and economic trends dive into various aspects with potential impact on the data economy development. For example, it looks at how the advancement of digital technologies is transforming consumption patterns, production processes and the overall structure of the economy. On the economic side, the key trends identified include macro-economic factors such

as GDP growth[3] and inflation, which influence the landscape of the data economy, investment behaviours and structural changes in the agriculture, especially at the farming level. The economic growth (positive or negative) influences markets and impacts the purchase power of households (through inflation rates) and investment opportunities. In addition, intense competition, price volatility and low digitalisation have a significant impact on the agricultural sector and often small farmers are forced to incorporate into larger-scale farms to survive, leading to a concentrated agricultural supply chain. On the societal side, the aspects analysed look at employment related aspects, the shift in food access of consumers and changes in dietary habits of citizens. Regarding employment, the impact of digital technologies, including artificial intelligence and automation, on labour markets is highlighted, especially for the agri-food sector where routine tasks are increasingly automated. This change necessitates a re-evaluation of workforce skills and the creation of new roles that leverage data and technology in food systems. As for shifts in food access and dietary habits, the analysis offers some insights on the impact of new apps that facilitate the access to food and tracking of healthy habits, as well as their economic impact in the market. Moreover, the smart use of data is an important factor in promoting transparency in food production and enhancing the overall efficiency of food systems. Overall, the section underscores the need for stakeholders to adapt to these evolving social and economic trends by embracing digital transformation, fostering innovation and ensuring that the benefits of the data economy are shared equitably across all sectors of society. This approach is essential for building resilient and sustainable food systems in the face of ongoing economic and technological changes.

The environmental trends focus on the significant environmental challenges posed by current food systems and explores the potential role of digital technologies in mitigating these issues. The food system is identified as a major contributor to environmental degradation, accounting for over one-fifth of all environmental and climate impacts, including air and water pollution, biodiversity loss, and excessive resource consumption. The report emphasises the urgent need for sustainable practices to address these challenges while ensuring food security and environmental conservation. The digital technologies could be tools for enhancing the sustainability of food systems. By leveraging data analytics, precision agriculture and smart resource management, these technologies can help reduce waste, optimise resource use and improve overall efficiency in food production and distribution. The integration of digital solutions is crucial for addressing environmental concerns, such as climate change and resource depletion, while also promoting transparency and accountability within the food supply chain. Aligning digital initiatives with environmental goals is an important factor for policies that support the adoption of sustainable practices through technological innovation. The collaboration among stakeholders, including farmers, technology providers and policymakers, is essential to develop integrated solutions that address both environmental challenges and the economic viability of food systems, contributing to a more resilient and sustainable future for food production and consumption.

Policies play a crucial role in shaping the data economy for food systems by establishing frameworks that govern data usage, promote innovation and ensure equitable access to resources. Regulatory frameworks define how data can be collected, shared and utilised, ensuring compliance with privacy and security standards, which is essential for building trust among stakeholders, including consumers, businesses and government agencies. Initiatives like the European Digital Decade policy programme facilitate the digital transition across various sectors, including agriculture, by setting targets for technological uptake and encouraging investment in digital infrastructure. Additionally, policies are designed to address and mitigate potential negative impacts of technological advancements, such as job displacement and data monopolization, ensuring that the benefits of the data economy are distributed more equitably. Overall, the section encompasses trends with impact to data economy and to food sectors, including the different European propositions for the twin green and digital transition and the strategies to bring the importance of data into the food system.

[3] The gross domestic product (GDP) is the most frequently used measure for the overall size of an economy. It is often used to monitor economic convergence or divergence within the European Union (EU) and can give valuable insights into the main drivers of economic activity (Source: Statistics explained, Eurostat).

Overall, the analysis underscores the transformative potential of digitalisation in food systems, highlighting both opportunities and challenges. Stakeholders must navigate the complexities of technological advancements while addressing societal expectations and environmental imperatives. The need for equitable access to data and resources is paramount to ensure that the benefits of digitalisation are shared across the food value chain. Policymakers, businesses and communities must collaborate to create a resilient and inclusive data economy that supports sustainable food systems and fosters innovation for future generations.

1. Introduction

Digital technologies have great impact in reshaping the economy and society, affecting different aspects of the daily lives of Europeans. As data volume grows in a fast pace, more opportunities arise for Europe to become a world leader in data economy, whilst collecting the benefits of economic development based on data (European Commission, 2020a).

Digitalisation has promoted changes in the food environment with increasing digital infrastructures and technology, which have altered how people seek, share and interpret food-related and eating-related information and practices (Schneider & Eli, 2021). As proposed by Granheim et al (2022), "all food environment dimensions are subject to digital transformation. Food environments are increasingly experienced through technology, and also shared by it in many ways," which amplifies the complexity of the food environment.

The European Strategy for data: the leading strategy for data economy

In 2020, the European Commission launched a **European strategy for data**, emphasising the vision of leveraging data to enhance decision-making and empower businesses and the public sector within the European Union (EU). This strategy targets the horizon of 2030 to align the data economy's share with its economic weight by establishing a European data space - a single market for data. This single market facilitates cross-sector data flow whilst respecting fundamental rights, such as data protection and privacy, and is supported by a framework of rules governing data access and use.

The cross-sectoral nature of the European data space acknowledges that each sector has its own specific characteristics and progress at different paces. Therefore, it advocates for the development of sector-specific **data spaces in strategic areas**, including "**agriculture**," leading to the creation of a Common European Agriculture Data Space - CEADS (European Commission, 2020a).

The Common European Agricultural Data Space aims to establish a secure and trusted data environment where the farming sector can share and access data. This initiative creates new opportunities for monitoring and optimising the use of resources, in alignment with the Green Deal and the Common Agricultural Policy (Common European Data Spaces for Agriculture and Mobility, 2021). **The amount of data from various sources within the agri-food sector can create additional services for farmers** by improving decision-making processes and by helping farmers understand and benchmark against their competitors and endorse the broader application of digital technologies in the sector.[4]

This initiative aligns with the goals stated under the EU Common Agricultural Policy (CAP), which highlights the agri-food sector as one of the largest economic sectors in the EU. The CAP aims to sustainably improve the productivity of European agriculture, strengthening the sector's competitiveness and sustainability by providing direct payments to farmers and supporting farm modernisation (ITU and FAO, 2020).

Data have been at the core of such digital transformations and data-driven technologies represent an opportunity for bringing benefits to citizens. In this context, **food innovation and the benefits of creating more resilient, transparent, and sustainable European food systems** are not to be disregarded. Although promising, the **digital transformation in food systems seems to have entered a twilight zone**, as data-driven innovation in the European food supply chains does not concur as quickly as expected (Wolfert et al, 2021). Moreover, the concept of data economy in agri-food system is relatively new, and research on the subject in the European context is falling behind (Verbeek et al, 2019).

[4] As endorsed by Kerstin Rosenow, Head of Unit at DG AGRI, during the Workshop on the Common European Agricultural Space in the Digital Europe Programme back in 2021. Report available at https://digital-strategy.ec.europa.eu/en/events/information-session-common-european-agricultural-data-space#:~:text=space%20event%20report-,Download%C2%A0,-EU%20workshop%20on

The European agri-food sector has encountered challenges in actively participating in the European Data Space and fulfilling the ambitions of European strategies towards a more-data driven sector. In response to these challenges, the Data4Food2023 project aims to comprehend and enlarge the knowledge base of data economy in European food systems. Meantime, the project also aims to develop a system to evaluate and monitor the development, performance, and impact of the data economy on EU policies. To be able to set up a sustainable path for the development of the data economy for food systems is important to have the proper knowledge on the system's situation at any moment in time. Therefore, monitoring and following up the changes occurred in the data economy for food systems over time help gather data, best practices and know-how, which are important factors in data-driven policymaking. Moreover, using the monitoring data and the analysis of future societal and technological changes and **trends** helps understand better the potential evolution directions of the data economy (in general) and the data economy for food systems (in particular). This will help with the updating of the monitoring system (both design and content) to keep the pace with the potential changes of the agri-food systems over time. It will also further contribute to the identification of the shape future requirements for the data economy for food systems development, including the **data value proposition for the food systems**, one of the first steps for the setting up the roadmap for long-term growth and design principles for an EU data space.

This deliverable presents the preliminary identification and analysis of trends that influence and shape the future requirements and data value propositions for food systems. It is the first step towards the identification of the possible recommendations for future developments that will be considered in the impact assessment scenarios in task 5.3 and deliverable 5.2 (M36). The assessment will lead to the consolidation of results and recommendations for the stimulation of DE4FS in Deliverable 5.3 (M48).

Objective of the Deliverable 5.1

The report aim is to analyse future societal and technological changes, focusing on trends that influence and shape the future requirements and data value propositions for food systems. It will look at recent and upcoming technologies relevant for the food sector, at the societal expectations for the food sector and new economic and non-economic value proposition, including the new societal and policy challenges and potential solutions.

This deliverable focuses on trends impacting the digital transformation in food systems and their influence on the data economy for food systems (DE4FS), aiming to provide a broad perspective for potential development paths for DE4FS. Before diving into the factors that impact the integration of food systems into the European data economy, an overview of the current contexts is presented in below, including definition and main concepts used in the analysis of trends.

The document is structured in seven chapters. Chapter one outlines the research context and presents the methodology used in the study; Chapter two includes an overview of the current developments of the data economy for food systems, providing a context for the analysis. The following four chapters focuses on the analysis of trends: Chapter three looks at technological developments, Chapter four at the social and economic trends, Chapter five focuses on environmental challenges and Chapter six analysis the policy developments. Chapter seven summarises the main finding of the report and sets up further research pathways for the development of the data economy for food systems.

1.1. Methodology

In today's dynamic economic landscape, understanding the ever-changing trends is important for all stakeholders. In general, the analysis of trends aims to identify patterns or changes in data and developments (e.g., technological advancements, societal changes, and economic growth) over time. It can be also used to forecast potential future developments and dynamics of society.

Analysis of trends can be used across various sectors, including finance, marketing, supply chain management, economics, healthcare and environmental sciences. Trend analysis is a useful tool to build evidence-based strategies based on historical precedents.

In this context, developing a methodology to assess the impact of technological, economic and societal trends on the data economy for food systems is needed. The first step involves identifying the main factors or elements relevant for this report and understanding the impact of these trends. The goal of Task 5.1 is to identify technological, economic, and societal changes that impact the development of the data economy for food systems. Therefore, it is important to tag the relevant factors related to technological, economic, and societal changes and assess their significance to the growth of data economy. Moreover, the analysis focuses on potential impacts both on the data economy (in general) and on the data economy for food systems (in particular).

In this study, we primarily used a desk study approach. This involved a comprehensive review and synthesis of existing data, scholarly articles, reports, and publications relevant to the topic of interest. The goal was to identify and interpret patterns, changes, and developments over time. The research method proposed is based on a funnel-type approach. First the literature review and desk research explore trends from a global perspective, identifying current trends relevant for the development of the data economy, with particular focus on food systems. Next, the analysis narrows the focus on the European Union context and aims at contextualising the impacts from this perspective. Whenever feasible, the analysis includes a country or regional perspective.

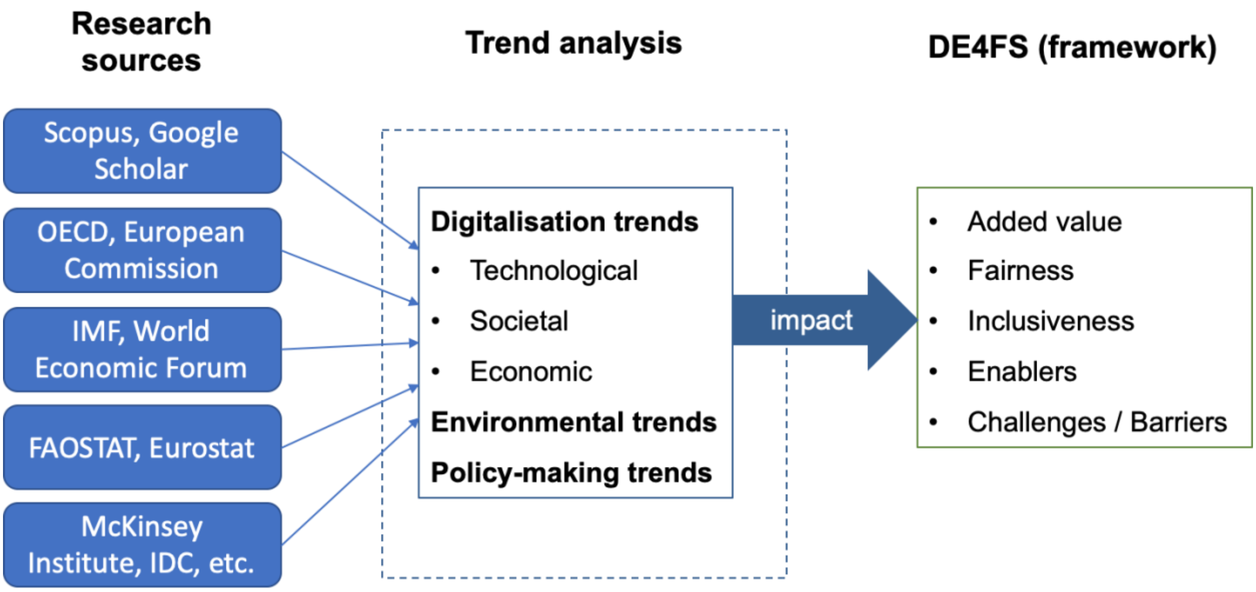

Figure 1. Research focus of the study

Following a brainstorming session with experts involved in the Data4Food2030 project, a set of keywords was developed for guiding the literature review and desk research. These keywords were “data economy”, “food and agri-food systems”, “social change”, “technological change”, “digital ecosystem” and “digitalisation", “trend analysis” and “digitalisation within agri-food systems”. The searches also included combinations of these key words to help narrow the results. In addition, to obtain more specific results, new combinations of other keywords were added, such as “big data use in agri-food sectors”, “artificial intelligence” and “machine learning”, “blockchain” and “3D printing”, and “sensors use”. To facilitate the preliminary scan of general literature, the trends were divided in four main categories: technological advancements and adoption, social and economic changes, environmental expectations and policy developments.

During the initial desk research, we looked at the global trends relevant for the data economy, without specifically focusing on food systems. Sources used for the preliminary research included Scopus, Google, Google Scholar, European Commission, including the Standing Committee on Agricultural Research (SCAR) and Joint Research Centre (JRC), European Parliament - the

Science and Technology Options Assessment Panel (STOA), Organisation for Economic Cooperation and Development (OECD), United Nations Commission on Science and Technology for Development (UNCTAD), World Economic Forum (WEF) and Food and Agriculture Organisation of the United Nations (FAO). For more specific focus (e.g., technological developments) additional sources were included, such as scientific articles from Elsevier (ScienceDirect), reports and articles from McKinsey Institute, CB Insights, Deloitte, Business of Apps, as they provide complementary information about topic assessed.

In addition to literature review, data analysis was also considered in the assessment process. The sources selected were mainly the official statistics published by EUROSTAT, OECD and FAO. These were complemented with data from Dealroom database, a private data source, which includes information on active data start-ups and scale-ups, an important factor in the development of the data economy (in general). Official statistics provide a relatively wide range of information on food systems for employment, value added, environmental challenges (including greenhouse gas emissions) and other economic areas, but remain rather limited when it comes to digitalisation and digital technologies adoption and use, circular economy or digital skills of the workforce in the food systems. The data analysis from Dealroom database adds another dimension to the data economy through the perspective of data companies active in food systems. The results aimed to provide an overview of the presence of data start-ups and scale-ups in food related industries, highlighting the potential changes data economy brings in this domain.

From the timeframe perspective, the analysis of trends considered the period from 2013-2023. This approach will provide the pre-pandemic perspective of various developments (2013-2019), followed by the context of pandemic challenges (2020-2021). The period 2022-2023 will point out the state-of play during recovery and lead to the analysis of trends. This timeframe will be considered for both literature review and desk research, as well as for data collection (whenever the information is available for the respective period). Moreover, inconsistencies in data availability made it difficult to preserve the initially agreed timeframe, therefore sometimes other timeframes were included in the analysis.

When it comes to impacts of the data economy on food systems, the study aims to understand potential benefits brought by these trends to stakeholders from food sectors and some of the future requirements and data value propositions for food systems. The analysis also considers possible challenges that rise from the trends for the food systems and the development of DE4FS. For example, the adoption of the latest digital tools is expected to improve production efficiency and enhance process management in the food sector. For the food systems, these tools can also contribute to improved products traceability and raise consumer awareness about the food they consume. On challenges side, the adoption of latest digital tools may require upfront investments (which may become a barrier for small farmers) adequate digital skills, user’s compliance with cybersecurity and data privacy rules. In addition, from data economy perspective, improving the systems’ interoperability for data access for both data producers and users is essential to achieve a proper exploitation of the data economy potential.

2. Data economy for food systems

Definition of data economy

Data economy constitutes an ecosystem in which different types of market players collaborate to ensure that data is usable and accessible, enabling market players to extract value from this data (European Commission, 2017). Data presented solely as input from the production of goods and services and data have no value on their own (OECD, 2019a). Data receives value when it generates actionable information and knowledge, often from data aggregation or re-use (Atik and Martens, 2020), data exchange (Dolfsma et al, 2021) or data transformation for better decision-making processes (Fresco et al, 2021).

Moreover, an initial definition for the data economy for food systems was proposed by the WP1, after an extensive analysis of the literature in the field. Deliverable 1.1 defines the DE4Fs as a spatial and temporal dynamic ecosystem, composed of numerous sub-ecosystems with loosed boundaries, where resource-integrating, service-providing and value-creating actors are connected by direct and indirect interactions and shared institutional arrangements to create value propositions though resources, institutions, technologies, data, relationships… connecting data ecosystems and Food Systems, as well as the broader economic, societal, digital, technological, and natural environments in which they are embedded in and connected to.

Data economy measures the overall impacts of the data market on the overall economy. It involves the generation, collection, storage, processing, distribution, analysis elaboration, delivery, and exploitation of data enabled by digital technologies. Data economy captures a wider concept than the data market only, as it considers the value and wealth generated in the economy as a whole (not just across businesses) by the exploitation of data. In a data economy, **data is considered a valuable resource and asset**, and its strategic management becomes crucial for businesses, industries, and economies as a whole.

Data economy is closely linked to digital transformation, as advancements in technology, connectivity, and computing power have significantly increased the volume and accessibility of data. Industries such as e-commerce, finance, healthcare, and agriculture are increasingly relying on data-driven approaches to enhance efficiency, improve decision-making, and innovate in their respective fields. As the data economy continues to evolve, policymakers, businesses, and individuals must navigate issues related to data governance, security, and privacy to ensure responsible and sustainable development (European Commission, 2024b).

In the agri-food sector, the data economy refers to economic activities and value creation related to the collection, storage, analysis and use of data (Wolfert & Isakhanyan, 2022). Data are increasingly used to improve efficiency, productivity and sustainability, and enhance the traceability and transparency of the food supply chain (Dolfsma et al, 2023). In recent years, the agricultural sector has undergone a substantial digital transformation, driven by the increasing digitalisation and increasing demands for sustainability (Wolfert et al., 2023). This transformation has given rise to a data-driven agri-food economy, with the potential to enhance efficiency and decision-making in farming and food production (Garske et al., 2021; Verbeek et al., 2019).

Despite the evident benefits and increasing demand for data-driven food production and consumption, the adoption of the data economy in the agri-food sector lags behind other industries, such as automotive and health (Verbeek et al., 2019). Research on the connection between the data economy and EU agri-food sector is still relatively new and its impact on future farm performance remains uncertain (Verbeek et al., 2019). Therefore, studying data economy trends in the agri-food sectors is crucial. It can help identify the challenges of digital transformation and develop proper solutions to overcome them, ensuring the sector can fully realize the benefits of data-driven innovations. It will also help aligning the sector's sustainability goals, enhancing efficiency and fostering transparency, eventually contributing to a more sustainable future for European food system.

However, before analysing the potential impacts of different trends on the data economy for food systems, it is important to have an up-to-date picture of the current status of the data economy for food systems. The following section will provide a short overview of the situation, based on the available data and indicators. The information aims to provide an assessment of the current developments related to data economy for food systems, looking at digitalisation level of different food-related sectors, data companies and professionals' actives in these sectors, the types of data start-ups and scale-ups engaged in food-related sectors and the funding received, etc. It sets up the scene for the trend analysis, helping to better understand the context of the data economy for food systems.

2.1. State-of-play of Data Economy in Food Systems

The current state-of-play of data economy for food systems has been analysed by the consortium, led by WP2. Some insights from Deliverable 2.2 "Intermediate state-of-play of the Data Economy for Food Systems" are derived herein. The insights gathered will help understand the current status of the data economy for food systems and provide a background for the analysis of trends to that will help to identify potential opportunities and barriers for further development of the data economy for food systems. A low digitalisation of the sector will delay the adoption of technologies and use of data-based solutions, slowing down the development of the data economy in the corresponding field. Disparities in development between regions or/and sectors will have a similar effect, while ethical and data privacy concerns might hamper the update of digital solutions due to lack of trust from stakeholders. At the same time, monitoring and understanding the context will help address the challenges, by setting up proper solutions, and further help with the development of the data economy for food systems.

The EU holds a prominent position as a major producer and exporter of agricultural products, with the agriculture and food sectors collectively employing approximately 25.5 million individuals, constituting around 12.4% of the EU workforce[5]. The Common Agricultural Policy (CAP) steers the governance of these sectors by ensuring a reliable supply of safe and high-quality food. Simultaneously, the CAP fosters sustainable development and provides support to rural communities (European Commission, 2023). The CAP, funded through the EU budget and executed by member states, has increasingly shifted its focus towards advocating sustainable and innovative practices. This includes initiatives aimed at enhancing traceability and transparency in the food supply chain, as well as measures to uphold food safety and quality standards (European Commission, 2023).

