EUROPEAN POLICY CENTRE

CropLife EUROPE

DISCUSSION PAPER

SUSTAINABLE PROSPERITY FOR EUROPE PROGRAMME

1 OCTOBER 2024

Towards sustainable and resilient agri-food system: What is the role for digitalisation?

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Credit: CANVA

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ACKNOWLEDGMENT/DISCLAIMER

This Discussion Paper builds on the findings of the EPC project, "Digitalisation for sustainable and resilient agri-food system", which was carried out from 2023-2024 with the support of CropLife Europe. The project looked at the state of play, prospects, and challenges of using data and digital solutions to help make the European food system more sustainable and resilient. It explored how the EU's policy and financial framework can support these efforts. It comprised two workshops, a Discussion Paper, and a Policy Dialogue to present the project's main findings. The Steering Committee advised the EPC on carrying out the project's activities without endorsing any of the actual deliverables. The EPC would like to thank the experts who took part in the Steering Committee including: Dr. Joelle Herforth-Rahme; Philippe Loudjani; Olivier De Matos; Iris Bouma; Annika Hedberg; Nevena Alexandrova; Elisabet Nadeu; Cecilia McAleavey; Federico Sgarbi; Emma Brown; Lisa Haller; Felix Harrer; Dr. Jacqueline E.W. Broerse; Valentina Peniche; Damir Filipović; Luis Perez Freire and Shaunagh Duncan.

Executive summary

The transition to sustainable food production, processing, distribution, and consumption requires modernising the sector and using data and digital solutions to steer the digital transformation towards supporting the climate and environmental objectives of the European Green Deal and UN Sustainable Development Goals.

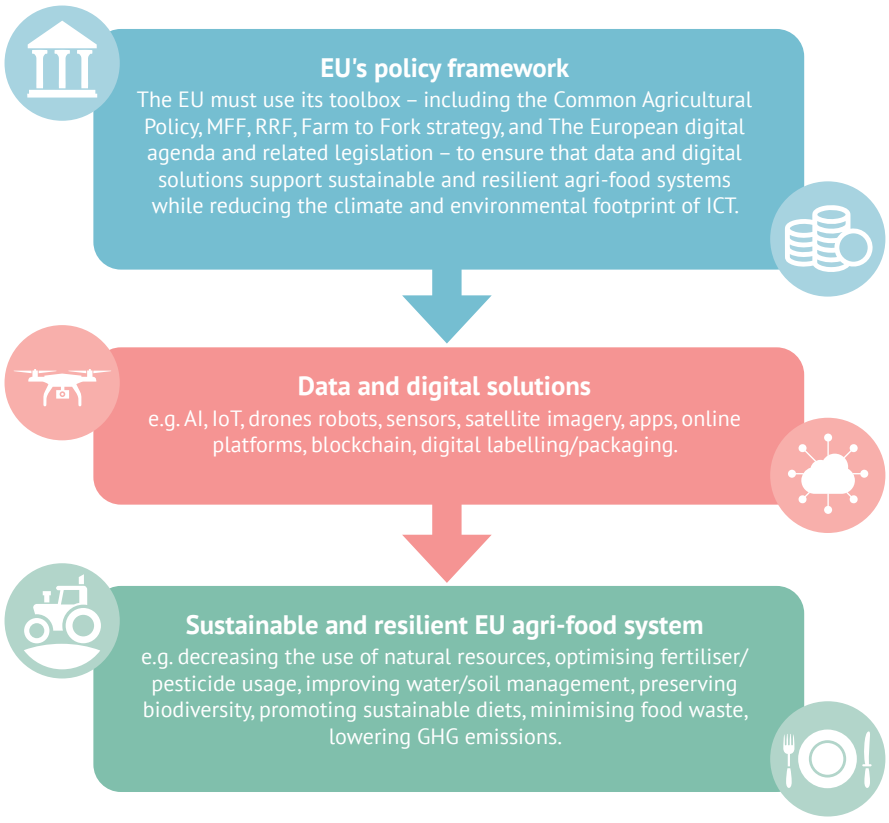
Data and digital solutions are already used to improve food systems from production and processing to consumption and carries the potential to enable transformation. For example, satellite imagery, sensors, AI, Internet of things (IoT), drones, and robots can support precision farming and ensure agricultural practices comply with environmental rules. At the same time, apps and platforms can be used to improve consumption patterns. However, the EU still needs to do more to optimise the use of data and digitally enabled solutions to make our agri-food system more sustainable, resilient, competitive, fair and inclusive (see Figure 1).

To fully align the agri-food sector with the twin green and digital transition, the EU must, in light of the new politico-institutional cycle, above all:

- **Demonstrate strong political vision and leadership** in implementing the existing rules and aligning the agri-food agenda with the Green Deal, with the help of data and digital solutions.
- **Establish a functional digital information system** for the sustainable agri-food sector, to help farmers, producers, retailers, consumers, and public authorities at the EU and national levels contribute to the Green Deal objectives.
- **Create a multistakeholder forum to discuss the twin transition in the agri-food sector** in an inclusive way, building on the outcomes of the Strategic Dialogue on the future of EU agriculture.
- **Use data governance and standards, and financial instruments** to speed up the deployment of digital solutions and the uptake of digital skills for sustainable agri-food system.
- **Take measures to counter the challenges** of digitalisation to the climate, environment, and society at large.

Figure 1

THE ROLE FOR DIGITALISATION FOR A SUSTAINABLE AND RESILIENT EU AGRI-FOOD SECTOR



1. Introduction

Our modern food system has evolved over the last decades moving towards more efficient farming practices. Furthermore, the current climate and ecological crises highlight the need to make our agri-food system more sustainable and lower its impact on land and resources. Moreover, the ongoing food and energy crises, further driven by the Russian invasion of Ukraine, demonstrates that more needs to be done to reduce strategic dependencies, develop resilient and reliable agri-food supply chains, and increase food security in Europe and beyond. As Ukraine is a major exporter of food, animal feed and fertilisers to Europe and the world, the war has crippled global food supply chains, which were already disrupted by the COVID-19 pandemic. Other regions of the world, namely in Asia and Africa, face food shortages which can result in malnutrition and famine. In 2023, around 345 million people are facing acute food insecurity worldwide – more than double compared to 2020.[1] As will be discussed further, digitalisation plays a crucial role in the transformation of the agri-food system, providing tools to optimise resource use and minimise environmental impact.

SUSTAINABILITY CHALLENGES IN THE AGRI-FOOD SECTOR

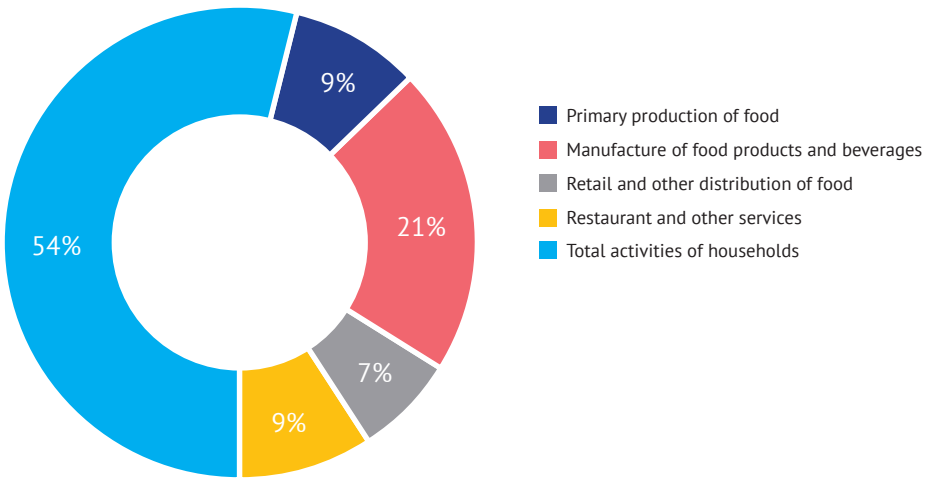
European agriculture has an enormous environmental and climate footprint and vice versa. Climate-induced extremes, soil degradation, biodiversity loss, and pollution undermine Europe's and global food security in the long run.[2] The European Environment Agency's 2024 Climate Risk Assessment highlights critical threats to crop production posed by heatwaves and droughts, with cascading effects impacting diverse ecosystems and biodiversity, leading to health consequences and causing unevenly distributed social and economic disruptions. It underscores the need to shift to sustainable diets and fully implement the Farm to Fork Strategy.[3] Furthermore, some agricultural practices have significant adverse effects on biodiversity,[4] and have caused around 10,5% of the EU's greenhouse gas (GHG) emissions.[5] The run-off nutrients from the sector also places significant pressure on the aquatic environment while more than 40% of freshwater in the European Union (EU) is used for farming.[6] In the EU, around 20% of food is lost or wasted along the entire value chain[7] while 30% of food is lost or wasted worldwide.[8]

In 2020, 58 million tonnes of food was wasted, with private households accounting for 54% and food production with 30% of this waste (see Graph 1). Furthermore, importing food from distant places may necessitate more energy for transportation, refrigeration, and storage, further exacerbating the environmental footprint of agri-food products.[9]

However, Europeans are witnessing a green backlash related *inter alia* to concerns that the new climate and environmental requirements would further increase the costs of agricultural production and undermine the livelihoods in rural communities. Farmers' protests in 2022-2024 were echoed by the rise of attitudes at the EU and member state level, which are sceptical of the green transition in the agri-food sector.[10] The ensuing Strategic Dialogue on the Future of EU Agriculture – comprising experts from a wider range of stakeholder groups - aimed to address the key challenges facing the agriculture sector and pave the way towards the Vision for Agriculture and Food envisaged in the first 100 days of the new European Commission.[11] At the same time, the green backlash was once again confirmed at the 2024 EU elections, which saw the rise of populist forces in the European Parliament and across member states,

Graph 1

FOOD WASTE GENERATED IN THE EU PER DESIGNATED SECTOR (2020)



Source: Eurostat

including France and Germany.[12] Consequently, the EU's climate and environmental objectives in the agri-food sector has been brought into question, which calls for novel ways, including the use of data and digital solutions, for the EU to respond to challenges brought by food crisis and ensure a just and fair green transition.

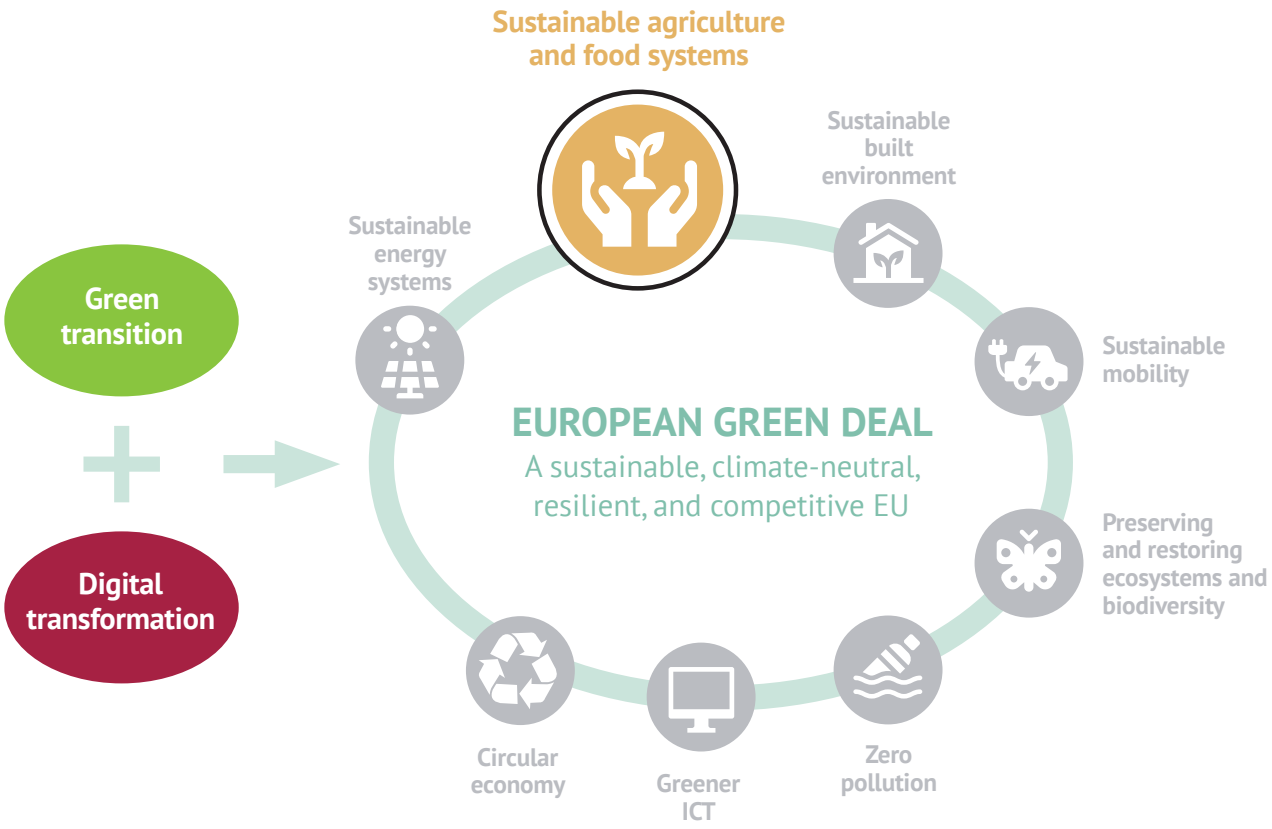
THE ROLE FOR DIGITALISATION

As recognised by the Report of the Strategic Dialogue on the Future of EU Agriculture, digitalisation can play an important role in enabling greater sustainability in the agri-food sector.[13] Data and digital solutions are already used to improve the whole food supply chain, from production to consumption, and arguably carry the potential towards the food system transformation towards greater sustainability and resilience.[14] Satellite imagery, sensors, AI, IoT, drones, and robot support precision farming,[15] data management and information sharing. They simplify working conditions and ensure compliance with environmental rules, while apps and platforms can improve consumption patterns and reduce food waste. At the same time, increasing amounts of data are generated in the different stages of agricultural production. For example, smart sensors and devices can be used to improve knowledge, provide predictive insights in farming operations, and help decide measures that can impact the whole food supply chain. Despite these promises, the EU still needs to do more to use data and digitally enabled solutions to make our agri-food system more sustainable and resilient.

Digitalisation could revolutionise agriculture and food systems if data and digital solutions are used to support a more sustainable agri-food model in accordance with the European Green Deal (see Figure 2). It would also help achieve the UN Sustainable Development Goals, especially Goal 2 Zero Hunger, Goal 12 Responsible Consumption and Production, Goal 13 Climate Action, and Goal 15 Life on Land.[16] Digitalisation in agri-food could boost productivity and efficiency, achieving more with fewer natural resources, limiting farmland expansion, and safeguarding biodiversity. This could provide significant environmental, societal, and economic benefits. However, digitalisation does not automatically lead to greater sustainability. Instead of just making traditional agricultural practices more productive, data and digital solutions should be used to drive a systemic change towards making our agri-food system more sustainable and resilient.

Figure 2

ALIGNING THE GREEN AND DIGITAL TRANSITIONS CAN SUPPORT SUSTAINABLE AND RESILIENT AGRI-FOOD SYSTEMS



SCOPE AND METHODOLOGY

This Discussion Paper explores the current practices, challenges, and prospects with using digitalisation to support a sustainable, competitive, fair and resilient agri-food system and how EU policies can provide an enabling framework for the future. It focuses on how information transfer could be improved so that the relevant stakeholders of the agri-food sector can contribute to a sustainable agri-food system. In this Discussion Paper, the terms 'agri-food sector,' 'agri-food system,' 'agri-food supply chain,' and 'agri-food value chain' are used interchangeably to refer to the entire agri-food supply chain, including farmers, food processors and retailers, crop consultants and advisors, consumers, and waste managers. In light of the recent farmers' protests and related green backlash, the paper gives particular attention to the twin transition in the farming sector; nonetheless other stages of the agri-food value chain are also addressed. The presumption is that a more sustainable agri-food system would also be a more resilient, inclusive, and competitive one in the long-term.

The Discussion Paper is based on the EPC's independent research conducted in 2023-2024 as part of the project 'Digitalisation for sustainable and sustainable agri-food system'. The research benefited from:

- A literature review of the relevant legislation, studies, and online information;
- Meetings and correspondence with the project's Steering Committee, including meetings held in September 2023, March 2024, and June 2024;
- Findings from two online EPC workshops and follow-up correspondence with relevant stakeholders. The first workshop (November 2023) investigated the role of digitalisation for sustainable and resilient farming, food production, and logistics while the second workshop (December 2023) focused on digital solutions for sustainable and resilient food consumption and waste management.[17]

The paper comprises an overview of how data and digital solutions can support the transition to sustainable agriculture, coupled with several case studies; the relevant EU policies for facilitating the use of digitalisation for sustainable and resilient agri-food system; and policy recommendations. The paper aims to provide valuable insights and support future policy developments and implementation in the agri-food sector, in light of the new EU institutional cycle.