The food services employs about 9% of the EU workforce in 2023, while agriculture accounts for 3% of EU employment. However, employment in the agri-food sectors varies significantly across the Member States, ranging from 32% in Greece (out of which 11% in agriculture) to 4.3% in Luxembourg (where less than 1% is engaged in the agricultural sector). Similarly, the economic impact (as the share in countries' GDP) of agri-food sector varies from 8.1% of GDP in Romania (where 4.55% is from agriculture) to 0.21% in Luxembourg (the share of agriculture in GDP, as information about the other food-related sectors is not available).

At the same time, the food system is influenced by the emerging digital technologies. Digital transformation significantly impacts food value chain, making it more data-intensive. Regulatory requirements, consumer preferences (e.g., product quality, sustainability, transparency and social concerns) contribute significantly to the increase of data intensity in the sector. Managing cross-border value chains, especially for perishable goods, necessitates extensive information exchange and processing. The growing ability to generate digital data on agricultural assets and production processes, along with the digitisation of trade logistics, is meeting the rising demand

[5] Eurostat, Employment by sex, age and detailed economic activity (from 2008 onwards, NACE Rev. 2 two-digit level), accessed 10 January 2024. NACE rev.2 sectors included are Crop and animal production, hunting and related service activities (A01), Fishing and aquaculture (A03), Manufacture of food products (C10), Manufacture of beverages (C11), Food and beverage service activities (I56) and Veterinary activities (M75).

for information along the value chain. At the same time, currently it is difficult to evaluate the impact of digital technologies (e.g., AI, blockchain, etc.) on trade flows with the food value chain. Despite this, stakeholders agree that digital technologies have the potential to address a several issues that constrain trade integration into the food system and the trade logistic chain (Jouanjean, 2019).

Despite the growing influence of digital transformation, the impact is uneven across the food system, with agriculture still lagging behind compared to other food-related industries in taking advantage of these opportunities. While big data analytics, deep learning, artificial intelligence and machine learning algorithms become more and more present in food-related industries and markets, adoption and use rates vary. For example, in 2020, only 10.34% of EU enterprises in the food industry used big data analytics, with the highest adoption rate in Ireland (25% of Irish enterprises active in food industries use big data analytics), and the slowest adoption rate in Slovenia (1.2% of Slovenian enterprises use big data analytics). In terms of cloud computing, the situation fares slightly better, with 28.3% of EU enterprises active in food industries using these services, in 2021. Across Member States, the shares vary from only 3.1% in Portugal to 47.5% in Sweden. Based on Eurostat data, in 2021, only 3.32% of the EU enterprises active in the food-related sectors were using AI (for both manufacturing and services sectors). At the EU Member States level, these values vary significantly, with 15.1% of the Irish enterprises active in food industries using AI, while only 0.2% of the Romanian ones do it. When it comes to IoT devices, in 2021, only 25% of the EU enterprises active in food industries were using them, going from 63% of the Austrian enterprises active in food industries using such devices to only 3.5% of Bulgarian ones doing so.[6]

The EU Data Market study by the European Commission offers a valuable resource for understanding the data landscape in food industries. The latest EU data landscape report, published in December 2023, showed that, in 2023, approximately 3.8% (155 companies out of 4091 companies selected) of the EU data start-ups and scale-ups were active in the food-related industry, out of which 46.5% (72 companies) are active only in food-related industries, while 53.5% (83 companies) have an additional industry where they are also active (Osimo et al., 2023). Out of the 155 companies, only 74% (115 data start-ups and scale-ups) provide additional information about the sub-industries (markets) they are active in.

As Figure 2 shows, the top four specific markets mentioned are agritech[7] (61.7%), food logistics and delivery (22.6%), in-store retail and restaurants (13.9%) and innovative food (12.2%).[8]

[6] The source of data is Eurostat. The sectors considered to calculate the estimate were “Manufacture of food products; beverages and tobacco products” (C10-C12) and “Food service activities” (I56). The statistical tables used are *Artificial intelligence by NACE Rev.2 activity* [Table: isoc_ eb_ain2], *Internet of Things by NACE Rev.2 activity* [Table: isoc_ eb_iotn2], *Big data analysis by NACE Rev.2 activity* [Table: isoc_eb_bdn2] and *Cloud computing services by NACE Rev.2 activity* [Table: isoc_cicce_usen2].

[7] Agritech refers to application of technology in the agriculture to produce more with less, to make the farming process more efficient (from field monitoring to the food supply chain itself).

[8] The percentages include double counting of companies, as a company could specify multiple sub-industries. The analysis is based on Dealroom’s database of start-ups and scale-ups.

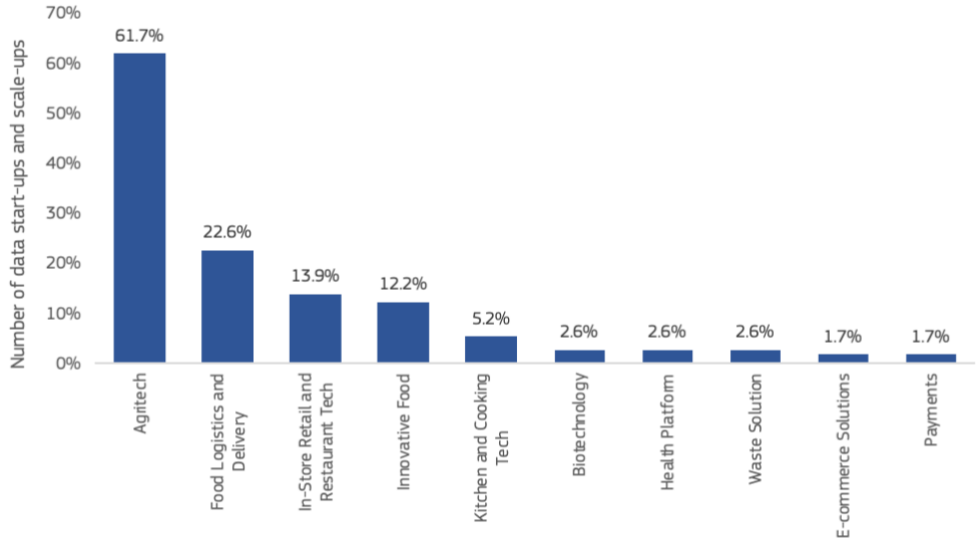

Figure 2: Top 10 sub-industries of EU data start-ups and scale-ups active in food industries, 2023

Source: Dealroom's database of start-ups and scale-ups (authors calculations, adapted from Osimo et al., 2023)

The fact that agritech dominates at 61.7% accentuates the ongoing transformation of agriculture through data-driven approaches. This focus on agritech suggests that the industry considers the improvement of agricultural productivity and sustainability fundamental to the future of food systems. This is especially relevant in the context of global challenges like population growth, climate change, and the need to produce more food with fewer resources. The presence of other markets complements agritech and aims to address different aspects of the food system, from ensuring that food is safely and efficiently delivered to consumers to innovating in response to changing dietary preferences. Together, these markets represent a comprehensive approach to modernising and improving food systems through data and technology.

Notably, the majority of these companies are headquartered in Western Europe (85% of data start-ups and scale-ups from food industries), while only 15% are established in Eastern Europe (see Figure 3).[9] The Netherlands, Spain, France, and Germany are the leading countries in hosting these data companies: 16.1% of the companies are in the Netherlands, followed by Spain (15.5%) and France and Germany (9%).

[9] The division was set from wide geographical perspectives. The Western Europe includes Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain, Sweden. Eastern Europe includes Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia.

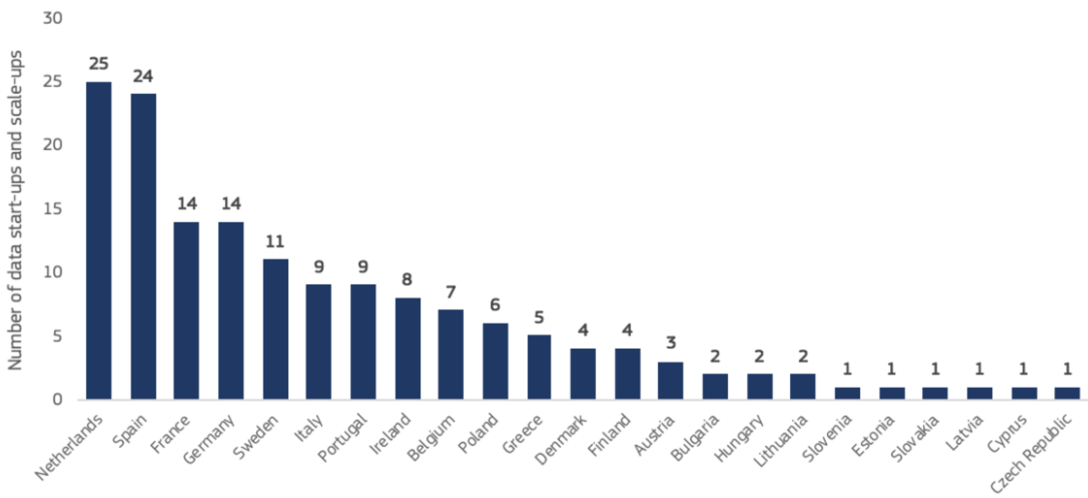

Figure 3: EU data start-ups and scale-ups active in food industries by country, 2023

Source: Dealroom's database of start-ups and scale-ups (authors calculations adapted from Osimo et al, 2023)

The data companies active in food industries are relatively young, with only 11% of them being over 10 years old. In 2023, 48% of the companies were between five and ten years old, and 11% were less than two years old (Figure 4).

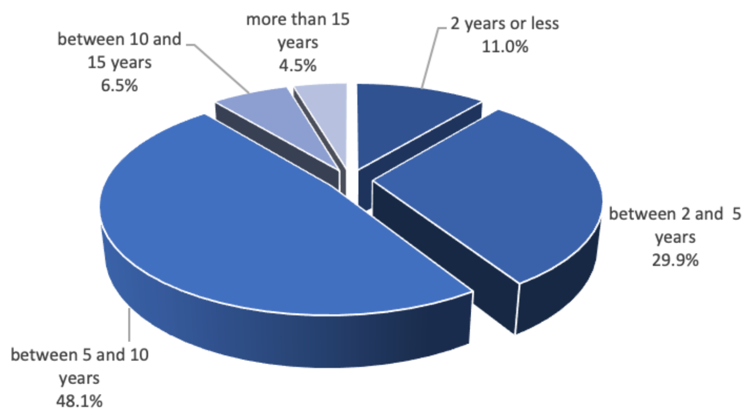

Figure 4: EU data start-ups and scale-ups active in food industries by age, 2023

Source: Dealroom's database of start-ups and scale-ups ups (authors calculations adapted from Osimo et al, 2023)

The fact that only 11% of these companies are over ten years old indicates that the majority have emerged in the past decade, due to the rapid technological advancements and the growing recognition of the value of data in improving efficiency, sustainability and profitability within food sectors. The fact that nearly half (48%) of the data companies in the food industry are between five and ten years old suggests that many of them were founded during a period when digital technologies were becoming more accessible and affordable, allowing for more widespread adoption across different sectors, including food. Moreover, the ongoing innovation and entrepreneurial activity in the sector is reflected by the new start-ups (less than two years old), potentially driven by the ongoing demand for technological solutions that address challenges in food production, distribution and consumption.

In 2023, the data companies active in food industries received €553 million in total funding, showing a 33.8% annual growth from 2021 to 2023.[10] At the same time, their valuation of EU data

[10] In 2023, 117 companies provided information about the total funding received compared to only 50 companies with this information available in 2021 (based on Dealroom database).

start-ups active in food industries increased by 33.5% since 2021, reaching €634.9 million in 2023 (Figure 5).

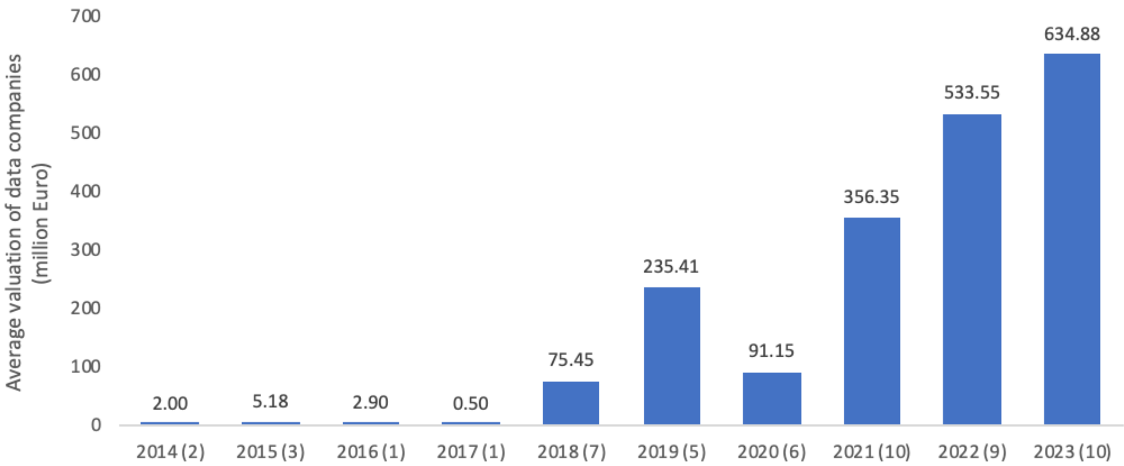

Figure 5: Average valuation (in million Euro) of EU data start-ups and scale-ups active in food industries

Source: Dealroom's database of start-ups and scale-ups (authors calculations adapted from Osimo et al, 2023)
Note: The number of companies with available data on valuation are mentioned in the brackets.

Unfortunately, due to limited breakdown of the statistics provided, the food industries are not separately covered, being included in broader categories such as industry and transport sectors. Nevertheless, the data shows that the agricultural sector lags behind other sectors in both data supply and data usage (Figures 6 and 7).

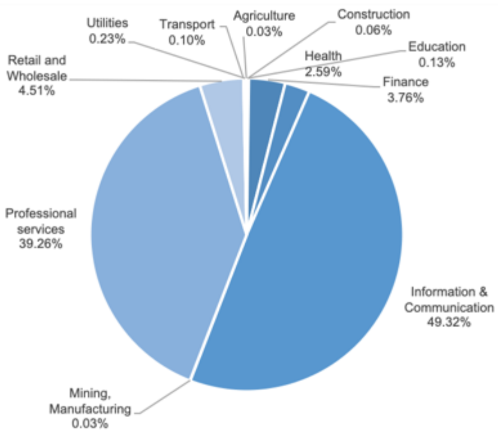

Figure 6: EU data supplier companies by economic sector, 2022

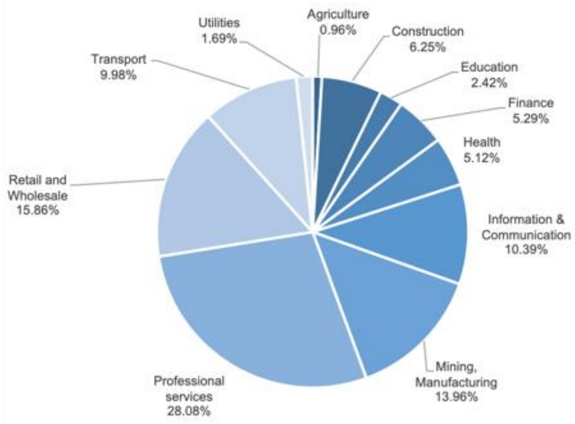

Figure 7: EU data user companies by economic sector, 2022

Source: European Commission, 2024b

The share of data professionals in employment in the EU has increased by 1.1% between 2013 and 2022. Only 0.53% of total data professionals are active in the agriculture in 2022, a considerably low share compared to other economic sectors (e.g., professional services accounts for 21.7% of data professionals, while retail and wholesale for 17%) (European Commission, 2024b).

Table 1. EU data professionals (in thousands) by economic sectors, 2019-2022

Economic sectors	2019	2020	2021	2022	Compound annual growth rate, 2019-2022
Professional services	1,277	1,385	1,497	1,583	7.4%
Retail and Wholesale	1,064	1,131	1,203	1,246	5.4%
Information & Communication	692	753	824	884	8.5%
Mining, Manufacturing	704	745	808	844	6.2%
Finance	571	609	652	680	6.0%
Health	479	518	555	586	6.9%
Education	443	480	509	538	6.7%
Public Administration	368	395	419	438	6.0%
Transport	185	197	211	219	5.9%
Construction	124	131	142	148	6.1%
Utilities	88	92	99	102	5.0%
Agriculture	32	35	37	39	6.7%
Total EU27	**6,026**	**6,471**	**6,957**	**7,307**	**6.6%**

Source: European Commission, 2024b

Table 1 provides an overview of the number of data professionals across various economic sectors in the EU27 from 2019 to 2022, along with the compound annual growth rate (CAGR) for each sector. Overall, the total number of data professionals in the EU increased from 6,026,000 in 2019 to 7,307,000 in 2022, representing a CAGR of 6.6%. The information and communication sector saw the highest growth rate at 8.5%, indicating a strong demand for data professionals in this field. Professional services and retail and wholesale sectors also showed significant growth, with CAGRs of 7.4% and 5.4% respectively. Even traditionally smaller sectors like agriculture saw growth, though it remains the smallest in absolute terms, with only 39,000 data professionals in 2022. The data highlights the increasing importance of data professionals across all sectors in the EU, driven by the growing need for data-driven decision-making and digital transformation.

Given these insights, it is clear that the data economy for the food systems faces significant challenges, particularly in the agricultural sector, which lags behind other industries in the adoption of advanced technologies. At the same time, the low representation of data professionals in agriculture also underlines the significant gap in data utilisation and innovation in this sector. The limited availability of detailed data on food industries and logistics further complicates the assessment of the data economy's state of play in the agri-food sector. Therefore, enhancing data availability and accessibility in these sectors is crucial for fostering growth and competitiveness in the food industries, which could support better decision-making and enhance efficiency across the full supply chain. In addition, the development of targeted initiatives to enhance data utilisation and innovation within the agri-food sector could help to fully leverage the potential of the data economy in this area.

In this context, analysing trends in the data economy is essential to understand the challenges and drivers of data economy for food systems. This analysis informs the development of targeted strategies to overcome barriers and capitalise on opportunities, ensuring the sector's growth and alignment with broader EU policy objectives.

3. Technological trends

Technological advancements have transformed nearly every aspect of human life, including the food systems and the growing data economy that supports them. Digital technologies like artificial intelligence (AI), the Internet of Things (IoT), blockchain and big data are revolutionising the agri-food sector, driving improvements in efficiency, transparency and sustainability across the entire value chain - from farm to table. These innovations optimise resource management, enhance process monitoring and reduce waste, helping food systems become more responsive to consumer needs and environmental challenges. The pandemic accelerated digital transformation, highlighting the importance of digital solutions in creating resilient and sustainable food systems. The analysis of these trends can help stakeholders anticipate potential future developments and make informed decisions to drive growth and innovation. It will also allow them to be more flexible and able to adapt to capitalise the benefits of change and knowledge (Otero Iglesias et al., 2024).

Digital tools are pivotal for "Smart Farming" by enabling precision agriculture through real-time data collection from drones, sensors, and satellite imaging. This allows farmers to optimise inputs like water and fertilizer, reducing environmental impact while boosting yields. Alongside these advances, digital technologies also support post-harvest processes, such as energy-efficient cooling, packaging, and logistics, thereby reducing food loss. Moreover, digital solutions enable consumers to make more informed choices, offering insights into product origins and sustainability, and supporting efficient supply chain management, which can cut costs and minimise waste. Therefore, data economy for food systems can be used to optimise every process within the food value chain, by enabling AI algorithms to improve products and processes, and by supporting new business models in the sector (e.g., renting heavy equipment instead of buying it). And, through personalised recommendations and tailored products and services to individual needs can boosting customer satisfaction and loyalty.

Despite these benefits, the development of the data economy in food systems is still in its infancy. The lack of specific research on data-driven innovations for the food sector limits the realisation of its full potential. For digital technologies to maximise their impact, improvements in digital infrastructure and increased digital literacy among all food stakeholders are essential steps in future developments. On the other hand, several challenges like uneven adoption rates across regions and sectors, potential biases in AI-driven decisions and data privacy and data sovereignty concerns still need to be addressed. The potential gains of adoption and use of digital technologies in food systems are numerous and a widespread and equitable adoption of them will be key to unlocking their full potential (Jouanjean, 2019).

Therefore, the rapid advancement of digital technologies is reshaping the agri-food sector, driving innovation, sustainability and efficiency across the entire value chain. Both the technologies and the innovations developed using them hold the potential to transform food systems making them more sustainable and resilient. Not all technologies will have the same impact on the food systems, therefore, based on the explorative desk study results, we have focussed our analysis on (a) advanced connectivity, (b) applied AI and generative AI, (c) big data and cloud computing, (d) smart sensors and IoT, and (e) blockchain and platform developments. These will be presented in a more detailed manner in the following sub-sections.

3.1. Advanced connectivity

Advanced connectivity refers to technological innovations and research that can improve the production of goods and services and connect the world through the internet, helping boost productivity and communication through digital transformation. It often consists of a range of building blocks such as 5G/6G, wireless low-power wide-area networks, low-Earth-orbit satellites and optical fibre that can drive new products and services, enable new business models, transform inefficient operating models and/or allow for reduced time to market. It will facilitate higher-quality network access for consumers and potentially unlock new use cases for industrial players. In 2020, a McKinsey report estimated a 21% increase in connected devices by 2025, the equivalent of approximately 51.9 billion connected devices in 2025 (Grijpink et al., 2020). This increase in number of connected devices, alongside high-speed connectivity, will generate a high volume of data and information, which can stimulate research and innovation that brings benefits to all economic stakeholders, including the ones from the agri-food value chain.