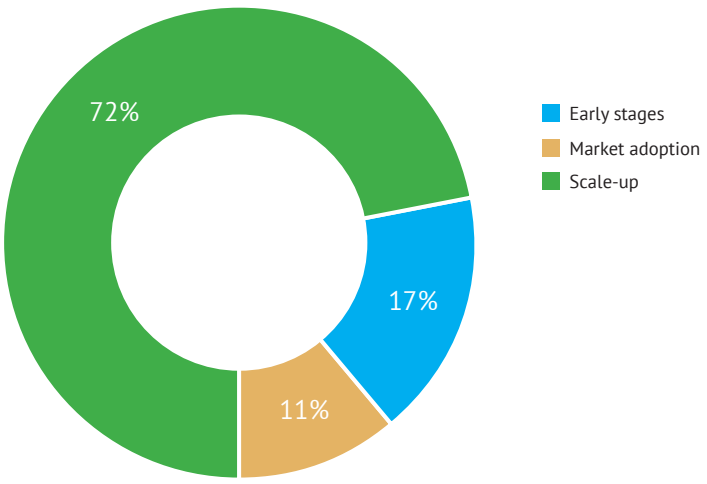
2. Overview of digital solutions

Digital solutions have already been widely used in the agri-food sector although a full inventory of numbers, applications and linkages with sustainability cannot be fully defined. The AgriTech Observatory,[18] established by FAO, lists 78 digital projects, which are mostly at scale up stage (Graph 2), although they are mainly focused on farming and they are not necessarily linked to sustainability (Graphs 3 and 4).

Moreover, in the agriculture sector alone, database SmartAgriHubs[19] identifies 28 Flagship Innovation Experiments[20] while database Aspexit[21] lists 1618 digital tools. The following sections provide a non-exhaustive overview of some of the existing and prospective digital solutions covering farm, supply chain, retail, and consumption management that contribute to the green agri-food transition.

Graph 2

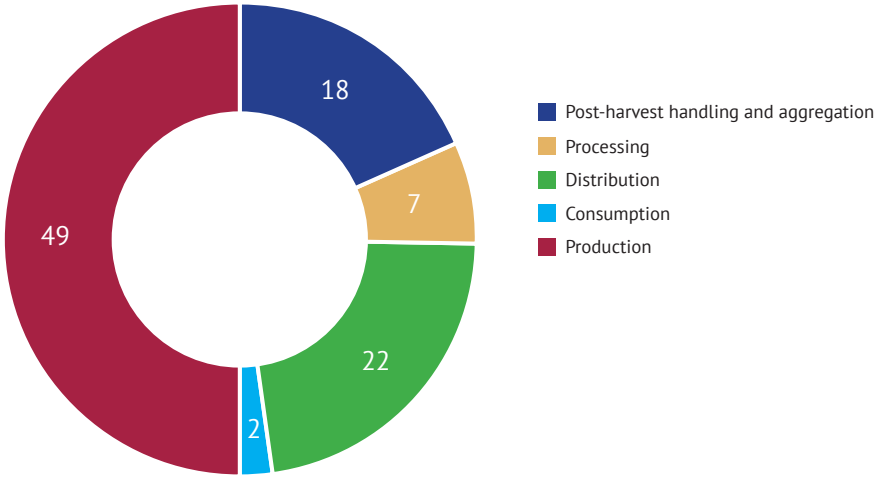
IMPLEMENTATION STAGE OF DIGITAL PROJECTS IN AGRI-FOOD



Source: The AgriTech Observatory

Graph 3

NUMBER OF DIGITAL PROJECTS APPLIED IN DIFFERENT STAGES OF THE AGRI-FOOD VALUE CHAIN



Source: The AgriTech Observatory
*Note: A project can be relevant for more than one stage

2.1. FARMING

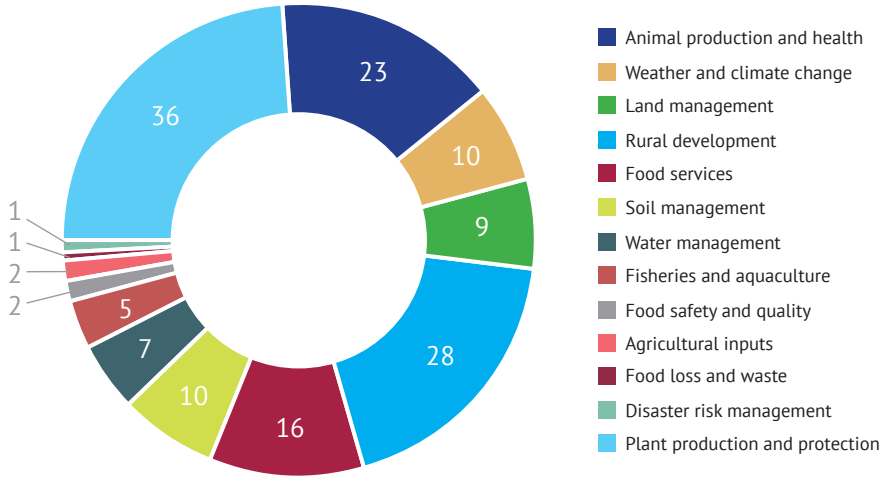
Data gathering, sharing, re-use and monitoring

Digitally-enabled data gathering, sharing, and processing can improve the monitoring of climate and environmental performance in agricultural production and assist in better decision-making.

Technologies such as AI, IoT, cloud computing, blockchain, big data, satellite/earth observation, camera imagery, smart sensors, robotics, drones, automation, and digital twins aid in gathering, sharing and management of data that can help advance the green transition in agriculture.[22] They collect vast amounts of data from croplands and farmers, providing real-time information to public authorities, farmers and other relevant stakeholders.[23]

Graph 4

NUMBER OF DIGITAL PROJECTS APPLIED PER EACH AGRI-FOOD THEME



Source: The AgriTech Observatory
*Note: A project can be relevant for more than one theme

EXAMPLES OF DIGITAL SOLUTIONS FOR DATA GATHERING, SHARING, RE-USE, AND MONITORING TODAY:

The NIVA project provides digital solutions to enhance sustainability, reduce administrative burdens, and promote the information-sharing in agriculture. It seeks to advance the role of the Integrated Administration and Control System (see Chapter 3) making use of ***digital solutions and developing harmonised data sets*** for agriculture performance monitoring, among others.

The DEMETER project brings ***interoperable smart farming-IoT based platforms***, following a farmer-driven and multi-actor approach ranging in the whole supply chain. Through advancing the adoption of IoT technologies, it enhances sustainable EU agri-food systems. DEMETER is applied to 25 deployment sites involving 6,000 farmers and over 38,000 devices and sensors being deployed.

GrainSense assists in real-data collection and processing from the field. Grain samples are inserted into ***a near-infrared device***, and then sample information on moisture and proteins, among others, is sent to a ***mobile app***, which analyses the results. It leads to better farming practices, resource efficiency, and less pollution.

Today/Tomorrow: The Hand-in-Hand Initiative, by FAO, focuses on driving market-based agrifood system transformations in nations with severe poverty, hunger, or limited resources. Using ***advanced geospatial modeling, analytics, and partnerships***, it aims to boost incomes, nutrition, and resilience to climate change through measures like value chain development, digital services, precision farming, and climate adaptation strategies, prioritising areas most in need.

Today/Tomorrow: The Digital Villages Initiative (DVI) by FAO aims to transform European and Central Asia's rural areas into ***digitally connected hubs***, fostering smarter and greener communities. Through inclusive and participatory approaches, DVI empowers villages to utilise digital technologies for increased agricultural productivity and access to services, enhancing rural livelihoods.

TOMORROW:

The FaST digital service platform aims to become a world-pioneer ***online platform*** for generation and re-use of digital solutions (machine learning, IoT data etc.) for sustainable and resilient agriculture practices. It makes use of ***space data*** such as Copernicus and Galileo data as well as public data and data from private datasets.

The Data4Food2030 project aims to foster fair data sharing among agri-food companies, promoting inclusivity, sustainability, and competitiveness. Through ***knowledge expansion and technological advancements, recommendations on data economy policies***, and a ***roadmap for establishing a data space***, it seeks to create solutions for monitoring and evaluating the development and impact of the data economy for food systems.

PATH2DEA aims to connect existing digital tools, traditional farming knowledge, and scientific expertise to catalyse a transition towards more sustainable farming practices, emphasising the importance of agroecological principles. Through ***socio-economic research and collaboration with showcase farms***, it seeks to foster responsible innovation and build ***a network of stakeholders*** in digital agroecology. Path2DEA is also developing an Open Source Repository of digital tools and technologies in agroecology with decision support functions and a R&I Roadmap to guide the transition to digital agroecology. Such repository could be linked to apps such as SynApps (see below) and facilitate more sustainable practices on the farm.

Precision farming

Precision farming emerges as a promising solution to address some of the sustainability challenges in agricultural production.[24] Data gathering, sharing, and monitoring are essential components of precision farming and other decision support systems.

Tools such as remote sensing,[25] GPS technology, and unmanned aerial vehicles (UAVs) facilitate crop monitoring, including crop health, growth, nutrient deficiency, and diseases. Automatic pesticide and fertiliser sprayers, applied by drones and autonomous vehicles, can help reduce the amount of these substances in the field and reduce the negative impact of farming on the environment. Smart irrigation systems[27] can detect moisture stress, reduce water and energy use, and control weed-related implications.[27]

2.2. SUPPLY CHAIN MANAGEMENT

Food processing and logistics

Digital innovations in post-harvest processes have the potential to reduce food waste and losses, thereby improving environmental sustainability, and enhancing food safety and product quality.[28] Digital solutions offer innovative approaches to enhance resource efficiency and reduce food waste and losses across the supply chain. Blockchain technology offers tracking tools for the agrifood sector, ensuring data integrity, transparency, and traceability. It verifies sustainability claims, connects small-scale farmers to each other and with consumers, bypassing intermediaries, and fostering direct connections.[29]

EXAMPLES OF DIGITAL SOLUTIONS FOR PRECISION FARMING TODAY:

Tellspec provides portable ***AI-powered sensors*** for rapid analysis of diverse samples, including dairy, oils, fruits, and other agricultural products. Their ***Data Collection and Management Software*** and their ***AI-platform*** facilitates easy machine learning model development from ***spectral data***. Sensors aid in real-time monitoring to counter fraud and contamination. Tellspec also provides ***Blockchain tools*** for product traceability and authenticity, ensuring immutable and auditable results, and an ***advanced AI-based cloud spectroscopy***. Based on real data, farmers better assess the value of their food products, which could help them determine a better price when negotiating with the distributors.

SynApps is a decision-support app for using biosolutions on crops. Using an algorithm, the tool provides access to information on nature-based products solutions on the market as alternatives to chemical products, considering the size of the farm, its constraints, and its objectives throughout the crop cycle. It enables farmers to make quick, informed decisions and perform data analytics to make their agricultural practices more sustainable (e.g. organic farming, reducing the usage of pesticides).

Libelium offers ***sensor technology*** and a ***IoT-based platform*** to improve farmers' productivity by enabling observation, measurement, and response to environmental conditions, diseases, and pests. This technology minimises pesticide, fertiliser, and water usage while increasing yields.

TOMORROW:

GALIRUMI project developed ***robots*** for removing weeds without the use of herbicides for application in dairy farming. Based on ***precise navigation*** provided by the European Global Navigation Satellite System, the robots locate and remove the weeds from the fields using computer vision. Naïo Technologies has also developed ***weed-killing robots*** that reduce the amounts of herbicides and other weed control products added to the soil.

The AgriDataValue project develops a ***multi-technology platform*** to enhance the agri-environmental monitoring and tackle challenges such as overirrigation and excessive use of pesticides and fertilisers. Utilising ***IoT sensors, drones, and Copernicus Hubs data***, it seeks to enhance competitiveness, fair income for farmers, and sustainability following a multidimensional approach, incorporating big data, agricultural expertise, new business models, and agri-environmental policies.

The QuantiFarm Project aims to increase the adoption Digital Agriculture Technology Solutions (DATS) in Europe offering capacity-building for farmers and advisors. It aims to provide an Assessment Framework, measuring DATS impacts, costs, and benefits, through ***participatory research and test cases in real farm conditions***.

AgriGuide, formerly known as Digital Label Compliance, is a multi-stakeholder initiative developed by CropLife Europe, which aims to apply a ***digital twin*** to help farmers with their record keeping and reduce the administrative burden. AgriGuide will provide easy access to regulatory compliant labels and help farmers with optimised use of their inputs, as well as enabling machine reading of labels and record keeping.

EXAMPLES OF DIGITAL SOLUTIONS FOR FOOD PROCESSING AND LOGISTICS - TODAY:

Alpro applies ***blockchain technology*** for better supply chain management. It enhances the freshness of their products and reduces food waste by better monitoring data (safety stocks calculations, lead time for raw materials etc.). Similarly, SAP utilising ***IoT farm management solutions (blockchain technology)*** creates more transparent and sustainable food supply chains.

Food Care Plus is developing a ***blockchain*** for food systems, enabling the tracking and monitoring of food products throughout a supply chain. By receiving ***real-time data*** on food products, such as outdoor temperature during food transportation, enhances food quality and security while saving energy and resources.

The Auchan French food retail group applies ***RFID technology*** to track plastic crates for reverse logistics. Reusing plastic RFID containers leads to crate loss reduction and saves tonnes of waste, resulting in a 30% decrease in carbon emissions according to their estimations. Similarly, Pack and Sea uses ***RFID*** to track fishing crates and their contents with the participation of 10 Danish harbours, thus reducing crate loss and enhancing their optimal usage.

Nestlé's factory in Juuka, Finland, supported by Siemens's digital technology utilised ***Industrial Internet of Things*** to collect, assess and use of large amounts of data leading to real-time transparency and minimising resource consumption in the factory.

Zest Labs provides ***blockchain digital solutions*** for post-harvest food quality, freshness, and traceability, thereby reducing food waste. Zest Labs determines the freshness of products using IoT sensors and it offers supply chain visibility through real-time web-based dashboards and event-driven notifications.

AgShift uses ***artificial intelligence*** to provide accurate assessments of the quality and freshness of products, enhancing the supply chain, and reducing food waste.

EXAMPLES OF DIGITAL SOLUTIONS FOR SMART PACKAGING AND LABELLING TODAY:

Innocentia, a Swedish startup, in collaboration with Canadian company Ynvisible have produced a ***prototype for shelf-life labeling***. This innovation monitors the gases present within meat packaging to assess the freshness of the product. They have been also working on a colour-changing label that would visually indicate the freshness of the product both in-store and at home, depending on the label's colour.

The TagitSmart project developed ***dynamically changed QR codes and barcodes*** according to context changes of the product to trace food products throughout the supply chain.

Timestrip is an UK company that has created ***smart indicator labels*** that help monitor changes in time and temperature during the transportation and storage of the products, indicating their freshness and security.

The SISTERS project aims to reduce food loss and waste by 27.4% and CO_2 emissions by 20% through various measures. These include developing ***a consumer labeling scheme***, assessing ***eco-friendly packaging materials, sensor-equipped containers*** for monitoring food quality and safety in its transportation, and creating a short chain ***platform app*** for direct sales from producers to consumers.

TOMORROW:

The WASTELESS project aims to reduce food losses and waste (FLW) by measuring ***FLW in critical food supply chains*** and developing ***personalised digital tools*** for stakeholders across the EU. Technical innovations include ***blockchain and AI-driven data analysis***.

The MICROORC project develops ***microbiome-based technologies*** to minimise food waste and enhance food quality and shelf-life. It focuses on ***predictive analytics, sensoring and smart labelling***.

Smart packaging and labelling

Smart packaging and labelling systems provide real-time information about product quality during the transportation and storage, monitoring both conditions internally into packages and external events. These technologies can include biosensors or chemical sensors[30] that measure temperature, pH, and pathogens, and communicate that information via QR codes and barcodes.[31] Such information can help reduce food waste and losses and improve food safety.