For example, in retail sector, sensors, trackers and computer vision optimise inventory management, enhance warehouse operations and streamline the supply chain. High-speed connectivity enables frictionless in-store experiences, real-time personalised recommendations and promotions drive increased sales. With technology advancements and improved affordability, widespread adoption of advanced digital technologies in retail is expected to potentially contribute €388.4 billion to €647.4 billion to the global GDP (by the end of the decade) (Grijpink et al., 2020).[11]

On the other hand, the agriculture sector is lagging in the benefits of advanced connectivity mainly due to two challenges: inadequate infrastructure, which impedes the technological deployment in some regions, and slow adoption of digital tools, often due to unproven benefits.

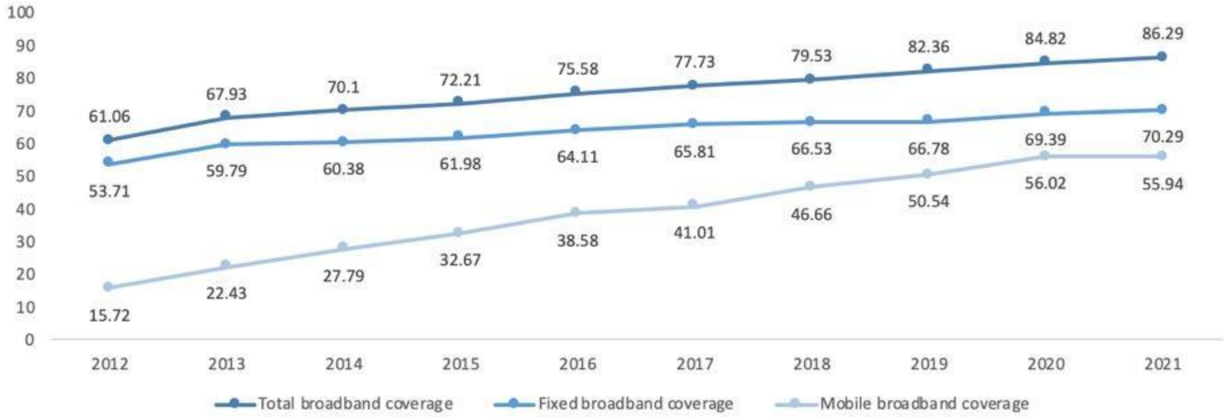

Figure 8: Change in the broadband coverage of the EU rural area, 2012-2021

Source: Eurostat (table: isoc_ci_it_h)

As shown in Figure 8, there is a positive change in broadband coverage in EU rural areas from 2012 to 2021. In the last 10 years, total broadband coverage steadily increased from 61.06% in 2012 to 86.29% in 2021 (4% increase). Fixed broadband coverage also showed consistent growth, rising from 53.71% in 2012 to 70.29% in 2021. The most notable increase was observed in mobile broadband coverage, which jumped from 15.72% in 2012 to 56% in 2021. The data highlights significant improvements in broadband access across rural areas of the EU, particularly in mobile broadband, reflecting the ongoing efforts to enhance digital connectivity in less urbanised regions. However, the development across Member States varies from country to country. In the Nederland, 98.5% of the rural households have a broadband connection, while in Bulgaria, only 72% of the rural households have one.[12]

At the same time, COVID-19 crisis has highlighted some of the issues concerning efficiency, resilience, digitisation, agility and sustainability within the sector. The disruptions of the supply chains highlighted the need for more local providers and diversified food delivery and logistics processes, especially concerning smaller farms. The pandemic has also emphasised the dependence on manual labour, posing significant challenges for farms with limited workforces, especially in the less-developed regions. IoT technologies on 3G and 4G networks can enable basic monitoring of crops and livestock and the decreasing prices of these technologies could

[11] The financial estimate refers to the retail sector as a whole; the lack of detailed data/information does not allow to narrow down the potential impact of the adoption of advanced connectivity technologies on food retail sector.

[12] In 2021, the share of rural households covered by broadband connections is below the EU average in 10 Member States: Bulgaria, Croatia, Czechia, France, Greece, Hungary, Italy, Lithuania, Portugal and Romania.

make their implementation financially viable. Some examples on how advanced connectivity can support smart farming are presented in Table 2 below.

Table 2. Example of advanced connectivity use cases with potential to radically transform the farming by 2030

Smart crop monitoring	Connected irrigation and nutrient-distribution equipment based on connected sensor data and imagery analysis, aimed at optimising resource usage and crop growth through real-time, precise, location-dependent adjustments.
Drone farming	Reduce costs and improve yields by using drone surveillance and remote interventions based on image analysis and connected sensors communicating data with the drone. It aims providing more frequent, cost-effective remote monitoring of large areas and enabling remote interventions to boost yield and reduce losses from pests as well as optimising deployment costs.
Smart-livestock monitoring	Improved monitoring by using individualised feeding-and-care plans based on connected-body sensor data and movement tracking. It is aimed at detecting illnesses early and providing each animal with its optimal feed and medicine mix to maximise growth.

Source: Goedde et al (2020)

The advanced connectivity solutions can help farmers saving time and provide them with new opportunities for land use or alternative work. New value opportunities emerge alongside digitalisation developments of the field. For example, seed and equipment sellers could expand their relationships with farmers by also providing innovative solutions (e.g., software) for optimal application based on field data. Similarly, equipment manufacturers could develop precision controls using satellite imagery and vehicle connections to boost field equipment efficiency (Goedde et al., 2020). And, while farmers are increasingly using data on soil, crops, livestock and weather, the access to advanced digital tools is still limited in this area.

In the context of the data economy for food systems, the advanced connectivity technologies could further provide the support for developments of new products and services tailored for food services. It can also facilitate and enhance the access to data from different economic sectors (including the food-related ones) encouraging the entrance of new market participants from different economic sectors to enter the food-related market with their own products.

3.2. Applied Artificial Intelligence (AI) and generative AI

Applied AI uses intelligent applications to solve classification, prediction and control problems to automate, add or augment real-world business use cases. As AI technologies rapidly push new frontiers of innovation, business adoption continues to grow across use cases. In 2021, the AI adoption rate by organisations in Europe was 51%, up 4% compared to 2020. However, the adoption rate in Europe remains below the world average (56% in 2021), and lagging behind other regions such as Developed Asia-Pacific (64%) and North America (57%). The overall annual economic potential of applied AI was estimated between €8.5 - €12.7 trillion, with the supply chain management and manufacturing accounting for €3 to €4.7 trillion, and marketing and sales €2.8 to €5.1 trillion. The technology-centric industries are leading adoption by businesses, while product and service development, service operations and marketing and sales are the business functions leading adoption of AI.

In the agri-food sector, AI leverages the ability of machines to acquire knowledge and make informed decisions by processing data. This encompasses technologies involving electronic devices, computer systems and robots that enhance the accuracy, speed and efficiency of agricultural activities. In this case, the main goal of AI is to enable computers, machines or robots to exhibit intelligent behaviour, including identifying objects, analysing profiles, finding solutions, making decisions, predicting anomalies and learning from supply chain processes. It can automate some of critical tasks in the agri-food processing, such as sorting, grading and packaging processes, it can help forecasting crop yields, by analysing historical data, it could detect food safety risks, by identifying potential contaminants and quality issues of the produce.

At the same time, AI technologies play a pivotal role in mitigating risks, improving food security, and achieving self-sufficiency. It can contribute to poverty reduction and increase food availability, by optimising the efficiency in food supply chain. It will support the transition towards sustainable agricultural practices, by improving use of water, fertilisers and pesticide in the food production and processing. Moreover, applied AI adoption is expected to have a significant impact in the agriculture sector, by enabling process optimisation (e.g., productivity forecasting and driverless tractor applications). In retail and consumer packaged goods, applied AI can boost sales by using ML to analyse huge sets of purchasing data, discern patterns and give shoppers customised recommendations (Chui et al., 2023).

Moreover, in the last years*, generative AI*, a key applied AI technology, started to gain more momentum. The technology can automate, augment and accelerate work by creating new content from unstructured mixed-modality data sets, including text, video, code and protein sequences. It has the potential to unlock novel use cases, enhance existing processes, redefine businesses and value chains, and improve both employee productivity and customer experience. In 2022, the equity investment in generative AI was of €4.75 billion, while the number of jobs posted increased by 44% compared to the previous year. Venture capital investments increased 425% from 2020, and nearly 80% of current AI research focused on generative AI. (Chui et al., 2023).

In the agricultural sector, generative AI, especially Generative Pre-trained Transformer (GPT) methods can play a crucial role by providing farmers with access to knowledge and information that ranges beyond their expertise. The algorithms can provide insights, suggestions, and solutions to agricultural problems and help farmers make informed decisions to improve efficiency. Considering the low digital literacy of farmers, generative AI can fill in the knowledge gap and, consequently, empower farmers and advance modern agriculture. For example, “AgriGPT” is generative AI technology developed in the agricultural sector, which serves as an AI advisor to assist with agriculture-related inquiries. It uses private and public agricultural data, real-time internet data and a user-centric feedback loop. The app is trained on extensive agricultural datasets, providing information about soil conditions, weather patterns, pest control measures, and offering personalized recommendations for crop production (Liu et al., 2023).

Another use of applied AI can be found in the industrial machine learning (ML) developments. Industrial ML integrates both AI and ML into production processes, aiming to address technical challenges and streamline the development and deployment for businesses. At the same time, it can accelerate AI adoption, through its four key stages—data management, model development, deployment, and live operations—, enhancing productivity within the food sectors and facilitating collaboration between experts. In 2022, equity investments in industrial ML reached €2.85 billion, with job postings up by 23% from 2021. For the agri-food sectors, this technology enables precision agriculture and optimised supply chains, leveraging data as a vital economic asset to boost efficiency, sustainability and resilience (Chui et.al., 2023; Cristea et al., 2021).

However, the use of applied AI does not come without challenges. High-up investments remain one important factor in the adoption and use process, especially when it comes to small and medium-sized farms. The AI ethics and compliance with regulations due to data privacy and cybersecurity concerns are other aspects to be considered with engaging with applied AI technologies (Chui et.al., 2023).

The AI technologies can help to create new patterns of development for food systems, generate new data and stimulate the data economy development. These technologies have the potential to enhance the use of inter-sectoral databases, creating new knowledge for further developments of products and services tailored for food services. Providing the proper infrastructure will further support the data use in food-related sectors, through faster and reliable access for service and product developers across various economic sectors. However, to maximise the benefits of the

AI technologies' use, couple of challenges need to be addressed. There is a need for improving the interoperability of the available databases for a swift data use and setting up a framework of applicability to reduce and limit the potential negative issues related to ethical use, cybersecurity and data privacy.

3.3. Big Data and Cloud Computing

Big data technologies are revolutionising the agri-food sector by leveraging large volumes of digital data gathered from connected sensors and other devices to enhance real-time decision-making. The five "Vs" of big data—volume, velocity, variety, veracity and value—enable the processing and interpretation of vast, fast-moving and diverse datasets that conventional methods cannot handle. Moreover, increased computer power enables the processing and interpretation of those large volumes of data to infer relationships, establish dependencies and perform predictions of outcomes and behaviours, helping inform real-time decision-making by combining a wide range of information from different sources. Big data could also help integrating farmers' data to generate new knowledge, fostering new and innovative services and processes and adapting big data models for agriculture. By tapping into external resources like the climate data, satellite imagery and geospatial data, big data plays a crucial role in optimising the food value chain, improving productivity, efficiency and sustainability across the sector.

Big data need appropriate environment to be stored, processed and analysed, and for this cloud computing are a viable option. Cloud computing is the low environment where big data information is stored and where applications and specialised software are executed to process and access the respective data. At the same time, cloud computing allows the processing of large volumes of big data information due to its scalability, allowing storage capacity to be increased as needed to prevent saturation of the platform. In this context, edge computing is the next step for tomorrow's networks, with computational resources strategically positioned at network edge nodes near end-users. This combines the advantages of traditional cloud computing by improving it by reducing data latency and enhancing data autonomy.

Cloud has already effected change across industries and will remain an important tech disruption. The market for public cloud continues to grow rapidly. The worldwide public cloud services market in 2020 was approximately €262.7 billion with an annual growth rate (CAGR) of approximately 25%, driven by growth in Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS). The cloud is increasingly becoming more hybrid and 90% of cloud users have a multi-cloud strategy, with over 80% having a hybrid mix of private and public cloud. Moreover, as distributed computing is becoming more popular and contribute to unlocking real-time insights of data, the edge computing is seen as the next step, which leverage many types of networking technology to connect end-users to a decentralised core of computing infrastructure located closer to the end-user. In addition, forecasts show that 26% of servers shipped in 2024 will be deployed at the edge, an increase of 20% compared to 2019 (Chui et al., 2022). While edge computing increases it relevance in the economy, the cloud computing remains a critical option in performing non-time-sensitive computing at better economies of scale at a distance from the end-user (Chui et al., 2022).

When it comes to edge computing, the technology is revolutionising the precision agriculture by enabling real-time data collection and processing through sensors and cameras in fields, leading to immediate adjustments in farming practices and enhanced sustainability. Additionally, it supports autonomous farming machinery and livestock monitoring, improving productivity and animal welfare while reducing resource usage and labour costs. Edge computing can help optimising bandwidth use, ensuring the execution of critical agricultural operations in rural areas, where often the internet connectivity is poor. At the same time, it helps promoting sustainable farming practices by using real-time data to reduce waste and environmental impact. In terms of overall financial impact, the estimated value of edge computing market ranges from €161.8 to €192.8 billion by 2025, with approximately €3.7 to €10.2 billion coming from chemicals and agriculture sectors.

For food sectors, big data use and cloud and edge computing will bring important benefits to stakeholders through improvements of processes and efficient production. However, there also some challenges that need to be addressed. For example, the agricultural sector's rely on diverse hardware and software from various vendors in its daily activities, which necessitates seamless interoperability to maximise big data and edge computing benefits. Moreover, managing the vast amount of data generated by smart devices requires robust solutions, which often requires new skills to operate and maintain these technologies. Therefore, stakeholders, including farmers, must acquire new skills, which make training and education initiatives crucial for their future development.

3.4. Smart sensors and Internet of Things (IoT)

Smart sensors convert various physical properties into digital data, acting as a bridge between the physical and digital worlds. The integration of sensors in agriculture and logistics enables real-time data communication, sophisticated cross-analysis through machine learning, and efficient tracking and management of inventory, location and processes. Therefore, they are often used in integrated technologies (e.g., microcontrollers, communication interfaces, etc.) to transmit real-time, context-like information. The reduction in sensor size and cost has allowed their integration in numerous devices in various economic areas, enabling the Internet of Things (IoT) and supporting the development of big data. For example, as today's consumers are becoming more and more health-conscious, the market for fitness trackers and smartwatches shows a significant growth on the demand side. These tools use sensors to monitor physical activities, steps, calories, etc. The global sensors market was valued at €189.50 billion in 2022 and is expected to reach €388.5 billion by 2030, with an estimated annual growth rate of 9.4% for 2023-2030.[13]

In the agri-food sectors, smart sensors' application is found in precision agriculture and animal tracking, as well as in transportation and logistics, especially due to innovations like Radio Frequency Identification (RFID) tags. The RFIDs offer advanced tracking and safety features, enhancing precision agriculture and animal tracking, and providing detailed product history and contamination warnings.

Due to sensor advancements that consistently provide precise and accurate measurements, the market demand for novel applications, especially in the fields of diagnostic and mobile-based access, is on the rise, contributing to the increase of the smart sensors' market. At the same time, IoT applications rely heavily on smart sensors to gather data and enable connectivity between devices and systems. IoT applications using connected sensors serve to monitor the health, location and activities of people and animals as well as the state of production processes and the natural environment. Moreover, when combined with big data analytics, these technologies can empower intelligent systems and autonomous machines. In agriculture, food sectors and the trade chain, IoT will rely on high connection volumes (i.e., large deployment of sensors), but small data traffic, with low cost and low energy consumption. The applications in this case might be used for the management of temperature of a warehouse, tracking of transport logistics or fleet management, as well as for monitoring smart meters and sensors in agriculture – e.g., soil quality, climate, crops, diseases, plagues and weeds (Jouanjean, 2019). For example, in agriculture, IoT together with smart sensors contributes to the enabling of smart farming, replacing the conventional agricultural methods. In this case, IoT approaches help to assess soil health, soil erosion, need of fertilizer, status of soil fertility and crop quality (Rajak et al., 2023).

However, the adoption of smart sensors and IoT devices on large scale still faces important challenges. One of the then is related to connectivity infrastructure. Continuous internet connectivity is needed to use smart agriculture sensors and IoT devices and this might proof difficult in the rural areas lacking necessary infrastructure. Another important factor in the adoption and implementation is the financial burden. Large-scale deployment of IoT-tagged sensors in agriculture faces significant financial requirements, which encompasses high costs for hardware,

[13] Data Bridge Market Research, *Global Sensors Market – Industry Trends and Forecast to 2030*, July 2023.

software and system operation. In addition, there is uncertainty about whether the benefits will justify the costs of implementation (Rajak et al., 2023). On the other hand, large deployment of IoT sensors will lead to an exponential growth of data, pushing computing operations and data analytics to the edge, increasing the need of speed and reliability of data. Thus, data spaces are a necessarily development rather than a “nice to have” one.

3.5. Blockchain and platform developments

A **blockchain** is a distributed database, replicated across many locations and operated jointly by a collective. The decentralisation eliminates the custodian restraints and all the data in the system are digitally encrypted for unique identification; any record added to the ledger cannot be change or deleted afterwards. In this sense, blockchain technology can significantly impact the agri-food sector by enhancing supply chain transparency and trust, through transparent, traceable and immutable records. In addition, the platform can execute small programmes, called “smart contracts” that can automate transactions based on predefined conditions, ensuring accountability and efficiency without third-party intermediaries. The blockchain’s governance can be open (i.e., anyone can join and participate in the network) and/or permissioned (i.e., the participation in the network is restricted, with specific rules on who is allowed to participate in the network and in which transactions). The open blockchain technologies are based on systems of consensus over the registration of blocs of information based on game theory principles that rely on incentive systems to create co-ordination among competing actors. Transactions recorded on blockchains are trackable and irreversible. For private blockchains, the governance mechanism relies on the selection of the network participants and can depend on compliance with a set of rules put in place by the network starter (e.g., licenses for participation) and on a consensus by all network participants (e.g., a consortium). While open blockchains offer decentralised and incorruptible ledgers, private blockchains allow controlled participation, providing flexibility and compliance with regulatory requirements, thus optimising supply chain management and potentially increasing market power concentration (Jouanjean, 2019).

Despite the fact that agri-food remains one of the less digitalised industries, blockchain technology could offer significant advantages for the industry. It can automate transactions and certifications through decentralised, self-executing smart contracts, potentially streamlining regulatory processes and information exchanges. It facilitates hardware and software cohesion, enhancing system integration and performance in the agri-food systems. Blockchain also provides an immutable record of transactions, fostering trust among supply chain actors through easier auditability. Additionally, it improves traceability and visibility of goods, enabling better inventory management and planning from farm to fork (Motta et al., 2020).

In many industries, the fragmentation of data remains a challenge for the development of digital-based market solutions, due to difficulties in gaining data access and potential interoperability concerns. A potential way to tackle these issues is to use **digital platforms**, which provide easier and broader access to data and information, creating leverage for further innovation and new products and services development. Data sharing is an important factor to build value creation, value capture and innovation opportunities for businesses, enhancing further the economic value of shared data. One of the outcomes of the digitalisation of international trade is the emergence of intermediary platforms that enable commercial transactions between providers of goods and services and buyers of those products or services. The platform economy and platform markets are changing the society in various ways, becoming one of the core elements of the sharing economy.

Digital platforms significantly impact the agri-food sector by enhancing data accessibility and transparency, potentially improving decision-making and sustainability in agriculture. They are increasingly being used in the agricultural sector to improve efficiency, traceability and sustainability. In addition, e-commerce platforms are reshaping domestic and international trade, making it easier for providers and buyers to connect. Overall, platforms allow farmers to connect with multiple actors from the agri-food sectors and use their knowledge databases to inform themselves about best practices, innovations and news; they offer valuable services for stakeholders helping them improve efficiency and market access (e.g., provide access to regulatory information and logistics management), benefiting the agri-food industry.

However, platforms come with various challenges too. One challenge concerns the concentration of power among a few dominant platform providers, which may exacerbate existing inequalities and lead to job losses or the erosion of local knowledge. Additionally, while platforms promise profitability and innovation, their long-term viability remains uncertain, as unclear business models could hinder adoption and create dependency on external funding. Overall, the development of these platforms necessitates careful consideration of the values they promote and the stakeholders they serve to ensure equitable benefits across the agricultural value chain.

3.6. Overall challenges and opportunities

In general, the technological trends highlight several key advancements for food sectors that enhance efficiency, transparency and sustainability. Blockchain technology improves supply chain trust and automates transactions through smart contracts, streamlining regulatory processes. Smart sensors and the Internet of Things (IoT) facilitate real-time data collection, enabling precision agriculture and better resource management. Digital platforms enhance data accessibility, fostering connections between farmers and stakeholders, which improves decision-making and market access. In addition, the integration of these technologies promotes sustainability by optimising resource use and reducing waste, while enhanced data sharing creates opportunities for value creation and innovation within food systems. Overall, these advancements signal a transformative shift in the food sector towards more efficient and sustainable practices.

However, significant challenges remain to be addressed to fully harness the potential of adoption and use of digital technologies. A primary concern is the fragmentation of data across diverse sources, which complicates access and interoperability. This issue is exacerbated in rural areas, where inadequate connectivity can limit the effectiveness of smart sensors and IoT devices. Additionally, the financial burden of deploying new technologies, alongside the need for robust data privacy and security measures, poses obstacles for many stakeholders, particularly small-scale farmers. The concentration of power among a few dominant digital platforms raises concerns about equity, potentially leading to job losses and erosion of local knowledge. Uncertain business models for these platforms can hinder their adoption and create dependencies on external funding, while the need for new skills necessitates comprehensive training initiatives for stakeholders. Addressing these challenges is crucial to ensuring that the benefits of the data economy are equitably distributed across the food value chain.

The information available to assess the impact of digital technologies adoption and use on the data economy for food systems remains limited. Often the literature used in the analysis focus more on the overall benefits of the technological advancements for food industries, rather than the impact on the data economy (in general) or on data economy for food systems (in particular). Additionally, the fluid nature of data makes it often difficult to assess the economic impact for specific economic sector or field of application. However, it is clear that technological trends (e.g., AI, blockchain, smart sensors, IoT and digital platforms) are enhancing data accessibility within food systems, promoting efficiency and sustainability, and fostering innovation across the supply chain.

4. Social and economic trends

The rapid growth of digital technologies is reshaping the global economy, with significant implications for both geographical and organisational structures. The digital innovations are transforming consumption patterns, disrupting production processes and leading to the creation of new products and services. As digitalization continues to advance, new businesses are emerging, with the potential to play central roles in global value chains and capture significant value of the market. However, these digital technologies also bring challenges, including enlarging technological gaps between advanced and less developed economies, shifts in the labour market, and changes in social values (Azmeh et al., 2021).

Digital technologies, such as AI technologies (including the generative AI, like ChatGPT) and digital platforms transition the labour market by reducing the demand for routine tasks that can be automated while increasing the demand for roles that benefit from AI augmentation or remain largely unaffected by it (OECD, 2024). This shift in labour demand impacts particularly the low-wage workers, especially in agri-food where automation takes routine labour that is largely present in agri-food operations. The changes in the labour market also transform the broader economy by reducing occupational wage premiums for routine jobs and reshaping the structure of work environments.

The smart use of data can create new opportunities for economic growth in all sectors of the economy, promoting fair access to resources and ensuring that benefits are shared equitably across all stakeholders. It also can help address issues like poverty, healthcare, education, housing, community development, and environmental conservation. However, to fully understand the economic value of data, it's essential to analyse when and how data becomes economically useful, and how value is generated and captured that can be done with the help of the data-intensive technologies (OECD, 2022).

At the same time, the data economy is increasingly reshaping not only the labour markets, but also the consumers behaviour, and business models. The smart use of data presents opportunities for transparency in food production and opportunities for economic growth. To maximize the economic value of data, it is essential to understand when and how data becomes economically useful and how value is generated and captured—especially with the rise of data-intensive technologies. For instance, how farmers can leverage data as an additional product within food systems, thereby adding value and addressing environmental concerns, reducing waste, and improving transparency.

This section explores societal and economic trends shaping the data economy, particularly in the European agri-food sector. A particular focus is shown to the changes in the agriculture due to the sector specificities. The coverage for the other food sectors is rather limited, as often data and information are embedded in wider economic categories, such as transport and logistics, warehousing and manufacturing industries. Based on the explorative desk study results, we have grouped the social and economic trends under (a) macro-economic trends, (b) impact investment and food system transformation, (c) trends in farming in Europe, (d) structural changes in agriculture, (e) employment challenges, and (f) access to food and healthy diet. The following sub-sections explain these trends in more detail.

4.1. Macro-economic trends

This section aims to provide an overview of the main macro- economic trends that currently impact the landscape of data economy, such as the GDP growth, inflation, structural changes in the sector, change in farm size, and discusses coping strategies.

The OECD Economic Outlook report from 2023 estimated moderate global GDP growth, expected to decrease from 3.3% in 2022 to 2.7% in 2023 and slightly increase to approximately 2.9% in 2024 (OECD, 2023a). These growth patterns, coupled with inflationary pressures, are likely to shape investment behaviours, which will have direct implications for the agri-food sector. Moreover, the restrictive monetary policies implemented in 2022 to limit the growth of demand are expected to show their effects late 2023 or early 2024. Annual consumer price inflation in the G20 economies is anticipated to decline from 7.8% in 2022 to 4.7% in 2024, driven by lower energy and food retail prices, moderating demand pressures and fewer supply bottlenecks (OECD, 2023a).

Economic Outlook 2023 of The Conference Board estimates an average annual growth of 2.8% in real GDP for 2025, with a slight decline to 2.6% for the period 2026-2031(Global Economic Outlook, 2024). However, growth in the European economy is expected to be lower, at 1.4% in 2025 and 1.2% over the period 2026-2031. In addition, estimated economic growth for the EU member states, for the period 2024-2035, varies between -0.08% (Italy) and 2.63 (Estonia). On average, the EU annual real GDP is approximately 0.84% (OECD, 2023a).

However, stricter-than-anticipated global financial conditions may increase vulnerabilities in emerging-market economies, leading to challenges such as increased debt servicing costs, capital outflows, and reduced access to credits. On the one hand the unpredictable trajectory of Russia-Ukraine war presents a significant downside risk to the global economic outlook, with the potential to disrupt energy and food markets. On the other hand, positive developments such as an early resolution to the conflict, improved financial conditions, robust labour force growth, and increased utilization of accumulated savings, could positively influence the economic outlook, although the impact on inflation may vary.

While inflation is not typically considered as a trend, its impact on investment behaviours is significant. Data shows that, although headline inflation started to decline in most economies due to falling energy prices, core inflation remains high, with food and services prices continuing to rise rapidly. In addition, the combination of high inflation and modest wage increases led to a decline in real wages in 2022. During this period, governments provided extensive support to shield households from the effects of high energy and food prices. The OECD estimated that the decline in real wages would slow down coming years.

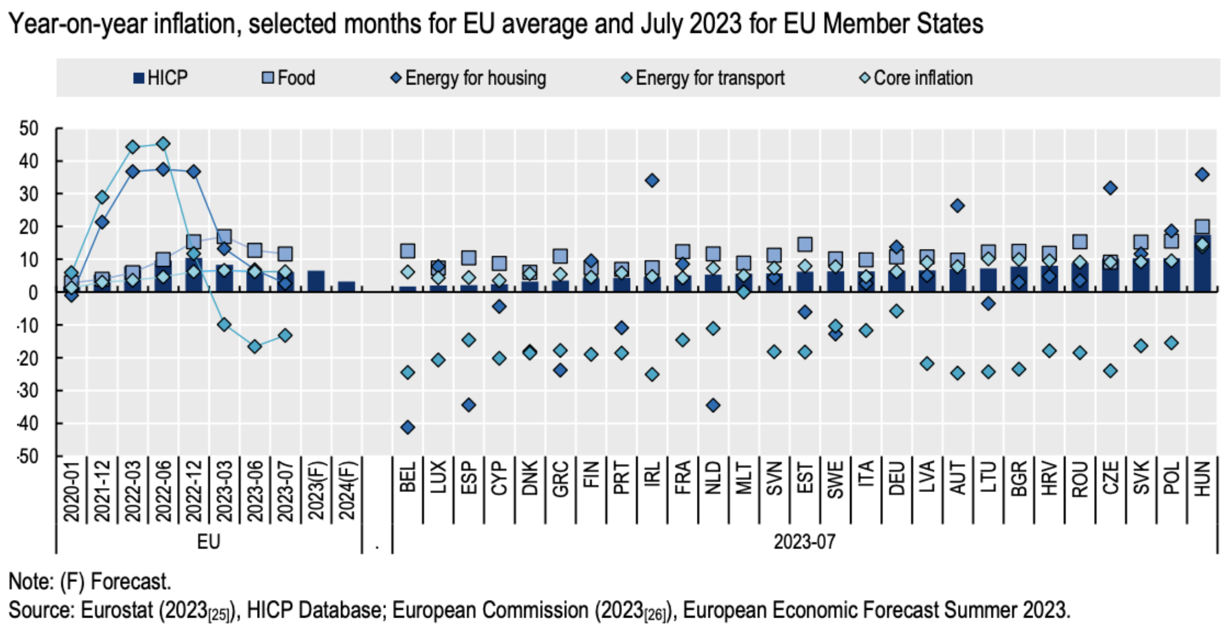

Figure 9. Inflation surged in 2022 as energy and food prices soared

Source: OECD (2023b)

Figure 9 presents year-on-year inflation data for the EU and its member states, focusing on selected months from January 2021 through July 2023, with forecasts extending into 2024. The data is categorized into overall Harmonized Index of Consumer Prices (HICP), food, energy for housing, energy for transport, and core inflation. As can be seen in the figure, the overall HICP inflation peaked dramatically around mid-2022, reaching nearly 50%, primarily driven by the energy for housing segment. This peak is likely due to external factors, such as supply chain issues or geopolitical tensions affecting energy prices. By July 2023, inflation has largely stabilized across most categories and countries, with values tightly clustered around zero for many states, suggesting a return to more typical inflation rates. The core inflation remains relatively stable and low compared to the more volatile categories of food and energy, indicating that the underlying economic conditions excluding food and energy prices are less vulnerable to sharp fluctuations. Finally, the forecast into 2024 indicates an expectation of stable or mildly fluctuating rates, with no severe deviations.

In summary, the current economic trends highlight the complex and multifaceted impacts on the general data economy and particularly on the data economy within agrifood sectors. Although the data economy constittes a relatively small share of the GDP, the economic trends still have a significant impact on its future development. Moderate global GDP growth, coupled with inflationary pressures and monetary policies, shapes investment behaviours that will impact the sector development.

4.2. Impact investment and food systems transformation

The financing is crucial for scaling innovation and addressing challenges agri-food systems are facing. Despite the urgency, the investments towards radical transformations in the food system remains limited (Chiriac et al., 2023; Diaz-Bonilla et al., 2023). This shortage in investments hampers the pace of innovations to achieve sustainability goals.

Recent research by International Food Policy Research Foundation (IFPRI, 2022) highlights a significant funding gap, estimated by the at $350 billion annually needed by 2030 for a transformative impact. The United Nations Environment Programme (UN, 2023) indicates the potential of private funders, including banks, investors, insurers, to close the funding gap through innovative financial instruments. Financial institutions with significant portfolio exposure to the agri-food sector have a fundamental role to play in addressing the world’s most pressing challenges. They can influence clients and suppliers across value chains to improve their policies and practices, demand accurate quantitative monitoring and reporting from investees and drive financial flows towards more sustainable food systems.

Moreover, the impact investing sector continues to grow in depth and sophistication, with clear indicators of market development over the period 2017 – 2022 (Hart et al., 2023a). The data show that from 2017, the amount of impact of the assets under management (AUM) of investors increased by 18%.[14] The industry continues to evolve and investors are focused on impact data and regulatory developments, aiming to tackle the new set of challenges that arises (Hart et al., 2023a).

[14] Asset under management (AUM) represents the market value of the investments managed by a person or entity on behalf of clients (Source: Investopedia).

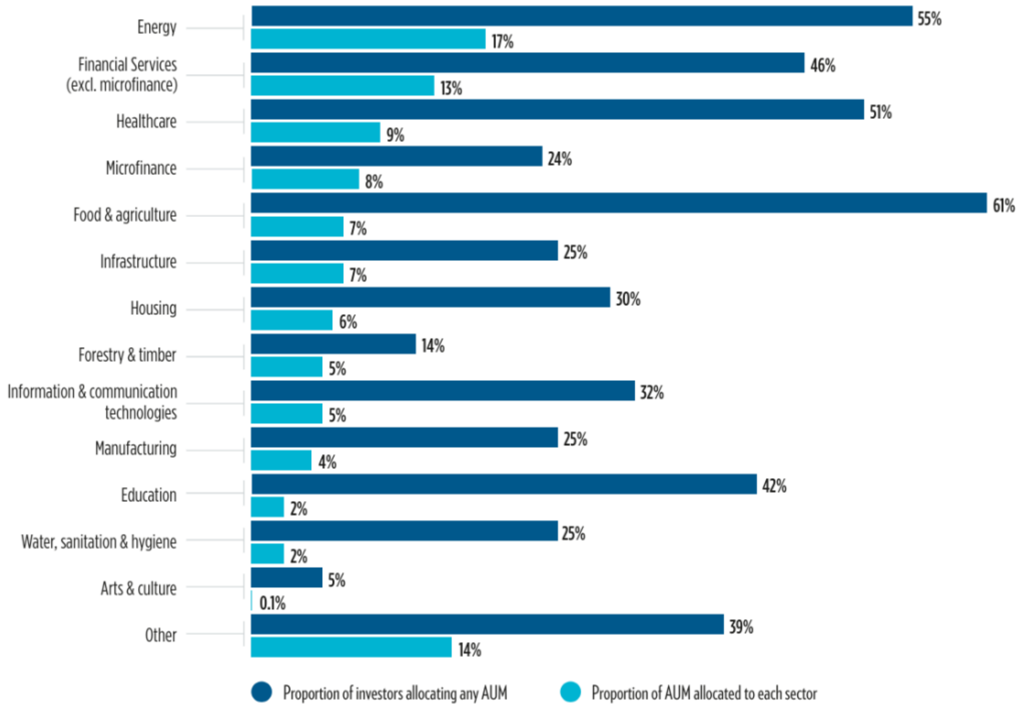

Figure 10. Impact Investment by sector of the economy (Asset under management, AUM)

Source: Hart et al. (2023a)

Figure 10 illustrates the distribution of impact investment across various sectors, emphasizing the focus on the food and agriculture sector, which attracts 61% of investors allocating assets under management (AUM). This is followed by the energy sector, which sees 55% of investors contributing, showcasing its importance in impact investing.

Impact investors in food and agriculture sector are increasingly pursuing both social and environmental impact and encourage sustainable agriculture practices (Xiao, 2023). When implemented well, sustainable farming can support jobs, empower women and mitigate rural poverty. It can also improve climate adaptation and resilience (Xiao, 2023). However, the transition to sustainable practices meets challenges, particularly smallholder farmers face high initial costs and a need for long-term investments to realise profits and yield improvements. Impact investors play a crucial role by offering non-financial support such as technical assistance, capacity building, and financial literacy programs, which are essential for facilitating the adoption of innovative and sustainable agricultural techniques (Isakhanyan et al. 2024).

In summary, the sustainability of agri-food sector also depends on effective bridging the substantial funding gap through strategic impact investments. By focusing on financial and non-finacial support, impact investors can boost agri-food sector not only for mitigating climate change, but also for economic resilience and the quality of life in rural and remote areas.

4.3. Trends in farming in Europe

If a sustainable food system is the goal, ensuring fair pay for farmers is essential (Gemtou et al. 2024; Isakhanyan et al. 2024; Pedersen et al. 2024). This section discusses the current state of the farming in Europe, reflecting on the model of the self-employed family farm, on which our Common Agricultural Policy was set up with the 1957 Treaty of Rome.

Today, 97% of EU farms can be classified as family farms, with 2.8% owned by legal entities that manage more than 27% of the land. Of the 11 million EU farms in 2013, 66% were smaller than five hectares, occupying just 6.2% of agricultural land. More than 43% of land is owned under a tenancy arrangement. Some 56% of farmers are older than 55, and only 6% are younger than 35. Women manage 28% of farms, and 40% of these women are older than 65 years. By 2020, the number of EU farms had dropped by 2.7%, reaching 9 million (Eurostat, 2023).

The farm workforce has also seen a decline, with about 17.5 million persons employed in 2020, down by 3% compared to 2013, when the farm workforce accounted for approximately 22 million people.

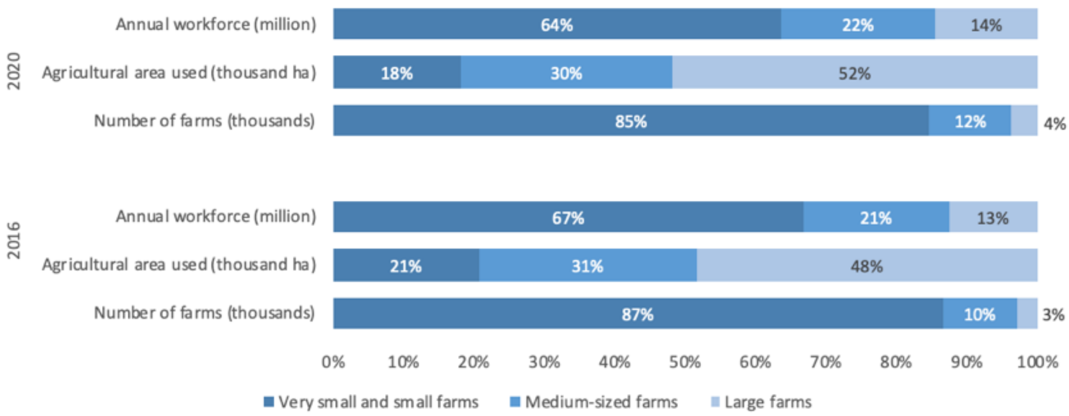

Figure 11: Farms in the European Union, by physical size, in 2016 and 2020

Source: Eurostat (ef_m_farmang)
Note: The physical size of a farm is assigned based on the utilised agricultural area. Thus, very small and small farms have less than 20 ha (very small farms are those up to 2 ha), medium-size farms are between 20 and 100 ha and large farms have over 100 ha in size.

Figure 11 illustrates the distribution of farms in the European Union by size—very small and small farms, medium-sized farms, and large farms—across three metrics: annual workforce, agricultural area used, and number of farms, comparing data from 2016 and 2020. In both years, very small and small farms dominated in terms of the number of farms, accounting for 87% in 2016 and slightly decreasing to 85% in 2020. However, their share of the agricultural area and workforce showed a decreasing trend, with the agricultural area used by these farms reducing from 21% in 2016 to 18% in 2020, and their workforce share dropping from 67% to 64%. Medium-sized farms experienced a small increase in workforce share, while large farms expanded their share of agricultural land, from 48% in 2016 to 52% in 2020, indicating a trend toward consolidation and increasing scale in European agriculture.[15]

Eurostat data shows a positive change in the share of young farm managers, which improved on an annual basis by 2.5% (over the period 2016-2020). Only the small farms show a decline in the young farm managers, falling by 2.3%, while the highest improvement is for the large farms, where this number grew by 3.7% annually.[16]

Finally, many people work part-time: one out of five farmers who manage fewer than five hectares of agricultural land spends less than a quarter of their working time on the farm. Since 2005 the number of family workers has decreased by 31%. Despite these challenges, many farmers have maintained their income levels through the use of economies of scale and specialization. (European Commission, 2020b). The COVID-19 pandemic highlighted how specialisation, seasonality and farm size have created a labour market with a strong reliance on seasonal

[15]Eurostat, *Farm indicators by age and sex of the manager, economic size of the farm, utilised agricultural area and NUTS2 region* [table: ef_m_farmang]. The percentages refer to annual working unit (AWU) data, where AWU corresponds to the work performed by one person occupied on a full-time basis.
[16] Eurostat, Farm indicators by age and sex of the manager, economic size of the farm, utilised agricultural area and NUTS2 region [Table: ef_m_farmang].

demand and migrant workers. Specialisation is particularly evident, with Ireland having the highest level, where 87% of holdings specialised in grazing livestock, and Finland showing 60% specialisation in field cropping. In Mediterranean regions, more than 60 % of agricultural activities are concentrated in permanent crops 60%. In many cases, vertical integration has increased the income of farmers. However, the current system, dominated by supermarket chains and large processors, often results in an unfair distribution of value. Farmer-owned cooperatives could play a role in improving the position of small and medium-sized farmers to improve their position in the value chain. Additionally, fairer contracts and business models that keep more added value on the farm – for instance, environmental and tourist services, high-quality products, on-farm processing, or short supply chains – could further support these farmers.

4.4. Structural changes in agriculture

The European Union's agricultural landscape has been undergoing significant structural changes, particularly at the farm level. These changes have been driven by various factors, including the increasing size of farms, market pressures, and the adoption of new technologies. Small and medium-sized enterprises (SMEs) in the agricultural sector, which are crucial for food production and rural employment, face unique challenges as they adapt to these shifts. This section explores the factors contributing to the decline in the number of farms, the strategies SMEs are employing to remain resilient, and the potential of digital technologies to support their sustainability and competitiveness.

Despite the European Union's efforts to support SME farmers through subsidies and rural development under the second pillar of the Common Agricultural Policy (CAP), the number of farms has declined substantially since the early 2000s (Schuh et al., 2022). Interestingly, while the total land dedicated to agriculture remained relatively stable (based on Eurostat data), in the average farm size at EU level has increased by 1.7% in the last ten years, from 14.4 ha (2010) to 17.1 ha (2020)[17]. This shift is largely due to several challenges unique to SMEs in the EU, particularly when compared to large-scale farms exceeding 50 hectares (Berti & Mulligan, 2016).

Small and medium-sized enterprises (SMEs), which play a crucial role in food production and rural employment, face challenges in accessing markets and competing with larger players (Ebel, 2020; Food and Agriculture Organization of the United Nations (FAO) & Lucas, 2018; Rivera et al., 2020). Structural changes in agriculture, such as the decline in the number of farms and the increasing size of remaining farms, are reshaping the sector. Typically, small farms, operating on plots smaller than 50 hectares, contribute significantly, accounting for between 51% and 77% of globally produced commodities (Herrero et al., 2017). Beyond production, SMEs also generate employment and support rural livelihoods (Borychowski et al., 2020). Additionally, they play a crucial role in maintaining biodiversity and promoting environmental sustainability (Polcyn, 2021).