2.3. RETAIL AND CONSUMPTION

Smart fridges and bins

Smart fridges incorporate cameras inside the fridges to track the products using product recognition technology, sensors, IoT, and WiFi.[32] Consequently, an app, based on the received pictures, can list available products based on expiration dates and best-before dates, suggest shopping lists and recommended recipes, utilising the available ingredients.[33]

Smart bins, backed by IoT technology and AI, can help inform food service providers about the quantity and types of food waste they generate, with the goal of encouraging behaviour change to reduce food waste and associated costs.[34]

EXAMPLES OF DIGITAL SOLUTIONS FOR SMART FRIDGES AND BINS TODAY:

Samsung Family Hub, LG ThinQ Fridge technology, and Haier Smart Fridge are examples that apply ***AI, IoT, and Wifi*** in combination with ***smartphone applications***. They permit remote control, track of food products and expiration dates of certain products as well as provide additional advises such as shop planning, recipes etc.

KITRO (likewise LeanPath and Winnow) offers a waste management solution for the hospitality sector. Through innovative ***AI technology***, businesses can accurately measure and minimise food waste. By placing their existing bins on ***Kitchen Chair scales***, which distinguish between various waste types, establishments can efficiently track and analyse waste data. This data is seamlessly processed by KITRO's ***software, utilising machine learning algorithms*** to identify disposed items, empowering businesses to make informed decisions for cost savings and waste reduction.

Consumer behaviour applications

Smartphone applications can help consumers follow sustainable diets. Food managing and reminder apps help users keep track of product expiration dates, manage shopping lists, and they provide recipes based on available products and their expiration dates. Some apps also offer information on products' carbon footprint.

Emerging platforms such as food-sharing or food waste-reducing platforms facilitate surplus food redistribution among retailers, restaurants, stores, charities, and consumers.[35] Online platforms can also enable direct marketing and sales of farm products to end consumers where farmers can customise the supply based on customers' preferences (e.g. type of food, delivery time).[36] This can help shorten the supply chains which can reduce food losses and unnecessary packaging along the supply chain while potentially increasing farmers' income.

2.4. CHALLENGES TO SCALING UP DIGITAL SOLUTIONS

As shown by these examples, there are significant prospects with using digitalisation to support sustainability across the agri-food supply chain. Nonetheless, these solutions are yet to be scaled up to reach their maximum potential. Some of the crucial challenges with using data and digital solutions are listed below:

Data governance

Concerns over protection of personal and business-sensitive data hinder data sharing, especially in agriculture. Now data is shared either as open access or under private data sharing.[37] Farmers, digital companies, public authorities, distributors, and consumers share data via sensors, earth, and aerial observation. Nonetheless, farmers and consumers can be reluctant to share their data due to concerns over the purpose of data collection.[38] This data is hard to acquire and use. Farmers' willingness to provide data can be constrained due to worries over how it will be used and the propensity of public agencies that collect, process, and store agriculture-related data.

Concerns over protection of personal and business-sensitive data hinders data sharing, especially in agriculture.

When earth observation technology, for example, is unable to provide data on the quantities of pesticides and fertilisers used, and quantities and types of livestock available, this information needs to be obtained from farmers or national authorities directly. Access to data can also be limited, conditional, or prohibited, due to a lack of interoperability between fragmented data sets[39] or concerns over the personal and business-sensitive data contained in public databases.[40] Studies looking for such data, such as in the H2020 project RELACS, reveal that data on agricultural inputs are sometimes inexistent leaving only estimations through experts, advisors, and farmers associations.[41] In the case of small-scale farms, it can be difficult to distinguish farmers' private and business data, thus complicating data privacy considerations. Moreover, access to data from public authorities as well as private actors is dependent on national or subnational rules.

Digital technologies may be subject to cyberattacks as part of a clandestine warfare amidst rising geopolitical tensions. Sabotage attacks could be aimed at disrupting agri-food systems and supply chains, causing economic and food security harms. This contributes to mistrust and unwillingness on behalf of farmers and other agri-food actors in sharing their data.[42]

EXAMPLES OF DIGITAL SOLUTIONS FOR CONSUMER BEHAVIOUR APPLICATIONS TODAY:

TooGoodToGo (similarly SIRPLUS and Food Cloud) creates ***a digital marketplace*** from various businesses across the food supply chain to combat food waste from surplus food. Consumers can purchase surprise bags of surplus food through the app, helping to reduce waste and greenhouse gas emissions.

Farmdrop (similarly CrowdFarming, Farmy, and Mandi.trade) ***platform*** shortens supply chains by connecting consumers directly with local farmers and consumers.

Belgian ***platform*** eFarmz provides a platform for buying bio-products, while the ***app*** Lowco maps local and low-carbon artisanal producers.

NoWaste and Love Food Hate Waste ***apps*** assist users in managing their food inventory and reducing waste. It sorts items by expiration date, name, or category and suggests recipes based on users' available ingredients.

FridgeSort, ***a serious mobile game***, where the gamers' goal is to organise their virtual fridge in a sustainable way. It aims to educate the users how to organise their real-world fridge to minimise household food waste.

Wasteless helps grocery stores set product prices according to expiration dates and perishable items ***using AI-driven real-time data***. It aims to reduce food waste by providing price incentives to consumers to choose products closer to expiration.

Large multinational companies, including software firms and machinery manufacturers, are driving digital technologies in the agri-food sector. Consequently, they control these developments and frequently own the data. Farmers' risk of technological lock-in, requiring continuous maintenance and updates could foster dependencies and intensive resource consumption. This can raise mistrust among farmers and reluctance to share data with digital technology companies. Moreover, farmers' perception that data sharing would harm them, considering the 'polluter pays' principle, fuels mistrust between them and public authorities. Therefore, ensuring legislative security and providing the right financial or other incentives becomes essential to facilitate a swift in attitude on both sides and improve the sharing of data and information.

The complexities of accessing data or reluctance of farmers and public authorities in charge of sharing data with other farmers, public authorities, or companies can undermine sustainability goals. As a result, environmental authorities cannot always access relevant data to evaluate the state of play or design measures for climate action, nature protection, and water management. It hinders farmers' access to valuable information on good practices elsewhere. Moreover, it undermines researchers' and innovators' ability to develop new sustainable solutions. Despite these challenges, projects like Agriguide, DIVINE, and Data4Food2030 (see section 2.1) aim to address the barriers to data sharing in the agri-food sector. Furthermore, EU policies on data governance (e.g. Data Governance Act, Data Act) are being developed to enable information transfer, including in the agri-food sector (see Chapter 3).

Digital literacy and convenience of using digital tools

Not all stakeholders in the agri-food sector have the same level of digital literacy, with some not having sufficient base knowledge. Less than half of rural residents possess basic digital skills.[43] This discrepancy varies across regions and generations, with younger generations typically processing better digital education and skills. However, one-third of farmers are above 55 years old and young people under 35 constitute 6.9% of the workforce.[44] Rural areas in the EU tend to have a lower proportion of individuals with higher education compared to urban areas, potentially exacerbating the problem.[45] Limited or non-existent digital education results in some farmers being unable to effectively utilise new digital smart farming technologies or, worse, misusing them. This improper use of digital tools and misinterpretation of data can lead to erroneous decisions and practices that may worsen crop productivity, quality, and environmental footprint rather than improve them. Furthermore, the scarcity of statistics concerning farmers' digital literacy in the EU presents a significant challenge in finding effective solutions to the issue.

In response, the EU has been funding several projects aiming to increase farmers' access and training to digital solutions under Horizon 2020 and Horizon Europe such as the QuantiFarm, SmartAgriHubs, CODECS, DEMETER, Path2dea, and Farmtopia projects. According to the recent Path2DEA project findings, farmers associations, advisors, and peers are key facilitators for farmers to adopt digital solutions by providing necessary knowledge, training, and trust.[46]

Not all stakeholders in the agri-food sector have the same level of digital literacy, with some not having sufficient base knowledge.

Consumers can also lack skills and understanding of how to use digital tools effectively.[47] Changing consumer behaviour poses a significant challenge, as it is influenced not only by personal beliefs but also by social and cultural norms. Many consumers underestimate their food waste and harbour scepticism about the benefits of waste reduction technologies, questioning whether it is worth investing time and money in using these apps.[48] Furthermore, consumers might be reluctant to share their data due to privacy concerns about its usage, such as being charged based on waste volume or for not correctly following recycling rules. Additionally, studies examining the efficacy of consumer apps in reducing food waste often reveal limited tangible reductions, underscoring the necessity for enhancing app design and functionality.[49] There is a need to enhance the user-friendliness of food sharing and distribution apps by providing regular updates and aligning designs with consumer preferences. For example, dependency on manual data entry by users for apps tracking food expiration dates may reduce incentives for consumer engagement.[50]

Limited access to data and digital solutions

Rural areas still lack access to adequate information and communications technology (ICT) infrastructure, including basic internet coverage as well as high-speed connectivity such as 5G.[51] Only 60% of EU rural households have access to high-speed internet, while the EU's average is 86%.[52]

Drones, robots, and unmanned ground vehicles can be expensive for farming and food processing. Also costly are electrochemical sensors in smart packaging (e.g. E-Tongues and E-Noses) and smart bins for food waste disposal.[53] In case of drones, national and regional zoning permits can limit their wide scale application in agriculture.