However, SMEs face significant challenges in accessing markets and competing with larger agricultural enterprises. The European agricultural sector is increasingly dominated by concentrated supply chains, where a few large supermarket companies hold substantial market power (McCullough et al., 2008; Vettas, 2007). This structure results in most food products passing through large aggregation and distribution centres, creating significant barriers for SMEs. Intense competition among supermarkets places continuous pressure on suppliers to enhance efficiency, reduce costs, and meet stringent quality and safety standards (Vettas, 2007). These dynamics create significant barriers for SMEs to access markets due to their limited production capacity, higher transaction costs, and the inability to benefit from economies of scale (Rivera et al., 2020). Meeting the exact standards set by supermarkets becomes particularly challenging for

[17] Eurostat, *Farm indicators by legal status of the holding, utilised agricultural area, type and economic size of the farm and NUTS2 region* [table: ef_m_farmleg].

SMEs due to their constrained assets and capital, diminishing their bargaining power with buyers (van der Meer et al., 2007).

Moreover, EU SMEs experience price volatility due to seasonal production and growing demand, which is further intensified by extreme climate events, such as droughts and flooding. Rising input costs, including those of energy and fertilizer, add to the overall price volatility (Velazquez, 2011). This leaves farmers in a vulnerable negotiating position, making them price takers, directly impacting their income (Madre & Devuyst, 2016). As a result, many farmers are forced to exit the occupation due to low and fluctuating incomes (Agriculture and rural development, 2022a; EAFRD). Structural trends favouring intensive production and large-scale farms with low margins and bargaining power are primary factors contributing to the decline of SMEs (Schuh et al., 2022).

Despite these challenges, SMEs continue to adapt and innovate. They often employ various strategies to remain resilient and sustainable (Isakhanyan et al, 2024). They leverage cheap or free family labour, possessing extensive local knowledge, and maintaining flexibility in entering and exiting the market (Poulton et al., 2010). Additionally, many small farms have improved their collective action by forming associations or cooperatives, addressing issues related to scale, market power, coordination, and transaction costs (Rivera et al., 2020). Some other SMEs shift from producing undifferentiated commodities to focusing on product differentiation and specialisation thereby adding more value (Vettas, 2007). Others opt to bypass modern procurement chains, choosing to sell directly to consumers through farmer's markets and other community-supported agriculture initiatives (Rivera et al., 2020).

Digital technologies offer a promising avenue for SMEs to overcome these challenges (Aubry et al., 2022). The increased use of data—encompassing monitoring, analysis, transfer, and application for decision-making—holds the potential to assist small and medium-sized farms in optimizing cultivation processes, marketing produce more effectively, and enhancing overall sustainability (Weber et al., 2022). However, the adoption of digital technologies remains a financial challenge for many farms, particularly those with limited resources (Aubry et al., 2022). Factors such as uncertainty about the benefits of adoption, missing skills, high upfront investment costs, and deficient digital infrastructure (e.g., internet coverage) further hinder the widespread adoption of these technologies (Garske et al., 2021). Even though the adoption of digital technologies is low and more complex technologies are lacking acceptance when a particular technology's relative advantage becomes clear, small-scale farmers have more reason to digitise, experts foresee (Gabriel & Gandorfer, 2023).

In sum, while the structural changes in EU farming present significant challenges for SMEs, these enterprises remain critical to the agricultural sector's resilience and sustainability. The shift towards larger farm sizes, driven by market pressures and price volatility, underscores the need for SMEs to innovate and adapt. Digital technologies offer promising solutions, but barriers to adoption must be addressed to fully realize their potential. Ensuring fair pay and support for SMEs is essential for maintaining a diverse and sustainable agricultural landscape in Europe.

4.5. Employment challenges

Overall, digitalisation impacts employment on different dimensions. While automation is linked to job loss, it also creates new job demands in emerging fields, driven by the need to exploit the new technologies. This can lead to a further increased demand for technology-based products and services, lower prices, and potentially new job market opportunities. Moreover, the COVID-19 pandemic has transformed the work environment across the globe, including in the EU. Hybrid work models, combining office and remote work have become possible thanks to the integration of physical and digital workplace. Organisations offering frontline workers democratised access to digital collaboration, process automation and similar tools are more likely to see relevant benefits (including in revenues) due to improved productivity.

Food and beverage industry is the major manufacturing employer in half of the EU member states. It employs 4.72 million and generates €1.2 trillion in annual turnover. The EU has become the world's largest exporter of food and drink products – amounting to €110 billion and generating a trade surplus of €36 billion (European Commission, 2020b).

To fully leverage digital technologies and data usage, basic or advanced digital skills are required. Figure 8 illustrates the percentage of the population with basic or above-basic digital skills across various European countries in 2023, and indicates whether there was an improvement or decline in these skills compared to 2021. The analysis of the data shows that the Netherlands (82.7%) and Finland (82.0%) lead with the highest share of the population possessing basic or above-basic digital skills. Countries such as Denmark, Czechia, Ireland, Sweden, and Spain also demonstrate relatively high percentages, ranging from approximately 69.6% to 66.2%. A significant portion of European countries, including Austria, Malta, Estonia, Luxembourg, and France, fall into the moderate category, with percentages ranging between 64.7% and 60.1%. Meanwhile, Greece, Slovakia, and Slovenia are on the lower end of the spectrum, with percentages between 52.4% and 46.7%. The lowest digital skills are observed in Bulgaria (35.5%) and Romania (27.7%), indicating significant room for improvement in digital literacy in these countries. Most countries show an improvement in digital skills, as indicated by the blue bars in Figure 8. However, some countries, such as Ireland, Luxembourg, France, Slovakia, Cyprus, Slovenia, and Latvia, show a slight decline in digital skills. Nonetheless, the decline is very small to hold significant importance.

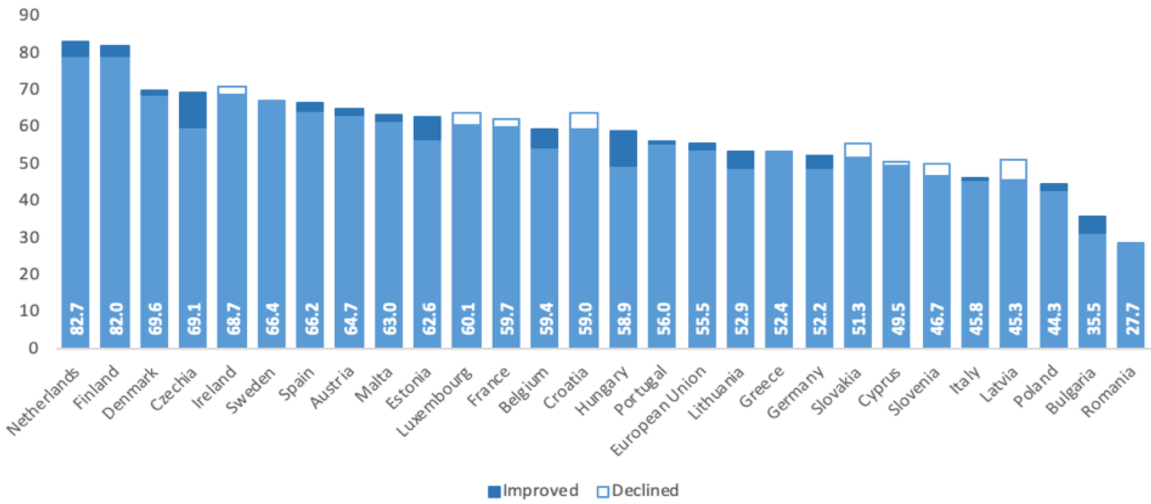

Figure 12: Share of the total population with basic or above basic digital skills in 2023 and the change compared to 2021

Source: Eurostat (table: isoc_sk_dskl_i21)

Figure 12 underscores the disparities in digital skills across Europe, with notable differences between Northern and Western Europe compared to Eastern Europe, where the digital skills gap remains a challenge.

While technological developments are expected to replace a significant part of the labour force, these changes will also create new types of jobs that require specific skills sets. To fully capitalise on the benefits of digitalisation, it is crucial to focus on skills developments. Prioritising efforts to enhance digital access and literacy among all stakeholders can empower farmers and food producers to adopt data-driven solutions and promote more equitable and sustainable development in the agri-food sector. Addressing this gap is essential not only for fostering inclusivity and fairness but also for unlocking the full potential of technological advancements in agriculture. In addition, to fully leverage these digital advancements, not only skills, but also reliable internet connectivity is essential. Thus, broadband connectivity plays an important role in this aspect (Figure 13).

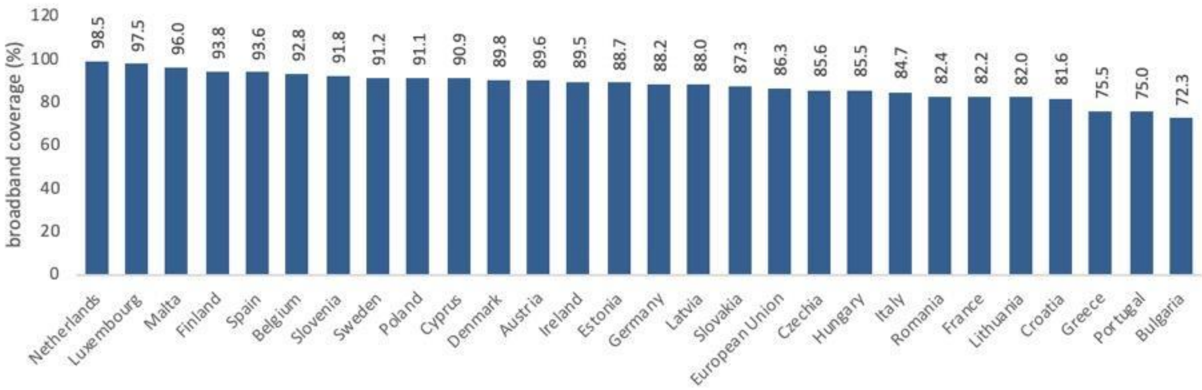

Figure 13: Total broadband coverage of rural areas across the EU Member States, 2021

Source: Eurostat (table: isoc_ci_it_h)

As data shown in Figure 13 reveals, there is a significant variation in coverage levels among the EU member states. The Netherlands leads with the highest broadband coverage at 98.5%, closely followed by Luxembourg at 97.5% and Malta at 96.0%. Other countries with high rural broadband coverage include Finland, Spain, Belgium, Slovenia, Sweden, Poland and Cyprus, all exceeding 90%. In contrast, several Member States have lower coverage rates, with Greece (75.6%), Portugal (75.0%), and Bulgaria (72.3%) at the bottom of the ranking. The overall EU average stands at 87.3%, highlighting the disparities in digital connectivity between rural areas of different EU countries.

In a data-driven economy, data contributes to the improvement of knowledge, which helps stakeholders to better understand and monitor the current state-of-play. To fully take advantage of the data, proper digital skills and infrastructure are needed. Thus, the digitalisation of the work environment brings forward the need for more opportunities of training and digital upskilling of workers, especially for low-skilled ones. The risk of replacement by robots and drones can further exacerbate the impact of the digital technologies on the workers' wellbeing, especially for low-skilled, which is often the case for agriculture and some of the food services. Thus, it is important to reduce the wellbeing imbalances brought by the digital transformation of the work environments, especially in food-related industries.

4.6. Access to food and healthy diets

Technological advancements have made accessing food more convenient than ever. It also helped customers to become more aware of the importance of a balance nutrition and healthy eating habits. A report developed by Business of Apps (a research firm) found that the food delivery market has seen significant growth over the past five years, mainly due to platform-to-consumer services (Curry, 2024). Food delivery services expanded from takeaways to ready food transport to any address, adding billions of dollars in potential revenue capture.

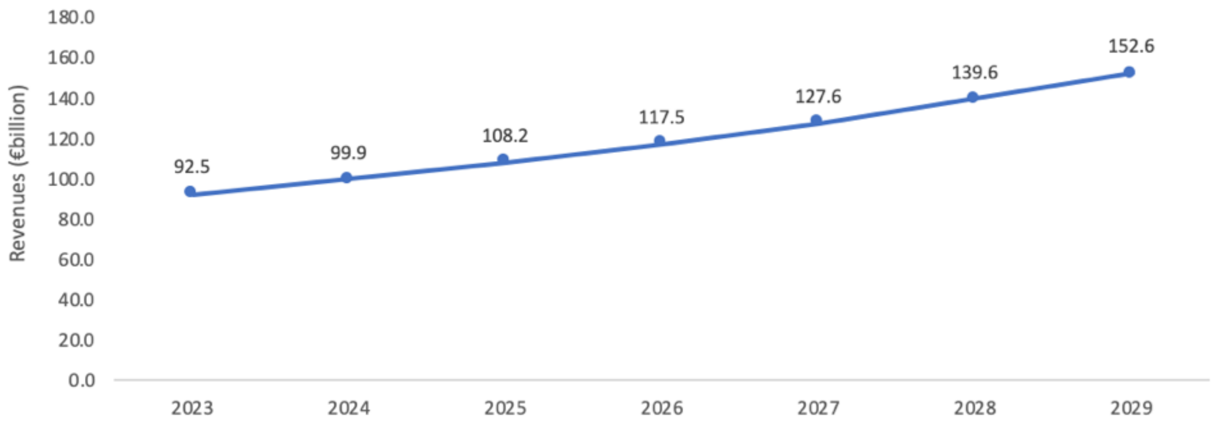

Figure 14: Food delivery app revenue estimates, 2023 - 2029

Source: Curry (2024), Eurostat
Note: For the period 2023-2028, the exchange rate €/$ used comes from Eurostat and it is the annual average value estimated for 2023.

Figure 14 shows a steady increase in food delivery app revenue estimates from 2023 to 2029. Starting at €92.5 billion in 2023, revenues are expected to rise consistently each year, reaching €152.6 billion by 2029. The data indicates significant growth in the food delivery market, with notable annual increments, particularly between 2026 and 2027 when revenues are expected to jump from €117.5 billion to €127.6 billion. This upward trend underscores the expanding demand and market potential for food delivery services over the forecasted period (Curry, 2024).

According to the Food and Drink Industry Association, soft drink companies are the most innovative in the sector, closely followed by frozen food and ready-made meal providers (European Commission, 2020b). This innovation has been great for the industry's growth, however, the industry's innovation has not always aligned with health and environmental goals, as the foregoing discussion suggested (European Commission, 2020b).

In the EU, Bulgaria and Slovakia are sources of concern, with 3.0% and 6.1% of the population undernourished, respectively. However, the issue expands beyond just the quantity of food to its quality. The food industry often offers packaged foods that are high in empty calories, from sugar and fat, high in salt, and low in nutritional value, all at a low price. The diversity of the diets, by this, shrinks, with just six crops that dominate agriculture, namely, maize, rice, wheat, sugar cane, soybeans and oil palm. While vegetable consumption has declined, fruit consumption has risen in wealthier EU nations. Today, about 2 billion people worldwide are overweight or obese – 2.5 times the number of those who are undernourished (European Commission, 2020b). In the EU-28 the proportion of adults (aged 18 years and over) who were considered overweight in 2014 ranged from 36.1 % in Italy to 55.2% in Malta for women, and from 53.6% in the Netherlands and 67.5% in Croatia for men. Obesity (body mass index greater than 30) among adults grew by 1% every three years in the first 15 years of this century, with no sign of slowing (European Commission, 2020b). This increase in obesity lead to health problems, including diabetes, heart disease, some cancers, and other problems that add to the costs to already overburdened healthcare systems. As Wylie (2024b) states, in much of the wealthy West, we are eating ourselves to death (Wylie, 2024b).

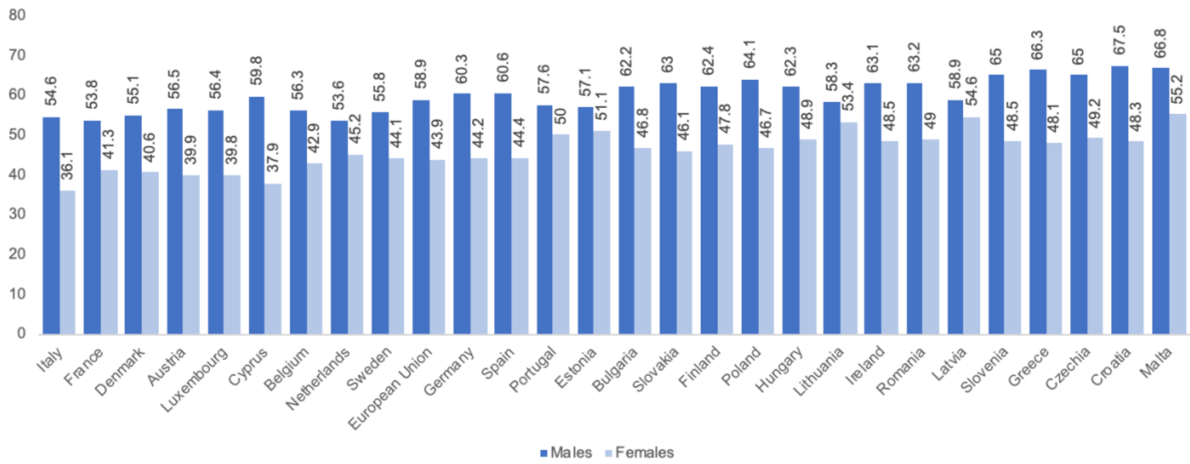

Figure 15. Prevalence of proportion of adults (aged 18+ years) considered overweight in EU, 2014

Source: Eurostat (table: hlth_ehis_bm1e)

Figure 12 shows the prevalence of adults aged 18 and older considered overweight across European countries in 2014. As can be seen in the figure, the highest prevalence observed in Malta, where 68.6% of males and 55.2% of females are considered overweight. Croatia, Greece, and Slovenia also exhibit high proportions, each with over 63% of males and approximately 50% of females classified as overweight. Conversely, the countries with the lowest prevalence are Italy and France, where around 54.6% of males and 38.7% of females in Italy, and 53.8% of males and 38.1% of females in France are considered overweight. This figure shows high percentages in overweight adults within the EU, although some differences exist among countries that may be influenced by lifestyle, diet, cultural factors, and healthcare systems among the member states.

For many people, keeping track of their health has become a continuous and often time-consuming task, involving monitoring what they eat, how often they exercise, their daily water intake, and more. Technological developments have brought some convenience in this area, with the introduction of health apps. Digital and innovative tools used for health promotion (e.g. smartwatches, fitness trackers, smart rings and virtual/augmented reality headsets) rely on behavioural science to motivate and incentivise users to adopt healthier lifestyles. Moreover, AI-based tools can collect, process and analyse the data, as well as provide personalised health messages and guidance (Vazquez-Venegas et al., 2024). These days, there are numerous apps that cover diet and exercise, reproductive health, water consumption, heart health and other health concerns. According to Health App Revenue and Usage Statistics 2024 report, more than 560 million people were using health apps in 2022, a 32% increase since 2015.

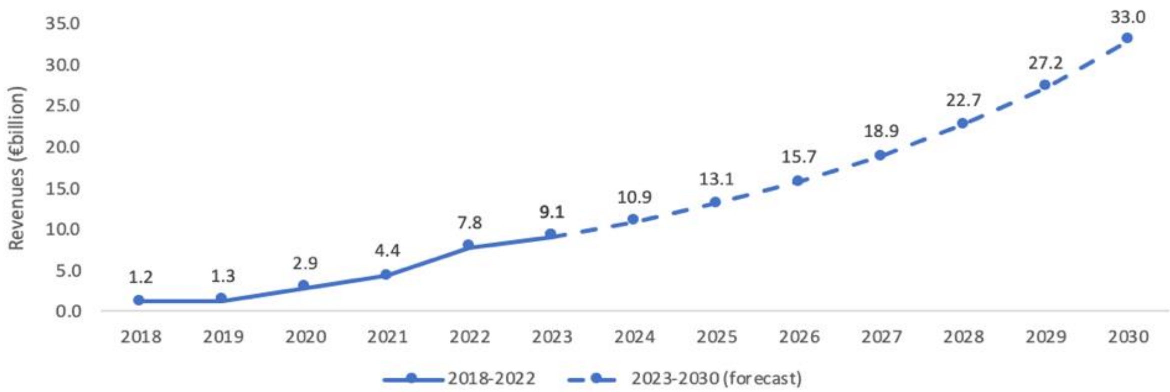

Figure 16: Health app revenue estimates, 2018-2030

Source: Wylie (2024b), Eurostat
Note: For the period 2023-2028, the exchange rate €/$ used comes from Eurostat and it is the annual average value estimated for 2023.

As Figure 16 illustrates, the health app revenues grow and will keep growing rapidly from 2018 to 2030. Starting at €1.2 billion in 2018, revenues steadily increased, reaching €7.8 billion in 2022. The forecasted trend indicates continued significant growth, with revenues expected to climb to €33.0 billion by 2030. The data highlights an accelerating market expansion, particularly notable from 2023 onward, where revenues are projected to more than triple within seven years. This trend underscores the growing demand and adoption of health apps, driven by increasing consumer focus on health and wellness, as well as advancements in digital health technologies. (Wylie, 2024b).

As data analytics and technology integration continue to advance, businesses are increasingly adapting to leverage data-driven insights to optimise production, streamline supply chains, and tailor offerings to meet changing consumer preferences. This evolution not only enhances efficiency and profitability but also underscores the critical role of data in driving future growth and sustainability within the agri-food sector. The data economy impacts the agri-food industry by reshaping labour markets and consumer behaviour, particularly through advancements in technology and digitalization. European food systems are experiencing shifts that enhance data exchange, leading to increased transparency in food production and providing consumers with better insights into the origins of their food. However, these shifts also pose challenges, such as the need for improved digital skills, where inequalities are significant within European countries. The food delivery market and health app revenues are both expected to grow substantially in the coming years, reflecting changing consumer behaviours and a greater focus on convenience and health.