Given the high costs connected with digital agriculture technology, diverse business strategies, and investment capacities, there appear to be discrepancies among farmers.[54] While these technologies may be cost-effective for large farms, small-scale farmers often struggle to adopt them.[55] Gender inequalities can also hamper access

to digital technologies, as women face systemic barriers in accessing training and adopting digital technologies critical for modernising our agri-food systems. Initiatives like the PROFEA Project, funded under NextGenerationEU, aim to address these challenges.[56]

Lack of interoperability between different databases and information systems hampers information transfer across the agri-food value chain. Consequently, data remains fragmented and farmers, producers, retailers, consumers, and public authorities cannot utilise data to make more sustainable decisions nor utilise data-driven tools such as AI to optimise their activities.

As indicated in sections 2.1 and 2.2 projects like DEMETER, Path2DEA, Food Care Plus, KITRO, and Tellspec, help increase access to digital solutions. Some of these projects are financed by the EU. As will be elaborated in Chapter 3, the EU is trying to create an enabling policy framework to help improve access to digital solutions, such as the creation of common data spaces.

Unintended side-effects of digitalisation

Despite the prospects of using digitalisation to support a sustainable and resilient agri-food sector, it is important to consider the potential adverse effects resulting from digital transformation.[57] It is paramount that digitalisation be seen not as the goal but as a tool to foster sustainable agri-food system.

It is important to consider the potential adverse effects resulting from digital transformation.

The ICT sector currently accounts for significant shares of electricity consumption and GHG emissions.[58] Data centres are one of the most important individual digital sources of GHG emissions. While data centres already use significant amounts of renewable energy,[59] making them sustainable would greatly impact the greening of ICT. In additional, further uptake of AI and blockchain can increase energy consumption.

ICT equipment is often made of critical materials and precious metals, as well as iron and aluminium. Mining, material processing, and product manufacturing contribute to GHG emissions, pollution, water stress, and biodiversity loss.

Computers, smartphones and other electronic devices eventually become e-waste. This is currently one of the fastest-growing waste streams because of multiple device ownership, the growth of cloud computing services, and short product lifespans and replacement cycles.[60] Some digital solutions like smart packaging might exacerbate waste issues due to recycling challenges.[61]

Data obtained by the farmers can be used by big agri-businesses and technology companies to offer advice to farmers or develop solutions that support intensive farming and disregard sustainability aspects.[62] Moreover, AI algorithms could lead to wrong decisions, such as overusing water, pesticides, and fertilisers.[63] As AI algorithms provide information based on existing and previous datasets, they may not be able to always provide best solutions when food producers face new challenges brought by global warming and biodiversity loss. The AI may instead offer solutions not adjusted to local circumstances and traditions and disincentivise farmers to think outside of the box when trying to adapt to climate change and make their farming practices more diverse and sustainable.

Although digital solutions are being used in the agri-food sector (see sections 2.1 and 2.2), their full uptake by farmers, businesses, and consumers are still hampered by aforementioned challenges. This situation calls for an enabling EU policy framework to facilitate the development and uptake of digital solutions for a sustainable agri-food system (to be discussed in Chapter 3).

3. Policy framework

3.1. COMMON AGRICULTURAL POLICY AND OTHER FINANCIAL TOOLS

Common agricultural policy

The EU's approach to agriculture revolves around the Common Agricultural Policy (CAP), which provides subsidies in the form of 'direct payments' for farmers and other financial support for farmers and rural development in the EU. The exact architecture of CAP financing is specified under every seven-year Multiannual Financial Framework (MFF).[64]

CAP and its €387 billion budget[65] will support farmers and rural development in 2023-2027. CAP 2023-2027 envisages a shift from a compliance base to performance. Previous top-down, 'one size fits all' structure is replaced with a more flexible approach, which gives national authorities a greater say on measures to be taken via their CAP Strategic Plans. Each member state has Farm Advisory Services (FAS) to support farmers in meeting the CAP requirements and to modernise their businesses. FAS has a major role to play in educating the farmers, sharing good practices, and explaining EU's agri-ecological requirements. It could thus play a major role in empowering the farmers to take

up digital tools and overcome some of the challenges concerning access to digital solutions (see section 2.3). Support under FAS is coupled by additional support provided by Agriculture Knowledge Information System (AKIS), LEADER approach, and European Innovation Partnerships connecting farmers, researches, and other agri-food businesses.

The CAP 2023-2027 refers to both digitalisation and specific environmental and climate conditions for receiving funding from CAP. [66] The extent to which digitalisation is geared to achieving the environmental and climate objectives is questionable. Under the CAP regulatory framework, digitalisation is a separate cross-cutting objective which, according to the ECA, "leaves the indicators linked to this objective outside the scope of performance clearance and multiannual performance review."[67] If digitalisation was considered together with the environmental and climate objectives, it would lower the risk of digital tools being deployed without any consideration for sustainability. The latest report on CAP implementation in the member states reveals that digitalisation of agriculture has been limited and its linkage with sustainability rather sporadic, mostly in the form of precision farming.[68] CAP support to strengthen farmers' digital skills (e.g. with the help of FAS, AKIS) also appears to be rather limited.[69]

The latest report on CAP implementation in the member states reveals that digitalisation of agriculture has been limited and its linkage with sustainability rather sporadic, mostly in the form of precision farming.

Lastly, it should be noted that the role of digital solutions to advance the green agri-food transition can be hampered by the lack of sustainability ambitions of CAP. In response to the Russian invasion and subsequent green backlash, the Commission removed the requirement to keep 4% of the fallow land in the EU uncultivated.[70] Even under original framework, CAP is still not fully aligned with the EU Biodiversity Strategy[71] while CAP subsidies can be used to support industrial livestock farming despite its major climate, environmental, and health impacts.[72] If pre-agreed rules are not followed through and if the CAP fails to be fully aligned with the Green Deal objectives, there is a risk that investments in digitalisation for sustainable agri-food system could become irrelevant.

Financing under other MFF instruments

There are ongoing EU efforts to support the use of digital solutions for data sharing under the CAP framework. For example, the Farm Sustainability Tool (FaST), is a digital service platform that provides space data and other public and private data on agriculture, the environment, and sustainability to EU farmers, member state paying agencies, farm advisors, and developers of digital solutions. Data will be used for generation and use/re-use of digital agri-food solutions and a mobile app will facilitate access to related data. It is supported by the European Commission's DG Agriculture and Rural Development, the EU Space Programme (DG DEFIS), and the EU ISA2 Programme (DG DIGIT). FAST is currently being implemented across different member states and regions. As mentioned in section 2.1, Castilla y Leon has developed Sativum, an app available for phones and desktops, to provide advice on best farming practices.[73] One limitation of FAST, however, is the lack of binding requirements for farmers to share the data that cannot be acquired via earth or aerial observation, such as the types and amounts of pesticides and fertilisers used on a farm.

The EU finances digital agri-food projects under formerly Horizon 2020, now Horizon Europe as well as Digital Europe programmes. Under Horizon 2020, over €200 million were allocated for research and innovation projects developing digital tools in the agri-food sector although not all of them are related to the green transition.[74] Some of the projects financed by Horizon 2020 and linked to the green transition were outlined in sections 2.1 and 2.2. EU's Digital Europe and Horizon Europe programmes support a number of initiatives to help develop and deploy digital solutions for sustainable agri-food. Digital Europe is used especially to help develop Common Data Spaces, including the one on agriculture (see section 3.5). Under Horizon Europe a dedicated partnership 'Agriculture of Data' (AgData) aims to support research and innovation regarding sustainable agricultural production, monitoring, and evaluation with the help of data and digital solutions.[75] The Commission together with co-funding from member states is planning to allocate around €300 million over 7 years.

The EU has put forth a number of initiatives that could help overcome the challenges of digital illiteracy and access to digital solutions.