5. Environmental challenges and digital technologies

According to the Europe Environment Agency (EEA), the food system is causing over one-fifth of all environmental and climate impacts[18], contributing to air, water and soil pollution. It plays a role in biodiversity loss, soil erosion and climate change, and consumes excessive amounts of natural resources, including water and energy, while a significant amount of food is wasted. In this context, this section aims to first describe those environmental challenges and explores the potential **impact of these environmental challenges on digital technology as part of the data economy** related to food systems.

5.1. Greenhouse gas emissions

Food systems are major contributors to climate change responsible for up to 37% of anthropogenic greenhouse gas (GHG) emissions, of which livestock alone accounting for 12–19 % of the total (Crippa et al. 2021). The combination of global population growth and dietary changes is likely to increase food demand by 56% between 2010 and 2050. As the consumption of resource-intensive food products, such as meat and dairy, is expected to grow, GHG emissions from food systems could increase by almost 90% if no mitigation efforts are undertaken. By 2100, global food consumption alone is expected to contribute nearly 1 °C to global warming (ECDPM, 2023).

In 2021, the agri-food systems accounted for 34% of the total EU emissions, within which the shares of emissions from “farm gate” and “pre- and post-production” activities represented circa 96.6% (with 52% for farm gate and 44% for pre- and post-production) of it, while 3.4% was due to land use change. The agricultural sector accounted for 11% of the EU's total domestic GHG emissions (European Parliament, 2023[19]).

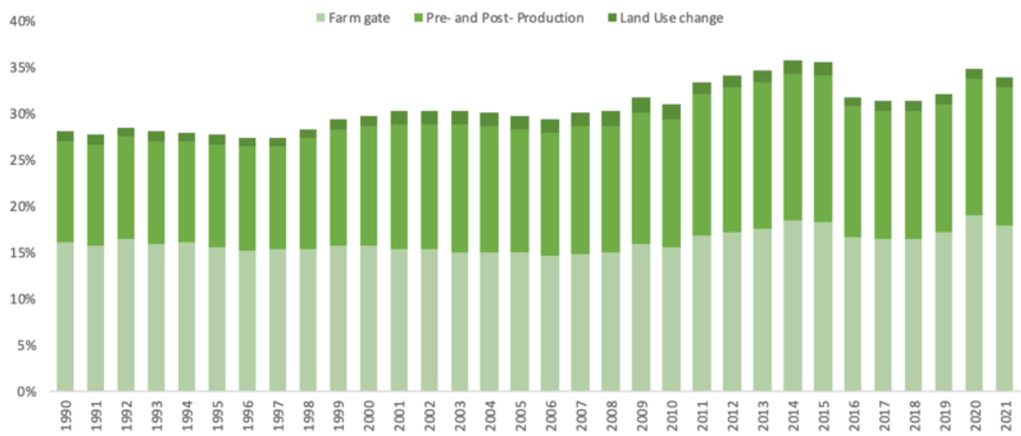

Figure 17: EU agri-food system life-cycle distribution of GHG emissions and share of total EU GHG emissions, 1990-2021

Source: FAOSTATS, Emissions totals, agri-food systems (accessed January 2024)

Figure 17 illustrates the distribution of greenhouse gas (GHG) emissions within the EU agri-food system over the period from 1990 to 2021, broken down into three components: "farm gate" activities, "pre- and post-production" processes, and "land use change." Throughout this period, the share of GHG emissions from the agri-food system as a percentage of total EU emissions shows variability, with a general upward trend, particularly from the early 2000s onward. "Farm gate" and "pre- and post-production" activities consistently account for the majority of emissions, with "land use change" contributing a smaller, yet still significant, portion. The data indicates an

[18]Source: https://www.eea.europa.eu/en/topics/in-depth/agriculture-and-food

[19]European Parliament – Towards climate neutrality

increasing trend in the agri-food system's share of total EU GHG emissions, particularly in the years following 2010, highlighting the growing impact of agricultural and food production activities on overall EU emissions.

Barriers for adoption digital technologies

Digital agriculture technologies have the potential to reduce greenhouse gas emissions, enhance productivity, and ensure food security. For example, accelerometer-based sensors that provide real-time data on feeding, rumination and activity in both housed and grazing cattle (McNicol et al., 2024). However, realizing these benefits in a sustainable and equitable manner requires a concerted effort from policymakers, researchers, and farmers. One significant challenge is the **unequal access to technology** and infrastructure, which is not always distributed equitably. Another challenge is the **high cost** of implementing digital agriculture technologies, which may restrict their adoption by small-scale farmers with limited resources (Balasundram et al, 2023).

Although many farmers are aware that precision agriculture technologies such as variable-rate nitrogen application technology and machine guidance, could reduce GHG emissions, **uptake in the EU is low**. Barriers for adopting those precision technologies are high investment costs, farm size and the farmers' age (Soto et al. JRC, 2019).

Transparency in data sharing needed

Data-driven technologies like smart farming technologies, digital tools and AI, raises **concerns by farmers** about data ownership, data sharing and privacy. To gain trust of farmers relating to the use of these data-driven technologies, **more transparency** in the procedures used for farmer **data collection and sharing is needed** (Gemtou et al., 2024).

5.2 Biodiversity loss

The global food system is the primary cause of biodiversity loss, with agriculture alone threatening 24,000 of the 28,000 species (86%) at risk of extinction (UNEP, 2021). Agriculture is a key driver of declines in biodiversity and associated ecosystem services. Although biodiversity impact assessment is very complex and affected by many context-related, spatial and temporal factors, it is evident that the current European diet is negatively affecting biodiversity both within Europe and globally. The consumption of meat and dairy products are the main drivers of these impacts (Crenna et al, 2019).

Data collection, sharing and analysis with AIDigital technologies have the potential to help improve biodiversity. **Collecting and managing environmental data** is crucial for monitoring changes in biodiversity. Digital solutions, supported by technologies like **artificial intelligence** and **the Internet of Things** can further improve the data management processes required for effective monitoring, decision-making and law enforcement of biodiversity. Additionally, digital platforms and applications can raise awareness of biodiversity challenges and encourage public support for necessary measures. However, to achieve these goals, **barriers to data sharing must be removed**. Data management practices need improvement, and the collection and sharing of relevant data must be optimized. Furthermore, the EU should make greater use of **data from satellites, sensors, and other sources** to initiate infringement procedures against member states that fail to **comply with environmental regulations**. Simultaneously, the EU should focus on improving global biodiversity databases and electronic information exchange (Hedberg and Sipka, 2020).

5.3 Air pollution by nitrogen and ammonia

As already mentioned, food systems are important contributors to global emissions of air pollutants like nitrogen and its components and particulate matter. In 2018, more than half of total

N (and 87% of ammonia) emissions came from food systems and up to 35% of particulate matter. The intensive use of nitrogen in fertilizers and feedstock leads to complex issues, including ammonia (NH3) emissions into the air and nitrate (NOx) leaching into the soil.
In addition, food system emissions are responsible for about 22.4% of global mortality due to poor air quality and 1.4% of global crop production losses (Crippa et al, 2022). In the EU **more than 90% of ammonia** emissions to air come from agriculture: 75% from manure and 20% from inorganic fertiliser. This leads to eutrophication and acidification of ecosystems, and to harmful particulate matter (European Commission, 2024c).

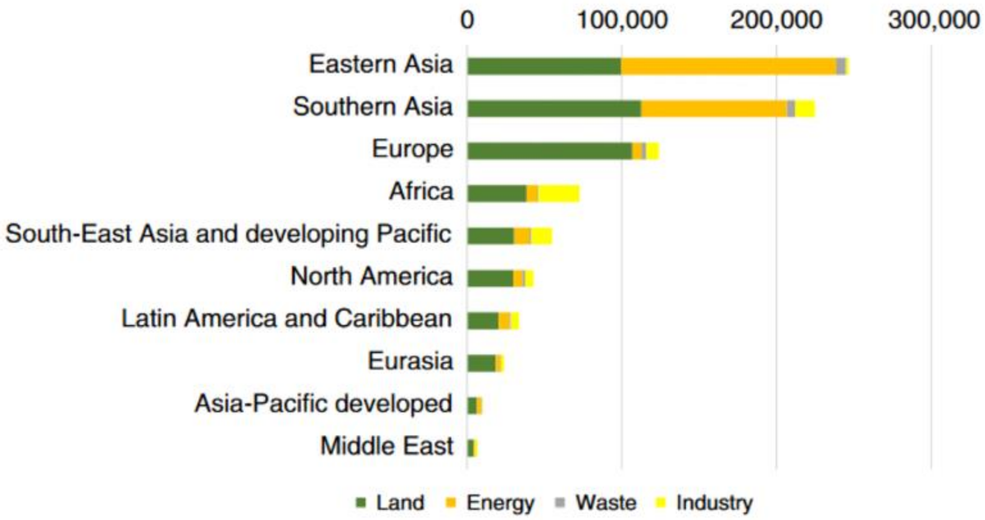

Figure 18: Sectoral share to premature deaths (associated with PM2.5 and O3 pollution from food systems, per macro-region in 2018

Source: Crippa, M. et al. (2022). p. 947.

A significant factor contributing to the nitrogen crisis is the lack of landscape-level technology implementation, compounded by weak policy frameworks for monitoring pollution dynamics. This crisis is causing considerable distress among farmers, while the government struggles to implement effective policies.

Data sharing across food supply chain

The digitalisation of agriculture innovation system could help to resolve the N-crisis. To achieve this, farm management must innovate by **streamlining real-time data from Farm Management Systems across the various stakeholders involved in the supply chain**. Additionally, there is a need for innovations in data rights to explicitly establish farmers' ownership of their data. AI algorithms, combined with blockchain technology, are key to ensuring commitment and transparency among the different collaborators (Kumar, 2021).

5.4 Water use and water pollution

In Europe, industries are the biggest users of water. Utilising a hefty 45% the European industry uses annually more water than agriculture (30%). In other parts of the world agriculture is the biggest water consumer (MacErlean, 2023). Nevertheless, agriculture remains a significant user of water resources and a major source of pollution in Europe. Agricultural production is highly dependent on water and increasingly subject to water risks. Irrigated agriculture remains the largest user of water globally, a trend encouraged by the fact that farmers in most countries do not pay for the full cost of the water they use. **Agriculture irrigation** accounts for 70% of water use worldwide and over 40% in many OECD countries (OECD, 2021). Irrigation water comes from streams, rivers and lakes (surface water bodies), wells (groundwater bodies), rainwater collection and reclaimed wastewater.

In 2017, it accounted for 59% of total freshwater use across the continent. Agricultural activities have substantially impacted Europe's water bodies, with 22% of Europe's surface water bodies and 28% of the groundwater areas are significantly affected by diffuse **pollution from nutrients and pesticides**. Additionally, 10% of surface water bodies have been altered physically, such as changes to the channel, bed or riparian areas due to flood protection and/or agricultural practices. Furthermore, flood protection and/or drainage for agriculture have led to nearly 7,500 water bodies being designated as heavily modified in 26 countries. The ambition of the EU for European waters includes counteracting the high discharges of nutrients and chemicals from agriculture by aiming a 50% reduction in nutrient loss and the risks associated with pesticides use (EEA, 2024).

Agriculture is responsible for 24% of water abstraction in the EU. The last 30 years have seen some reduction in pressures, achieved thanks to efficiency gains in resource use. Agricultural water use at the EU level has decreased by 28 % since 1990 (EEA, 2020).

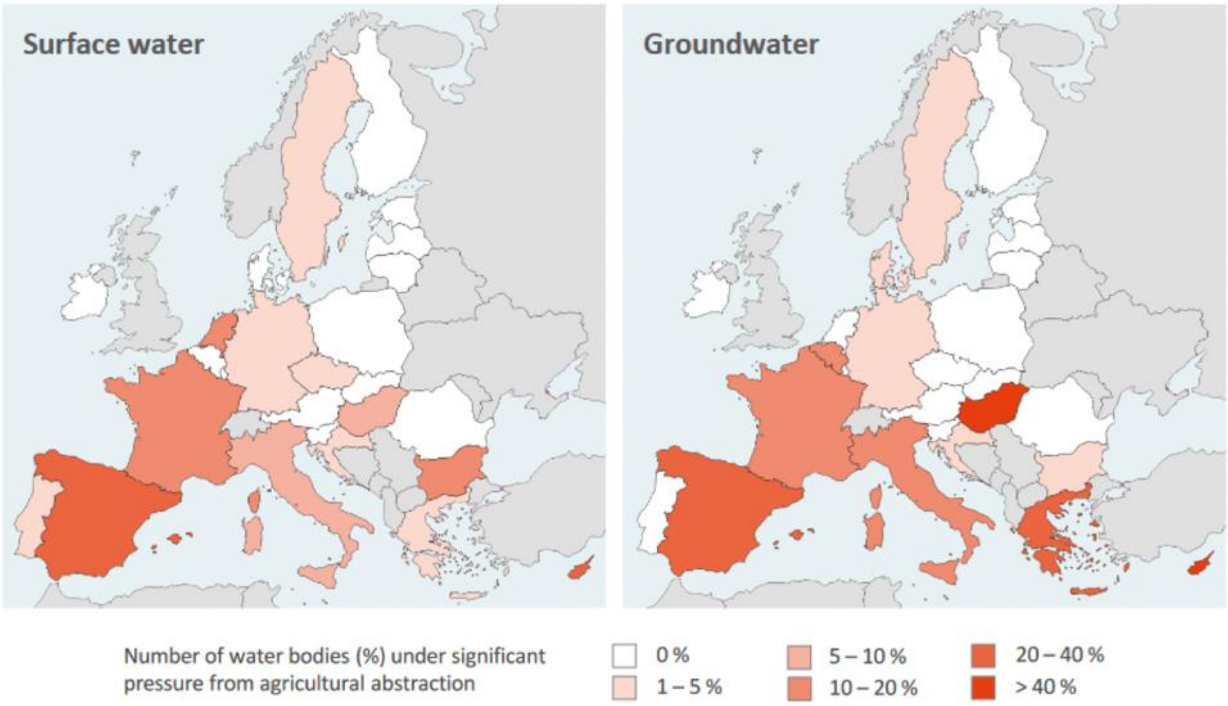

Figure 19: Water bodies under significant pressure from agricultural abstraction

Source: ECA (2021)

Figure 19 illustrates the percentage of water bodies, both surface water and groundwater, under significant pressure from agricultural abstraction across various European countries. The map on the left shows surface water bodies, while the map on the right shows the groundwater bodies. The intensity of pressure varies by region, with southern European countries such as Spain, Hungary and Greece experiencing the highest levels of pressure, indicated by the darkest shades of red. In these areas, more than 40% of water bodies are under significant stress from agricultural activities. In contrast, many northern and central European countries, particularly those in Scandinavia and parts of Eastern Europe, exhibit little to no significant pressure, as shown by the lighter shades or absence of shading on the map.

Satellite data

The US-governed Landsat satellite and European Sentinel satellites provide images for the monitoring of water resources and land use. That data shows the impact of irrigation on the crop productivity. The accessibility of the data of the Landsat and Sentinel satellites has facilitated the development of **remote sensing tools for irrigation management** and the efficient use of water resources (Manivasagam, 2024).

Digital technologies for irrigation

In case of irrigation, AI is being used for the optimization of the available resources like water and energy. Machine learning is used in irrigation systems to perform predictions. Furthermore, commercial sensors for irrigation systems in agriculture are very expensive. That makes them less available for smaller farms. However, manufacturers are recently offering low-cost sensors that can be connected to nodes to implement low-cost systems for irrigation management (Garcia et al., 2020).

Data can also be gathered by sensor attached to drones and robots which allow obtaining new data that could not be obtained by aerial images of satellites. And robots with sprinklers can be used to irrigate precise areas (Garcia et al., 2020).

Data for policy monitoring and evaluation

Measuring policy progress on agriculture and water policies is essential to help decision-makers identify necessary policy changes and understand how further progress may be achieved to improve agricultural water management. The use of digital technologies can support the implementation agencies with monitoring and enforcement (OECD, 2019b) such as remote sensing tools measuring evapotranspiration to track water withdrawals by large number of farmers (OECD, 2021).

5.5 Soil pollution and erosion

Farmers in Europe are suffering under increasing heat, drought and flooding (Abnett, 2024). Climate change and intensive agricultural activities impact the quality of agricultural soil as well. Agricultural soils can become contaminated with a wide range of compounds, from both direct inputs such as the application of pesticides and fertilizers and indirect inputs such as flooding and atmospheric deposition. These polluted soils also represent a secondary emission source of contamination, releasing pollutants into the surrounding air, surface waters, groundwater, and eventually into oceans. The main **sources of soil pollution in agricultural areas** are: i) pesticides; ii) mineral fertilizers; iii) organic fertilizers (manure and sewage sludge); iv) wastewater for irrigation; v) plastic materials such as films for mulching and greenhouses, drip irrigation tubes and empty packaging; and vi) rural wastes (FAO and UNEP, 2021).
Soil erosion is the process by which the land surface is worn away by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or human activities that detach and remove soil or geological material from one location, depositing it elsewhere. Agriculture is both negatively affected by and contributes to soil erosion, as land use and land management practices are key driving forces of this process. **Agriculture is a major contributor to soil erosion caused by water.** The share of agricultural areas and natural grasslands estimated to be affected by moderate or severe soil erosion due to water declined by 2.6 percentage in the EU-27 between 2000 and 2016 (Eurostat, 2024b).

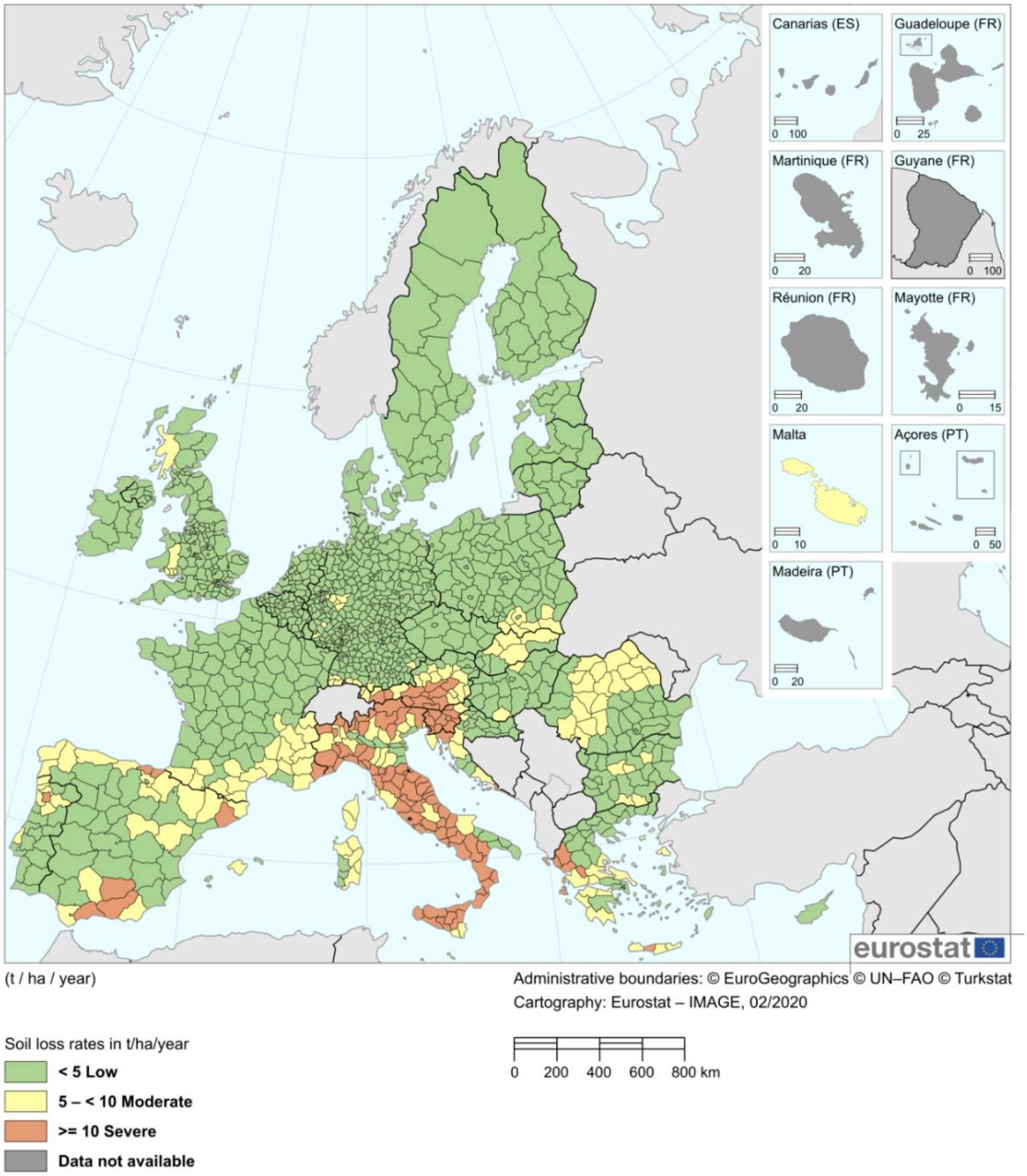

Figure 20: Change in share of soil erosion by water on agricultural areas and natural grassland, NUTS 3 regions, 2016 (percentage of mean soil loss)[20]

Source: Eurostat

Figure 20 is a map that illustrates the changes in soil erosion by water across agricultural areas and natural grasslands in Europe between 2000 and 2016, measured as a percentage of mean soil loss. The map shows a mix of improvements and deteriorations across different regions. Areas in dark green experienced the most significant decreases in soil erosion, with reductions of up to 30% or more. Light green regions also saw reductions, but to a lesser extent. Conversely, regions marked in pink indicate areas where soil erosion increased by 1% or more. Some areas, particularly in southern and far western Europe, show a mix of trends, while regions in northern

[20] The nomenclature of territorial units for statistics (NUTS) divides each EU country into three 3 levels: NUTS 1: major socio-economic regions; NUTS 2: basic regions (for regional policies) and NUTS 3: small regions (for specific diagnoses) (Source: Eurostat).

and eastern Europe generally experienced reductions in soil erosion. The map highlights regional variations in soil erosion trends, reflecting the diverse environmental and agricultural practices across Europe.

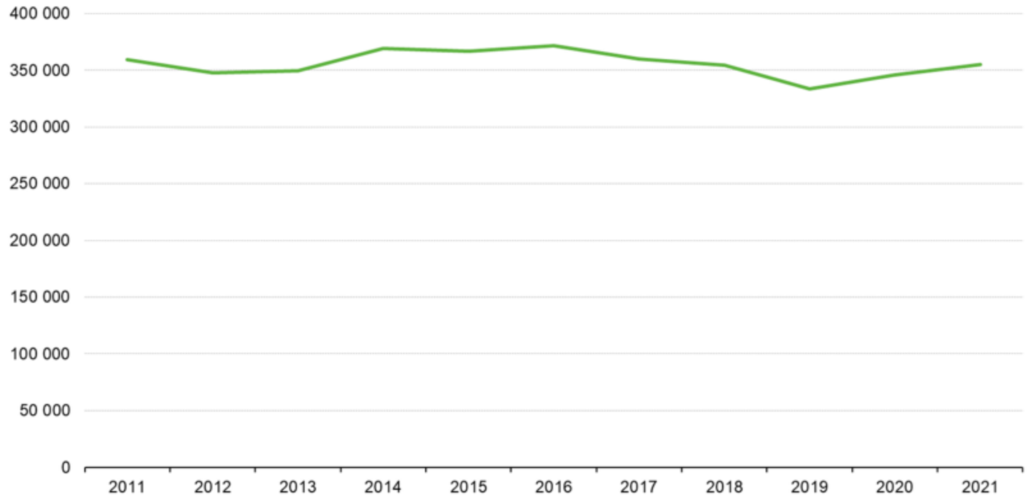

Figure 21: Sales of pesticides (tonnes, EU, 2011-2021)

Source: Eurostat (Table: aei_fm_salpest09)
Notes: EU estimate for 2021 includes 2020 data for Belgium; EU data do not consider the confidential values, which represent <1% of the total sales over the entire time series.

Figure 21 displays the trend in pesticide sales across the European Union from 2011 to 2021. Over the decade, pesticide sales remained relatively stable, fluctuating around 350,000 tonnes annually. There were minor variations, with a slight increase observed between 2013 and 2016, followed by a gradual decline from 2017 to 2019. However, sales began to rise again towards the end of the period, indicating a return to previous levels by 2021 (Eurostat, 2024a).

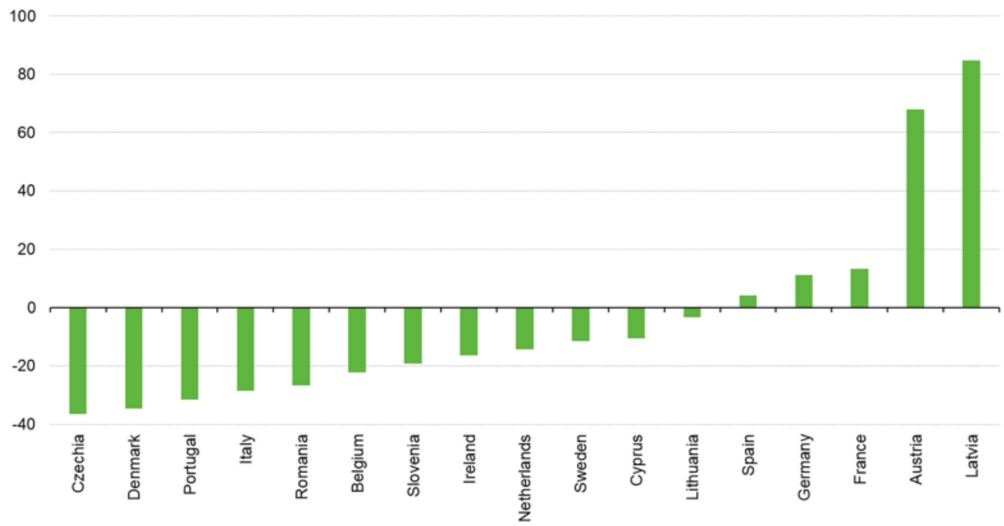

Figure 22: Changes in the sales of pesticides in selected EU countries between 2011 and 2021 (%)

Source: Eurostat (Table: aei_fm_salpest09)
Notes: Data for Belgium are available for 2011 and 2020.

Figure 22 presents the percentage changes in pesticide sales across selected EU countries between 2011 and 2021. The data shows significant variability among the countries, with some experiencing substantial reductions, while others saw notable increases. Czechia, Denmark, and

Portugal recorded the largest decreases in pesticide sales, with reductions ranging from approximately 20% to about 40%. In contrast, Latvia and Austria showed the most significant increases, with Latvia's pesticide sales rising by nearly 100% over the decade. Other countries, such as Germany, France, and Spain, also saw moderate increases, while nations like Italy, Romania, and Belgium experienced slight declines. This variation highlights the differing approaches and trends in pesticide usage across the EU during this period.

Overall, Figure 21 and Figure 22 suggest that despite ongoing environmental and regulatory efforts, pesticide sales in the EU have not significantly declined over this period.

Digital technologies for soil

Soil sensors measure all kind of essential soil properties to guide precision irrigation and fertilization practices (Soussi et al., 2024). Advancements in earth observation platforms, proximal soil sensing technologies, geo-statistics, spatial data science, and machine learning have significantly enhanced the agricultural system's ability to rapidly measure and characterize soils. These digital technologies have contributed to the ability to **get detailed insights about** the status and functions of **soils**. Those insights are underscored by digital soil mapping methodologies. Farms nowadays and in the future can benefit from **rich datasets, big data, and monitoring technologies** that assist and augment on-farm decision-making. In this context, a spatial soil data infrastructure that can be continuously updated, improved, refined, and expanded, would be highly supportive. Eventually, digital technologies can create 3D-like soil condition baseline maps relevant to the farm enterprise (Malone et al., 2022).

Data integration

The data collected from soil sensing technologies need to be combined with data from field measurements or from process-based simulation models to get a better understanding about local, regional and global variability of soil functions (Silvero et al. 2023).

5.6 Energy consumption

Agriculture and forestry are significant consumers of energy, both directly and indirectly. Direct energy consumption includes **the use of machinery** for field cultivation, as well as **heating for livestock stables and greenhouses**. In 2021 agriculture and forestry sector accounted for a 3.0 % of the total direct energy consumption in the EU, with oil and petroleum products being the primary sources of fuel. The Netherlands reported the highest share of energy consumption in these sectors, at 9.2%. On average, the EU's agriculture and forestry sectors consumed 171 kilograms of oil equivalent per hectare (KgOE/ha) in 2021. Indirect energy consumption also plays a role, particularly in the production of agrochemicals, farm machinery, and infrastructure, with natural gas being a key input for producing inorganic nitrogen fertilizers. (Eurostat, 2024c).

Digital technologies

The role of digital technologies in the overall reduction of non-green energy in the economy is limited. While digital technologies hold promise for improving energy efficiency and reducing non-green energy use, their impact varies significantly across sectors. In agriculture, digital tools such as precision farming, agro-robotics, and drones are becoming increasingly prevalent. However, **the production and operation** of these technologies **require substantial energy and resources,** contributing to their overall carbon footprint. (EIT Digital, 2022). Currently, the digital sector is responsible for approximately 4% of global CO_2 emissions—surpassing those of the aviation industry—and it is expanding at a much faster rate than other sectors, with an estimated growth of around 8% per year in the coming years. This rapid expansion is driven by the proliferation of the Internet of Things and a predicted 50% increase in global internet traffic by 2022. Additionally, the production of digital tools r**equires a wide variety of metals**. The rising demand for digital infrastructure and devices, coupled with the substantial quantity of materials and metals necessary for their creation, raises several critical concerns. Chief among these is the issue of the criticality of the materials involved (Aspext, 2020).

Precision farming in Europe relies heavily on data collection through Internet of Things (IoT) devices, including robots and drones equipped with cameras and sensors. These devices are often constructed with new materials, electronics, and batteries, raising concerns about their **repairability** and the potential contribution to **electronic waste** (Aspext, 2020).

Additionally, the **energy** required **for data storage and processing**, particularly in data centres, adds another layer of environmental impact. Europe's data centres, which store vast amounts of agricultural data, consume significant power and water for cooling purposes. The number of data centres in Europe is expected to increase dramatically by 2025, potentially exacerbating power shortages and further contributing to climate change.

Artificial intelligence (AI) is increasingly being used in agriculture for applications such as disease detection, yield prediction, and soil classification. However, t**raining AI algorithms is energy-intensive**, requiring large amounts of power and contributing to the sector's carbon footprint. As the demand for AI and data-driven solutions in agriculture grows, so does the need for data storage, leading to the rapid expansion of data centres[21]. These centres not only consume vast amounts of energy but also require significant quantities of drinking water for cooling, further straining natural resources.

Also, societal resistance is growing (e.g., in the Netherlands) towards the impact these “ugly” buildings (i.e. data centres) have on the surrounding nature and landscape (Wijnen et al., 2023).[22] In the Netherlands, the regional government of North-Holland has even developed a special policy for the settlement of data centres on their territory. Its policy prescribes that the building must be in line with its surroundings (Richtlijnen voor verduurzaming, 2023).

In sum, the integration of digital technologies into the agri-food sector offers significant opportunities for improving efficiency and productivity. However, these advancements come with substantial environmental costs, particularly in terms of energy consumption and carbon emissions. The increasing reliance on digital tools, AI, and data centres necessitates a careful evaluation of their environmental impact, with a focus on sustainability and resource management. Addressing these challenges is critical to ensuring that the benefits of digitalization in agriculture do not come at the expense of the environment.

5.7 Food waste and food loss

If food loss and waste were considered a country, it would be the third-largest greenhouse gas emitter globally, following China and the United States. The current global food supply chain leaves food behind at every stage—on fields and farms, during transport, in processing and packaging, and finally, during serving and disposal. In total, at least one-third of potential food production, equivalent to 1.3 billion tonnes annually, is lost. This amount of food, if saved, would be sufficient to feed all undernourished people worldwide, who account for about 10.8% of the global population. Additionally, reducing food waste would significantly decrease greenhouse gas emissions by minimizing the need for excess food production. These facts have raised interest in zero-waste "circular economy" policies, championed by the EU over the past decade. However, progress has been slow, prompting important questions about how to make the benefits of reducing food waste outweigh the costs, and how to achieve a tipping point in this global challenge (European Commission, 2020b).

Food waste and loss present significant challenges within the European Union, both from an environmental and economic perspective. With the EU aiming to reduce food waste as part of its broader sustainability goals, the need to understand the current trends of food waste, the potential

[21]See Data Centers Map.
[22]https://fd.nl/economie/1500098/na-boeren-en-bouwers-lopen-nu-ook-datacenters-tegen-een-grens-aan).

role of digital agricultural technologies, and the societal changes required to address these issues is more pressing than ever.

In 2021, approximately 131 kg of food waste per inhabitant were generated across the EU. Households were the largest contributors, generating 54% of food waste, which translates to 70 kg per inhabitant. The remaining 46% of waste was generated upwards in the food supply chain, with primary production and the manufacture of food products and beverages contributing 11 kg and 28 kg per inhabitant, respectively, accounting for 9% and 21% of the total food waste (Eurostat, 2024d).

In February 2024, the Environment Committee of the European Parliament voted on new EU-wide food waste reduction targets, as part of the revision to the Waste Framework Directive. The Committee members agreed to ambitious targets: a 20% reduction in food waste for processing and manufacturing, and a 40% reduction for retail, restaurants, and households. However, these targets fall short of the European Parliament's 2020 resolution under the Green Deal, which aimed at a 50% reduction in food waste from farm to fork (Zero Waste Europe, 2024).

Digital technologies

Digital agricultural technologies hold potential in supporting food loss and waste prevention, yet their role has not been fully explored. Studies suggest that while technologies can support in preventing and reducing food loss and waste, their adoption is often driven more by economic benefits rather than environmental or socioecological considerations. Benyam et al. (2021) argue that food loss and waste reduction is rarely the primary goal when implementing digital technologies. Instead, the focus tends to be on profit maximisation and cost reduction. Researchers recommend further investigation into whether agri-food actors would adopt digital technologies specifically to reduce or prevent food loss and waste, especially if it does not offer direct economic benefits. Benyam et al. (2021) also suggest exploring whether the economic gains provided by DATs are inherently linked to food waste reduction.

Addressing food waste and loss in the EU requires a multifaceted approach that combines legislative action, technological innovation, and social transformation. While recent efforts, such as the revised Waste Framework Directive, mark progress, achieving the EU's ambitious food waste reduction goals will likely depend on how effectively digital technologies are leveraged and whether society can embrace the necessary changes. Understanding and navigating the complex interplay between economic incentives, technological advancements, and social dynamics will be critical to making meaningful strides in reducing food waste and its associated environmental impacts.

6. Policy and regulatory developments

As Europe launched the Digital Decade policy programme which had targets set in order to support the digital transition among citizens, businesses, infrastructures, and government agencies by 2030. The programme sets the tone for technological uptake, as well as societal and economic preparation for a more data-oriented society, with ambitions that can be related to and join efforts with other legal and political developments in Europe[23].

Policy and legal trends related to the data economy and food systems relate to the trends previously listed in the reports primarily to ensure negative impacts of trends are mitigated. The main developments are presented below.

The following policy and regulatory developments were selected according to their relevance to the DE4FS and their importance for further development of future scenarios and roadmaps (*SO5: Provide future scenarios and a roadmap and sustain the monitoring system to support policy development and accelerate the desired future state of the DE4FS*). Those policies will be checked with the action plans developed by the stakeholders in the backcasting workshops (WP4, T4.2) and will be the input for further impact assessment and policy recommendations (WP5). In this section, the research aimed to look at (a) legal frameworks that impact data economy in Europe and what legal frameworks impacts food systems and (b) political and strategical documents adopted by the European Commission and proposed by relevant stakeholders influence the development of the data economy in food systems, including digitisation and technological push.

6.1. The Twin Transition in Europe

The “twin transition” in Europe refers to the simultaneous pursuit of the digital transition and the European Green Deal. This policy trend represents a significant strategic direction for the European Union, aiming to integrate digital technologies with environmental sustainability. Regarding the Digital Transition, this aspect focuses on advancing the digital and data economy and integrating digital technologies across various sectors. Key priorities include enhancing digital skills, promoting digital infrastructure (like broadband and 5G), and fostering digital innovation and services. The digital transition is seen as crucial for economic growth, competitiveness, and addressing societal challenges (Muench et al., 2022).

The European Green Deal, launched in December 2019, is a comprehensive plan to make the EU's economy sustainable by turning climate and environmental challenges into opportunities. Key elements include achieving net-zero greenhouse gas emissions by 2050, decoupling economic growth from resource use, and ensuring a just transition for regions and workers affected by the green transition.

The twin transition is at times criticised as a misnomer, as the green deal and ecological transition is a necessity to ensure continued sustainability, evade climate catastrophe, while the digital transition is a tool to enhance competitiveness. So, while, the twin transition is seen as mutually reinforcing, it is imperative to consider the elements in terms of existential priority. Digital technologies can be crucial in achieving the goals of the Green Deal, but these also need to be balanced. The costs of a digital tools, and digital fuel (i.e. data) are often unseen and their carbon output are seen as minimal even though the levels of data accruing around Europe and the world are growing.

There is emerging a mobilisation among citizens seeking to mitigate the proliferation of data centres. Specifically, recent actions taken by the municipalities of Amsterdam and Haarlemmermeer, the latter of which encompasses Schiphol Amsterdam Airport, have garnered attention. These municipalities have announced a temporary suspension of new data centre projects within their respective jurisdictions. Their rationale for such measures centres on

[23] Europe´s Digital Decade: digital targets for 2030

concerns regarding the extensive spatial and carbon footprint associated with data centre operations (City of Amsterdam, 2023). This decision signifies a concerted effort by local authorities to address the multifaceted challenges posed by the expansion of data centre infrastructure in their regions. It can also signal a shift towards recognising there can be limits to data and what is the limits of what data can be held, thus leading questions to what data is needed and what data is nice to collect. In the realm of food systems, as this is essential to supporting life this raises questions on balancing necessity in data collection.

Key to this twin transition, and the emergence of a lot of regulation is the European Digital Strategy which represents a forward-looking framework aimed at harnessing the transformative potential of digital technologies to bolster the continent's socio-economic resilience and global competitiveness. At its core, this strategy endeavours to foster a digitally empowered society by promoting universal access to high-quality digital infrastructure, enhancing digital skills and literacy among citizens, and ensuring the ethical and responsible use of data. It implies that 70% of SMEs will be operating in AI and data by 2030. This requires embracing principles of innovation and sustainability, the strategy seeks to drive digital innovation across sectors, from healthcare and education to manufacturing and agriculture, thereby fostering a dynamic and inclusive digital economy. Moreover, the European Digital Strategy underscores the imperative of bolstering Europe's digital sovereignty, asserting the continent's autonomy in the digital realm while championing values such as privacy, security, and democratic governance. Through strategic investments, regulatory measures, and international cooperation, the European Digital Strategy aspires to position Europe at the forefront of the global digital landscape, driving progress towards a prosperous, resilient, and digitally-enabled future for all its citizens.

Overall, the twin transition is about aligning the digital revolution with climate and environmental objectives, ensuring that Europe's digital transformation supports sustainable development. It is an essential policy for the development of policy actions and recommendations for future DE4FS (WP4 and WP5). The Netherlands' example of refusing to build the data centres shows the indispensability of the assessment of environmental and technological impacts. Twin transition is part of the broader European strategy to remain competitive globally while adhering to its commitments under the Paris Agreement and other international environmental accords.

6.2. Data acts and their impact on the data economy

The European Union has ratified a number of regulations governing how data can be used, shared and protected. The regulations build on the Data Protection Directive 95/46/EC[24] which offered data protection but focused primarily on personal data. Since the reunification of Germany, there was a growing awareness in Europe of data collection practices in East Germany which were not conducive to the protection of private life, a human right, nor conducive to a free and democratic society. The directive intentionally kept the definition of what data is to be quite broad, meaning any data that can be used to identify a person.

The data protection directive was followed by the General Data Protection Regulation. While a regulation becomes effective in EU Member States immediately upon its enactment, a directive requires incorporation into each Member State's national legislation before it can be applied. The GDPR helped create more harmony and offered citizens greater authority over their data, such as the right to access, modify, and even delete their data.

In terms of the data economy, GDPR has been invaluable for protecting data subject rights, but too many data holders are reluctant to share data seamlessly, partly arguing that the sharing of data may be a GDPR violation, or their data sets are mixed. There have been efforts by regulators to address this challenge with the Regulation on a framework for the free flow of non-personal data in the European Union (regulation 2018/1807) and the Directive on open data and the re-use of public sector information (2019/1024). The regulations aim to ensure that non-personal

[24] Directive 95/46/EC on the protection of individuals with regard to the processing of personal data on the free movement of such data.

data can be shared, while the directive aims to ensure that public sector data remains open and available for reuse. The regulation has largely been without much impact leading to yet two more regulations to be developed: Data Act (2023/2854) and Data Governance Act (2022/868).

The Data Act is designed to enhance the EU's data economy by making industrial data more accessible and usable, and by encouraging a competitive and reliable European cloud market. It aims to ensure widespread benefits from the digital revolution. Key aspects include: enabling users of connected devices to access and share data, fostering innovation while protecting manufacturers' trade secrets; preventing unfair contractual terms to protect EU companies, especially SMEs; allowing public sector access to private sector data in emergencies or for legal mandates; establishing rules for easy switching between cloud data-processing services to avoid vendor lock-in and ensure secure data environments; and promoting interoperability standards for data-sharing in alignment with the EU Standardisation Strategy.

The data governance act builds on the Open Data Directive and aims to regulate the re-use of protected data held by public sector bodies, such as personal and commercially confidential data, under specific EU or national legislation. In the Data Governance Act, Member States are required to ensure technical measures are in place for data privacy and confidentiality, like anonymization or secure processing environments. Public sector bodies should assist in obtaining necessary consent for data re-use and limit exclusive data re-use agreements to cases of public interest. Reasonable fees may be charged for data reuse, with incentives for scientific, non-commercial use, and for SMEs and start-ups. Decisions on re-use requests should be made within two months. Member States designate competent bodies to support public sector data management and accessibility. Additionally, a single information point in each Member State, complemented by the European Register for Protected Data held by the Public Sector (ERPD), assists in locating and re-using data within the EU.

While these acts are in place, based on previous experience, the enforcement of sharing data has not been seamless, nevertheless, there is a risk with data silos and a data economy that does not flow. The importance of the Data Acts for DE4FS is undelayable since they establish rules of data sharing, data re-use, and protecting trade secrecy. They had to be acknowledged in the process of developing policy pathways (WP4) and recommendations (WP5).

6.3. Artificial Intelligence Act

The European Act on Artificial Intelligence is a ground-breaking regulation that seeks to ensure a safe and trustworthy use of AI in EU Member States. By acknowledging the potential high risk of the use of this technology, it proposes a classification of different types of the use of AI according to their risk of affecting fundamental human rights and attributes obligations and penalties accordingly.

The AI act proposes then a risk-based approach, which is intrinsically related to data use. AI applications are usually based on data inputs, especially if the solutions are available for end-users. In this sense, by pushing for transparency, the regulation shall have an impact on how users understand the technology, its risks and benefits, and create more trust. Hence, it is expected to incite innovation and boost investment in areas covered in data economy (European Council, 2023).