The EU has put forth a number of initiatives that could help overcome the challenges of digital illiteracy and access to digital solutions (see section 2.3). The EU's Regional Recovery Facility and Cohesion funds supported investments in digital infrastructure in Europe, including in rural areas. Digital Europe and Horizon Europe support pilot projects while Digital Europe supports the development of digital solutions in agri-food such as common data spaces.

EU's Digital Innovation Hubs (DIH)[76] is an initiative backed by Digital Europe coupled with national and regional funds. The aim is to advance digital transformation across the EU in collaboration with businesses, experts and public authorities. Some of the projects being funded include support to digitalisation in the agri-food sector. However, linkages between environmental goals and digital skills in DIH projects appear to be rather sporadic.[77]

Likewise, the EU's Digital Skills Agenda,[78] offers opportunities for Europeans to improve their digital skills. It is backed by multiple financial instruments, such as the European Social Fund+. However, these initiatives do not make direct linkages neither to agri-food sector nor sustainability. There is no obvious connection between initiatives on digital skills and institutions such as the farm advisory system nor consumer organisations.

Private financing

Besides EU funds, it is worth recognising the prospects of using private investments for the twin green and digital transition in the agri-food sector. As recognised by the Letta report,[79] the EU's public investment will likely fall short of achieving the green transition. The Report suggests doubling the effort to create a Savings and Investments Union (building on the previous initiative on Capital Markets Union) and facilitate private investments also in the green and digital transition. This initiative is anticipated to gain significant momentum in the EU's new institutional cycle as underscored by the Strategic Agenda 2024-2029 and Political Guidelines for the next European Commission.[80] EU's sustainable finance agenda envisages rules to include sustainability-related concerns into the decision making within the financial sector. However, the Savings and Investments Union is still work in progress while the EU's sustainable finance agenda remains to be implemented and its effectiveness needs to be assessed.

Besides EU funds, it is worth recognising the prospects of using private investments for the twin green and digital transition in the agri-food sector.

3.2. DIGITAL TOOLS FOR MONITORING COMPLIANCE AND ENFORCING ENVIRONMENTAL RULES

Monitoring of CAP implementation and performance

Member state authorities, known as the 'paying agencies', administer financial support and ensure that CAP rules, including environmental conditionalities for receiving subsidies, are respected by farmers, as part of the integrated audit and control system (IACS). Building on the data collected from farmers and managed within the IACS, member states report on their respective CAP-related measures to the Commission.

Traditionally, paying agencies have conducted field investigations on farmers' activities by doing on-the-spot checks on a limited number of farms (checks-by-monitoring approach). This system was notorious for its rigidity, administrative complexity, and lack of accuracy. It has also made it more difficult to ensure that the use of CAP funds follows environmental and climate rules.

The area monitoring system was introduced as a mandatory approach with the new CAP 2023-2027, building on the previous checks-by-monitoring approach. The new system benefits from the application of Earth observation (via e.g. satellites) coupled with drones and geotagged photos (provided e.g. by farmers). As of 2017, satellites Sentinel-1 and Sentinel-2, managed by Copernicus, provide free access to high-resolution and -frequency images. As of 2018, imagery from the Sentinel satellites can be used as evidence when checking farmers' compliance with CAP requirements, thereby reducing the need for on-site checks significantly.[81] Satellite images already feed into the Land Parcel Identification System (LPIS), which is a key component of IACS and managed by paying agencies.

The area monitoring system provide the possibility for continuous and comprehensive monitoring of agricultural parcels. By sending early warnings to farmers based on the new monitoring of parcels, paying agencies can help farmers meet their commitments, instead of penalising them.[82] Improved monitoring of the performance of farmers' activities could help them achieve climate and environment objectives. Nonetheless, work remains to be done and paying agencies still need to streamline the area monitoring system to determine farmers' environmental and climate performance.

Interoperability and information sharing

Creating an efficient data sharing system for public authorities at the EU and member state levels requires much work. Different databases for agriculture, such as Land Parcel Identification System, Farm Accountancy Data Network,[83] Commission's Agri-Food Data portal and the environmental sectors, such as Copernicus Climate Data Store, Water Information System for Europe, Biodiversity Information system for Europe, and Climate-ADAPT, already exist. However, they are not yet adequately

interconnected, neither to one another nor to national databases or the EU common data space for agriculture which is currently being developed (see section 3.5).

Different databases for agriculture already exist. However, they are not yet adequately interconnected.

The challenge appears to be recognised as the work has started to improve relevant stakeholders' access to agriculture-related data of relevance for sustainability. For example, the NIVA project aims to modernise IACS by *inter alia* making efficient use of digitally-enabled solutions and harmonised data sets for monitoring agricultural performance. NIVA is exploring how to increase the interoperability between IACS databases and make data accessible to various users via specific contracts between farmers and data collectors, or by making data anonymous. The project was initiated by paying agencies from nine member states.

This said, the work is ongoing and prospects are promising. European satellite observation and navigation infrastructure (e.g. Copernicus, the European Geostationary Navigation Overlay Service) will undoubtedly play a growing role in CAP monitoring as the technology further advances. To improve the performance of remote sensing, several projects have been developed under H2020, national and regional programmes, and in cooperation with private companies.[84] These projects can provide solutions based on a mix of high-resolution satellite imagery and on-site sensory equipment (e.g. Advanced Platform for Intelligence Inspections, RECAP, gaiasense, the project on a 'New IACS Vision in Action' or NIVA, the Sentinels for Common Agricultural Policy, EO4AGRI). Under the new CAP rules aiming to respect subsidiarity, several of these projects on data sharing remain the responsibility of member states, so a forum at the EU level could foster, animate, and further coordinate these necessary developments.

Soil monitoring law

The Commission has proposed the Soil Monitoring and Resilience (Soil Monitoring Law)[85] as part of the EU soil strategy for 2030. The proposed law aims to establish a comprehensive soil monitoring framework to strengthen food health quality, resilience, security, and pest control. This proposal aligns with CAP's regulations regarding environmental performance. CAP Strategic Plans for 2023-2027, include commitments for soil management and quality that would be applied to half of the EU's used agricultural area. Under the proposed law, a digital soil health data portal establishes better soil management and monitoring. Existing space-based data from Copernicus regarding soil remote sensing would be utilised to support member states' efforts.

3.3. FARM TO FORK STRATEGY AND RELATED LEGISLATION

Farm to fork strategy

It is widely recognised that the CAP, focused primarily on production, is limited in its approach to making an entire agri-food value chain more sustainable. As such, a more comprehensive sustainable food system is needed. The Commission's Farm to Fork Strategy, published in May 2020, provides an additional push to adopt more holistic thinking, including the demand side of the agri-food value chain. The Farm to Fork Strategy calls for improving sustainability across food's supply chain, including production, marketing, labelling, and waste reduction. Moreover, it recognises even more clearly the link between digitalisation and achieving climate and environmental goals. As will be discussed further, the question is to what extent Farm to Fork can actually drive the use of digitalisation for sustainable agri-food.

Sustainable food system law

Farm to Fork Strategy envisaged a Sustainable Food System law that would streamline sustainability in all food-related policies.[86] This could be an opportunity to approach digitalisation for sustainable agri-food systematically. However, in the light of ongoing green backlash in the agri-food sector (see the Introduction), this legislative initiative was put on hold.[87] Therefore, it is difficult to discuss the role of digitalisation while the entire sustainability vision of the strategy is being disputed.

It is difficult to discuss the role of digitalisation in greening the agri-food system while the entire sustainability vision of the Farm to Fork Strategy is being disputed.

For a similar reason, the Commission's proposal for a regulation on the sustainable use of pesticides was scrapped by the Parliament and withdrawn by the Commission. The proposal recognised the importance of digitalisation. It called for establishing electronic records by member states on the use of pesticides and the cross-linking of data on pesticides with other national data on water and the environment. This provision would have complemented the FAST tool which does not contain such strong requirements on information sharing (see section 3.1). The proposal also envisaged rules to allow the deployment of drones for spraying plant protection products in a way that does not result in adverse health and environmental impacts.[88] Therefore, failure to introduce this legislation is also a drawback on the efforts to facilitate the use of data and digital solutions for precision farming.