For the specific case of food systems, the use of AI in production and consumption standards shall provide more transparency in data-related for consumers. The AI systems already are and have the potential to become even more important element of the DE4FS. Therefore, this regulation has to be acknowledged in the process of developing policy pathways (WP4) and recommendations (WP5).

6.4. Interoperable Europe Act proposal

The Interoperable Europe Act proposal has recently adopted. This act is part of a broader, ongoing trend in the European Union towards greater digital integration and harmonization, in line with the

EU's digital strategy. It reflects the EU's strategic vision of creating a unified digital single market, ensuring that member states and citizens can fully benefit from digital transformation. The proposal focuses on digital infrastructure, data sharing and management, digital services and platforms, public administration, and e-government services.

The Interoperable Europe Act is an initiative designed to enhance digital public services by improving interoperability—the ability of diverse digital systems, processes, and data to seamlessly integrate across the EU. As a crucial component of the EU's digital strategy, it aims to foster a digitally unified and cohesive Europe. The proposal highlights the need for enhanced cooperation among EU member states and institutions in developing interoperable digital solutions, ensuring the smooth functioning of services across borders. It emphasizes establishing common standards and frameworks, crucial for efficient communication and data exchange, and seeks to improve the quality and accessibility of cross-border digital services in areas like healthcare and business. The Act is intended to drive digital innovation, modernize the public sector, and contribute to the EU Digital Single Market, enhancing the efficiency, transparency, and accessibility of services. It also highlights the importance of secure data sharing, privacy in accordance with the GDPR, and ensuring that digital services are inclusive and accessible to all citizens, including those with disabilities. This proposal marks a significant advancement in enhancing the EU's digital landscape, ensuring more efficient and effective delivery of digital public services for citizens and businesses (European Commission, 2022a).

This reflects a concerted effort to achieve greater digital integration and harmonization across several key areas. These include establishing common standards and protocols for data sharing, storage, and security, which are vital for sectors like DE4FS. This they have to be acknowledged in developing policy pathways (WP4) and policy recommendations (WP5). Efforts are being made to harmonize digital services and platforms to ensure seamless operation of e-commerce, content services, and social networks across EU borders. Public administration is being digitized with interoperable systems to facilitate smoother cross-border processes, such as tax filing and business registration. Regulatory frameworks, exemplified by the GDPR, are being aligned for consistent digital activity governance. Cybersecurity is being strengthened with unified standards and protocols to protect networks and data EU-wide. There are also focused efforts on harmonizing digital education and skills development to ensure citizens are equipped for the digital economy. Additionally, e-Government services are being enhanced to facilitate easier interactions with public administrations, regardless of location within the EU. These initiatives collectively aim to create a more connected, efficient, and secure digital environment across the European Union.

6.5. Farm to Fork Strategy

The Farm to Fork Strategy is a key component of the European Green Deal, aiming to make food systems fair, healthy, and environmentally friendly. This strategy is crucial as food systems are a major driver of climate change and environmental degradation and reforming them is vital for achieving sustainability goals. One of the core policies of the Farm to Fork Strategy is to promote sustainable food production. This includes reducing the usage of chemical pesticides, fertilizers, and antibiotics, which can be harmful to the environment and human health. The strategy also focuses on sustainable food processing, retail, and consumption. It encourages the adoption of sustainable practices in food processing and retail, promoting waste reduction and the circular economy. The strategy aims to address the entire food supply chain and invest in research and innovation to transform the food system. This includes developing new technologies and practices for sustainable agriculture, improving food processing and packaging, and finding solutions for food waste reduction.

In summary, the Farm to Fork Strategy is an ambitious plan to transform the European food system, making it more sustainable, resilient, and fair. It covers every aspect of the food chain, from production to consumption, and seeks to achieve its goals through a combination of regulatory measures, voluntary initiatives, and investments in research and innovation. The DE4FS is an environment that is strongly shaped by this policy and DE4FS can significantly contribute to this transformation. Thus, it has to be considered in the context of developing policy pathways (WP4) and policy recommendations (WP5). The success of this strategy is seen as vital for the EU to achieve its overall environmental and climate objectives under the European Green Deal (European Commission, 2020c).

6.6. EU Code of Conduct on responsible food business and marketing practices

The Code of Conduct for food businesses emphasizes sustainability, healthy food options, and responsible practices. It encourages companies to reduce greenhouse gas emissions and waste and promote biodiversity for a more sustainable food industry. Nutritional quality is also a focus, urging businesses to lower salt, sugar, and fat in products to improve public health. The Code advocates transparent, fair practices in consumer interactions and supply chain operations, promoting responsibility and fairness.

Responsible marketing, especially for healthy and sustainable food choices, is a key element, with guidelines on advertising and special attention to vulnerable groups like children. Providing clear, accurate, and accessible information to consumers about sustainability and nutrition is essential for informed choices.

To align with the EU's goal of halving food waste by 2030, the Code calls for actions to reduce waste in all food supply chain stages. Efficient and sustainable use of resources in food production, like water and energy, is emphasized to lessen the environmental impact.

The Code also promotes plant-based diets due to their lower environmental footprint compared to animal-based diets. Collaboration among food chain stakeholders is encouraged, with businesses expected to pledge to the Code and report on their progress, ensuring accountability and collective advancement towards sustainable food practices (EU Farm to Fork Strategy, 2021). The Code is an interesting example of soft law, that combines important aspects that DE4FS have to include to be fairer and more sustainable.

6.7. EU Code of conduct on agricultural data sharing

The EU Code of Conduct on Agricultural Data Sharing is a set of guidelines designed to facilitate the sharing of agricultural data, particularly between farmers and service providers in the agricultural sector. This initiative aims to harness the potential of digital technologies in agriculture while addressing concerns related to data ownership, privacy, and control. It is written in the framework of a sectoral code of conduct (article 40 of GDPR) which states that codes of conduct help support the proper application of the regulation accounting for taking account of the specific features and needs of sectors, in this case, the agricultural sector.

The EU Code of Conduct on Agricultural Data Sharing ensures clarity about what data is collected, for what purpose it is used, and who has access to it. Service providers should clearly explain the benefits and implications of data sharing to farmers. It also affirms that farmers retain ownership of their data and have control over how it is used. This includes the right to decide who can access their data and for what purposes. It emphasizes the importance of protecting personal and sensitive data. Service providers must adhere to relevant data protection laws (like the GDPR) and ensure that data is stored and transmitted securely. It should promote fair and equitable terms in data-sharing agreements. This includes ensuring that farmers receive fair compensation or benefits for sharing their data. Encourages the use of standard formats and protocols to ensure that data can be easily shared and used across different platforms and services. Recognising that data sharing can drive innovation in agriculture, the code encourages practices that support the development of new technologies and services. It also ensures that farmers have access to their data and can easily transfer it between different service providers and establishes clear mechanisms for resolving disputes related to data sharing (COPA & COGECA, 2020).

The EU Code of Conduct on Agricultural Data Sharing is voluntary, and it is part of a broader effort to digitize agriculture in Europe, improve the efficiency and sustainability of farming practices, and support farmers in the digital economy. Thus, it has to be acknowledged as an element of the development process of policy pathways (WP4) and policy recommendations (WP5). The Code makes many references to GDPR, but that largely regulates personal data. It is expected there will be an updated code of conduct in line with the Data Act and Data Governance Act.

6.8. Common Agricultural Policy 2023-2027

The Common Agricultural Policy (CAP) of the European Union has been a cornerstone policy since its inception in 1962. For this reason, it has to be recognised in the process of development of policy pathways (WP4) and policy recommendations (WP5). The CAP has been noted for ensuring Europe has enough food production to feed itself, since its inception Europe has moved from a net-food importer to a food exporter. It is typically divided into two pillars, one of Agricultural production support and another in rural development. Some criticisms of the CAP have emerged as it focused on increasing the efficiency of agricultural production, which has resulted in the creation of larger farms and monocrops and this has not always been sustainable.

The current cap, which will run from 2023 to 2027, represents a shift and an update to what has been the standard operating procedure. The CAP aims to promote a fair distribution of income for farmers and reduce income inequalities by promoting a fair distribution of income which may particularly help those farmers running smaller-scale farms. This will strengthen the second pillar of the CAP to continue to support rural development. A recent trend has seen that while the proportion of agricultural land in the EU has been relatively stable, the number of farmers and family farms has been reduced over the years. This will also protect some of the traditional farming culture in Europe, and support initiatives for generational renewal. This also involves increasing support for young farmers. Additionally, the CAP aims to prioritise the role of farmers in the food supply chain.

In alignment with the EU digital strategy, the CAP also encourages innovation and the use of technology in agriculture which will continue to promote digital farming practices, research, and development (European Commission, 2022b).

6.9. Overview of identified trends in policy and regulatory developments and potential impacts on DE4FS

The development of the EU policies and regulations that affect and can be affected by the DE4FS is a dynamic process. There are four identified trends in the regulations and policies described above: *evading climate catastrophe*, *developing a trust environment*, *greater digital integration*, and *enhancing competitiveness*.
Evading climate catastrophe is one of the key trends of the EU regulations and policies. In the context of DE4FS, one of the key elements is to integrate digital technology to build and strengthen the sustainability of the food system (The Twin Transition, The From Farm to Fork strategy), to promote the circular economy and waste reduction to make food production more sustainable (The From Farm to Fork strategy), to contribute to biodiversity, plant-based diets, and reduction of greenhouse emissions, (EU Code of Conduct on responsible food business and marketing practices), to draw attention to unseen and/or hidden costs of the digital transition, such as the environmental impacts of the digital infrastructures (The Twin Transition).

Developing a trusted environment is the second trend identified. The policymakers aim to earn the trust of digital and food system actors by applying transparency requirements, contributing to a better understanding of risk related to technologies, and securing inclusion of vulnerable actors (AI Act, EU Code of Conduct on responsible food business and marketing practices, Interoperable Europe Act). The central aspect of this trend is to guarantee appropriate data protection, and cybersecurity of the digital infrastructure (Data acts and their impact on the data economy, Interoperable Europe Act, EU Code of conduct on agricultural data sharing). From the food system perspective, it should be resilient and healthy, securing nutritional quality (EU Farm to Fork strategy, EU Code of Conduct on responsible food business and marketing practices). The attention is on keeping the green transition just for regions and workers (The Twin Transition) and fair distribution of income for farmers (Common Agricultural Policy 2023-2027).

The third trend aims to achieve *greater digital integration*. It should unlock the potential of data flow (Data acts and their impact on the data economy) and make the digital environment more efficient (Interoperable Europe Act). The key elements of this trend are promotion of interoperability standards, digitalisation of public services working smoothly across borders (Interoperable Europe Act), providing rules for fair data sharing (also among food producers and service providers), data access, protected data re-use, and data portability (Data acts and their impact on the data economy, EU Code of Conduct on Agricultural Data Sharing).

The fourth identified, trend is *enhancing competitiveness*. It includes notions like strategic investments, promoting digital infrastructures across various sectors, enhancing digital skills, protecting trade secrets, fostering digital and agri-food innovations, turning climate challenges into opportunities (The Twin Transition, Artificial Intelligence Act, Interoperable Europe Act, From Farm to Fork strategy). It aims to protect EU companies, especially SMEs. In the context of climate change, it has the ambition to turn the challenges related to transformations into opportunities (The Twin Transition).

Data-driven policy

Data-driven policymaking is critical for ensuring that regulations and strategies are effective, efficient, and targeted. By moving beyond anecdotal evidence and relying on quantitative data, policymakers can accurately diagnose systemic issues, measure the potential impact of interventions, and allocate resources optimally. This approach is believed to foster transparency, and accountability offering a neutral manner in governance, enables continuous monitoring and brings necessary adaptive course-correction measures required to manage complex, evolving challenges like climate change and food system resilience. However, it is important to consider that data used in data-driven policy making is often used to justify certain ends which can include policy, it is worthwhile to remain critical of the neutrality of data. Moreover, it strengthens the legitimacy of policy decisions and maximises their success in achieving ambitious sustainability and economic goals.

In this context, an important example is the Farm Sustainability Data Network (FSDN), a key instrument for evidence-based policymaking. FSDN was developed under Farm to Fork strategy, and it is the restructured version of Farm Accountancy Data Network. It requires robust data on climate change, soil quality, carbon sequestration, pesticide use, water and air quality, energy consumption, and biodiversity. In addition, by harnessing B2G data collected through digital technologies in the FSDN, the European Economic and Social Committee (EESC) advocates for the creation of a common data space for agriculture. This includes promoting co-ownership of data and supporting data cooperatives, especially considering the current lack of a harmonized methodology for data comparability and shared use across the agri-food sector (EESC, 2022)[25].

Moreover, to address these data and methodology gaps and ensure long-term resilience of data infrastructures, the FSDN should be integrated into a broader monitoring system, such as the monitor developed in Data4Food, that continuously evaluates the development, performance and impact of the data economy on EU policies. It may be possible to also may linked with the agri-data space. Embedding iterative loops within this system would allow for the ongoing incorporation of new societal challenges, technological innovations, and policy shifts. These feedback mechanisms would not only keep the monitoring framework responsive and up to date, but also reinforce the strategic alignment between data collection, policy design, and sustainability goals. Ultimately, this dynamic approach would strengthen the foundation for a future-proof EU data space and support the evolution of a resilient, data-driven agri-food sector.

[25] Opinion – Conversion to a Farm Sustainability Data Network (FSDN).

7. Conclusions and next steps

Overall, the report underscores the transformative potential of data use and digitalisation in the European food systems as the sector struggles with the dual challenges of sustainability and competitiveness. It also highlights how integration of data-driven solutions can bring both opportunities and challenges for the food value chain. But, at the same time, stakeholders must navigate the complexities of technological advancements while addressing societal expectations and environmental imperatives. Therefore, the need for equitable access to data and resources is paramount to ensure that the benefits of digitalisation are shared across the entire food value chain. Policymakers, businesses and communities must collaborate to create a resilient and inclusive data economy that supports sustainable food systems and fosters innovation for future generations.

The desk research and literature review for the analysis of trends in data economy for food systems allowed for the identification of key aspects to look into when addressing "data economy," "food systems" and "data economy for food systems." The digital transition and technological development, especially after the COVID-19, has impacted all the five types of trends, both in the identification of opportunities and barriers. The trends analysed in this report reveal that while there is significant potential for data to drive improvements in efficiency, transparency, and sustainability, there are also substantial challenges. These include the uneven adoption of digital technologies across different regions and sectors, the high energy consumption associated with data infrastructure, and the need for robust data governance frameworks to ensure security and privacy. Furthermore, the evolving regulatory landscape, as seen with initiatives like the European Digital Strategy and the Common Agricultural Policy, will play a crucial role in shaping how data is used and managed in the agri-food sector.

The integration of **digital technologies** into food systems is reshaping the agricultural landscape, enhancing efficiency and improving market access for stakeholders. The rise of data-driven platforms offers opportunities for innovation and profitability, by enhancing data accessibility and fostering connections between farmers and stakeholders, which improves decision-making and market access. Artificial intelligence and machine learning are revolutionising decision-making processes within supply chains, enabling stakeholders to predict anomalies and optimise operations. The use of blockchain technology can also improve supply chain trust and automate transactions through smart contracts, streamlining regulatory processes. Smart sensors and the Internet of Things (IoT) facilitate real-time data collection, enabling precision agriculture and better resource management. These technologies facilitate better resource management and sustainability practices, aligning with societal expectations for environmentally responsible food production. However, the rapid pace of technological change necessitates ongoing adaptation and upskilling within the workforce to mitigate potential job displacement. It also raises concerns regarding the concentration of power among a few dominant providers, which can exacerbate inequalities and lead to job losses. Therefore, the equitable access to resources and information across the food value chain is an essential need for all stakeholders.

The **societal factors** show a growing demand for transparency and traceability in food systems, driven by consumer awareness and regulatory pressures. It also demonstrates that despite the perks of digitisation and the opportunities that new technological developments bring about, such as new job opportunities accompanying the development of new markets, Europe still faces a low rate of skilled workers to follow the fast-pace of the transition. Moreover, the impact of the availability of food-related applications both for food access and healthy dietary habits does not overcome food insecurities in some parts of Europe. This societal shift is impacting businesses by encouraging them to adopt more sustainable practices and invest in technologies that enhance data sharing and collaboration. When it comes to the **economic aspects**, these show a moderate economic growth in recent years in Europe, partially related to the pression on the market from the Russian aggression to Ukraine, which has led to increasing pressures on food system development. Moreover, the restrictive macroeconomic policy has shifted the demand, whilst inflation has impacted on the purchase power of households. Additionally, volatile economic perspectives and costly digital adoption contributed to changes in the farming structure. While the land for farming has been stable, the number of farms diminished over time, suggesting an incorporation of small farmers land into bigger structure to be able to cope with the market competition. Moreover, the increasing importance of data as a valuable asset is reshaping business models and creates new value propositions within the food sector.

The **environmental challenges** further complicate the landscape, necessitating innovative solutions that leverage data for sustainable practices. They are equally dual: on one hand, the agri-food sectors impact negatively the environment contributing significantly to climate change concerns (such as pollution and erosion); on the other, it equally pushes for the development of green technologies to mitigate these effects. This context, policymakers play a crucial role in shaping the future of the data economy for food systems by establishing frameworks that promote innovation while ensuring equitable access and protecting local knowledge.

The **European policy** plays a crucial role in shaping the data economy for food systems by establishing frameworks that govern data usage, promote innovation and ensure equitable access to resources. **European regulatory frameworks** define how data can be collected, shared and utilised, ensuring compliance with privacy and security standards, which is essential for building trust among stakeholders, including consumers, businesses and government agencies. Initiatives like the European Digital Decade policy programme facilitate the digital transition across various sectors, including agriculture, by setting targets for technological uptake and encouraging investment in digital infrastructure. Additionally, policies are designed to address and mitigate potential negative impacts of technological advancements, such as job displacement and data monopolization, ensuring that the benefits of the data economy are distributed more equitably**.**

Recent strategic documents and action plans developed by the European Commission and relevant stakeholders stress the European goal of responsibly advancing a fair data economy and the adoption of new technologies, fostering collaboration among various actors in the food system and encouraging partnerships between public and private sectors. These collaborations facilitate knowledge sharing and the development of integrated solutions that leverage data for improved food production and distribution across the food value chain. Moreover, by aligning data initiatives with sustainability goals, policymakers can drive innovation in areas such as precision agriculture and supply chain transparency. Overall, policies significantly impact the data economy by supporting research and development, creating a robust and inclusive environment that benefits all stakeholders involved in food production and distribution

It is important to underscore that the research led to the identification of gaps in main and grey literature, given that most of the literature analysed lacked a clear connection between drivers and challenges for data economy and their direct and indirect impacts in the European food systems. It equally highlighted the interconnected work between WP5 and WP2 in terms of understanding the state-of-play of data economy for food systems in Europe and justifying the need for data-related improvements in the agri-food sector. Also, given the gaps in literature, as aforementioned, it highlighted the interconnection with WP4, where the identification of main stakeholders shall allow for the validation of results through different methods of research.

Overall, the digitalisation and the use of digital technologies offer significant potential to enhance the efficiency, sustainability and resilience of food systems. By leveraging technologies such as precision agriculture, predictive analytics and blockchain, stakeholders can optimise resource use, reduce waste and improve traceability across supply chains. These changes can unlock important opportunities within the data economy, driving innovation, improving productivity and creating new revenue streams. However, realising these benefits requires addressing key challenges such as data ownership, privacy, and the digital divide. Ensuring equitable access to data and fostering transparent governance frameworks will be critical to avoid concentration of power among a few stakeholders. Moreover, fostering collaboration between policymakers, businesses and technology providers will be crucial to scale these innovations, ensuring that data infrastructure is inclusive and accessible to support sustainable food production and distribution. And, it is essential that the policies developed balance innovation with ethical considerations, promoting data-sharing ecosystems while safeguarding the interests of all actors in the food supply chain.

Looking ahead, the project will continue to explore the potential impacts these trends might bring to the data economy for food systems, with a focus on developing actionable recommendations for policymakers, industry stakeholders, and other key players in the food sector. The goal is to enhance the development of a data economy that not only supports the economic objectives of the EU but also contributes to broader societal goals, including sustainability, food security and social equity. It will be essential to maintain a focus on the practical implications of these trends, ensuring that the insights gained are translated into concrete actions that can drive real-world change in the food sector. Furthermore, leveraging monitoring data alongside foresight analyses of future trends will support a deeper understanding of potential evolution pathways for the data economy in general, and for food systems in particular. This dynamic approach will facilitate timely updates to the monitoring framework and contribute to shaping future requirements, including the articulation of a compelling data value proposition for food systems. Ultimately, this will inform the roadmap for long-term growth and guide the design principles of a resilient and future-proof EU data space. Maintaining a responsive monitoring framework will also help reinforcing the strategic alignment between data collection, policy design, and critical sustainability and competitiveness goals. Moreover, it will also make sure that European food sector is well-positioned to harness the full potential of the data economy, leading to a more resilient, sustainable, and competitive future.

The findings of this report will provide the foundation for future work for the next steps of the project. First, it sets up the scene for the identification of the key data value proposition, which is the activity of the next task in the WP5 (Task 5.2). Next, the preliminary findings from the first two tasks together with the results from WP4 (scenario development and backcasting workshops) and WP2 (the modelling activity) will be used for the impact assessment of different the strategic options for the development of the data economy for food system. The assessment will provide proposals for actions and recommendations that could enhance the development of the data economy for food systems. It will incorporate a set of iterative feedback loops that will also allow the monitoring of new societal challenges, technological innovations and policy shifts, and consider their potential impacts when develop the future roadmap and policy recommendations for the improvement of data economy in food systems (WP5: D5.3 *Recommendations and roadmap for improving the DE4FS*, in Task 5.4).

8. References

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