Industrial emissions directive and Emissions Trading Scheme

Although not mentioned in the Farm to Fork Strategy, the EU's Industrial Emissions Directive (IED) has a role to play in reducing climate and environmental impacts from the agri-food industry. The IED requires industrial facilities, including those related to food production, to apply the best available techniques (BAT) before obtaining a permit. The EU develops BAT reference (BREF) documents that help identify BAT for a specific facility. The recent adoption of IED revision introduces stricter binding achievable emission levels in industrial installations and large pig and poultry farms, while the Commission will review in 2026 whether rearing livestock, including cattle farms, should be included in the rules.[89] Arguably digital tools like monitoring sensors to measure pollution and waste generation could be systematically included in BREF documents to help reduce waste, and minimise climate and environmental impacts of industrial production of food products.

The European Emissions Trading Scheme (ETS), a key policy tool for the reduction of GHG emissions, setting a limit "cap" on the total amount of GHG emissions allowed, and enabling the trading of emission allowances. The inclusion of the agri-food sector in the ETS can create incentives for food industry and farmers to reduce their GHG emissions. Data sharing and digital solutions can play an important role in this context, as it enables the precise tracking and verification of emissions and carbon sequestration.[90]

Regulation on Food Information to Consumers

Under Farm to Fork Strategy, the Commission is also planning to revise the Regulation on Food Information to Consumers (FIC). The revision would feature harmonised mandatory front-of-pack nutrition labelling and clarify the meaning of expiry dates on food packaging to make it easier for consumers to choose healthy and sustainable diets and avoid food waste. The Commission aims to revise EU food marketing standards and support diets that are better for the environment and climate. These revisions currently do not contain references to the prospects of digital tools such as IoT or digital product passports to share information about sustainability of food products with consumers. At the same time, the Ecodesign for Sustainable Products Regulation (ESPR) envisages introduction of digital product passports to products. However, the ESPR does not prioritise food products within its regulatory framework.

Waste framework directive

The Commission proposed a revision of the Waste Framework Directive (WFD).[91] It calls upon member states to prevent the generation of food waste in primary production, processing, and manufacturing, in retail and other distribution of food, in restaurants and food services as well as in households. While leaving concrete measures to member states, the proposal envisages binding EU targets of reducing food waste by 30% in restaurants and food services and in households, and by 10% in processing and manufacturing by 2030 compared to food waste generated in 2020. The WFD also asks from member states to prevent food waste in the production stage and the Farm to Fork Strategy mentions that the Commission will also 'investigate and explore ways of preventing food losses at the production stage'. However, no concrete policy initiatives reducing food loss in the primary production stage have been envisaged thus far. Lastly, under the existing WFD separate bio-waste collection is mandatory as of 2024.

New WFD requirements could boost the introduction of digital solutions such as sensors, IoT, and AI-based analytics to reduce food waste across the value chain. In the explanatory notes, the Commission refers to the role of Digital Innovation Hubs (see section 3.1) to help reduce food waste. That been said, the WFD revisions do not highlight the role for digital solutions nor information transfer to help reduce food waste.

EU platform on food losses and food waste

EU's policy efforts are backed by the EU Platform on Food Losses and Food Waste (FLW). Being a digital tool itself, the platform acts as a multi-stakeholder initiative aiming to support all actors in defining measures needed to prevent food waste, sharing best practices, and evaluating progress made over time. One of the outcomes of Platform's work are recommendations for reducing food waste and loss across the value chain. Recommendations recognise the role of information sharing, for example to make farmers aware of the market demand to adjust their production and reduce food losses.[92]

In collaboration with the FLW Platform, in 2017 the EU adopted guidelines on food donation, which should facilitate the distribution of unsold food to those in need in accordance with the Union's food health and safety standards.[93] The guidelines make a reference to the use of digital tools by intermediary organisations matching supply and demand between food providers and recipients. Proposed revision of the WFD also mention food donation as one of the measures that member states could take to prevent food waste. Nonetheless, there is currently no EU regulatory requirement that would require retailers to donate surplus food or to share information about the existence of surplus food.

3.4. DATA GOVERNANCE

Overview of the data governance framework

The EU has already made significant advances in creating rules for the development of safe and efficient information transfer and the work on improving access to data and ensuring data flow between stakeholders is progressing. For example, the Database Directive 96/9/EC, Trade Secrets Directive 2016/943/EU, ePrivacy Regulation 2002/58/EC, Regulation 2018/1807 on the free movement of non-personal data and General Data Protection Regulation 2016/679/EU (GDPR) aimed to address these concerns. While those developments

address some of the challenges concerning data governance (see section 2.1) there is still a long way ahead for the EU to complete the policy framework needed to enable optimal data and information sharing for sustainable agri-food transition.

The EU's 2020 Data Strategy aimed to facilitate the free flow of data, including a number of initiatives to improve data governance, interoperability and infrastructure. Political Guidelines for the next European Commission envisage the adoption of the European Data Union Strategy, although the specifics of this strategy are yet to be laid out. What follows is the overview and analysis of some of the EU's legislative work on data governance while subsequent sections discuss other relevant initiatives, namely, common data spaces and AI legislation.

There is still a long way ahead for the EU to complete the policy framework needed to enable optimal data and information sharing for sustainable agri-food transition.

Open data directive

The Open Data Directive 2003/98/EC (ODD) makes public sector data reusable for commercial and non-commercial purposes. There are limitations, however, as private actors can, for example, make such data available on the condition that it cannot be accessed by a wider audience to safeguard data confidentiality. The ODD establishes categories of 'high-value datasets', which should be available free of charge to requestors and in a machine-readable format. The ODD identifies a broad range of such categories including on 'earth and environment' which can be relevant for farmers and the list can be extended over time.[94]

INSPIRE directive

The INSPIRE Directive 2007/2/EC sets rules for "the establishment of the Infrastructure for Spatial Information […], for […] Community environmental policies and policies or activities which may have an impact on the environment."[95] The Directive covers monitoring, production, industrial and agriculture facilities. INSPIRE directive is connected with the IACS system. Member states are obliged to make geospatial data covered under INSPIRE and collected under IACS available and free of charge to other public authorities and to make such data publicly available, provided that it is anonymised.[96] Under the GreenData4forAll initiative the Commission is aiming to further improve accessibility and data sharing of geospatial information.[97]

Data Governance Act

The Data Governance Act (DGA) facilitates different stakeholders' (i.e. businesses, citizens, researchers) access to information held by public authorities, notably when such data is provided by private entities and data confidentiality is an issue. Moreover, the DGA would help intermediary organisations manage data on behalf of data providers and users. It would facilitate data sharing for 'altruistic purposes', meaning that data sharing is done on a non-for-profit basis to achieve objectives of general interest, including on climate.

The Data Governance Act is a step in a right direction although the results of its implementation remain to be seen. Envisaged rules and conditions can make data sharing between different actors safer and trustworthy which could in return enable data sharing to a greater extent and support the green agri-food transition. For example, governments store huge amounts of data which can be used to drive innovation for precision agriculture, development of alternative plant-based proteins, and food waste reduction along the value chain. Intermediary organisations can receive and manage information to farmers, food industry, retailers, and food service providers. Defining the more systematic, altruistic sharing of data could facilitate research and data analytics to advance sustainable agri-food practices.

Data Act

The Data Act is another legislation which establishes rules under which data users (e.g. farmers, consumers), data holders (providers of digital solutions) and third parties (e.g. other providers of IT services) can receive and reuse data. It aims to facilitate data access and sharing while recognising the need to condition such practices upon the respect of trade secrets and data privacy and on compensating data holders for data sharing with the third parties if there are costs incurred in the process. Such rules are important especially in case of connected machines which can generate and share data among multiple stakeholders, including between farmers, providers of digital services, and public authorities. The Data Act also lays the ground for interoperability rules on information transfer between different actors involved. The legislation also requires from data holders to share information with public authorities in case of emergency situations which do not include sustainability-related topics.

As the Data Act covers a wide range of situations and may be difficult to apply it directly in the agri-food sector. Nonetheless, the EU envisages the development of additional soft law to enable its application, such as model contracts to clarify in which cases can the sharing of data be restricted. The full impact of its legislation on enabling the sharing of data in the agri-food sector remains to be seen.

It is important to note there are industry-led initiatives led by the private sector to enable the sharing of data and information in the agri-food sector. The Code of Conduct on agricultural data sharing provides a set of

principles for data governance, putting farmers at the heart of collection, processing, and management of agricultural data.[98] The relevance of this Code of Conduct was noted in the Data Act. Moreover, the Agricultural Interoperability Network (AgInt) aims to improve interoperability of data exchanged between farmers, machine producers, and other agri-food businesses.[99] EU's further work on data governance and interoperability standards could build on the ongoing developments in the private sector, notwithstanding that the EU must safeguard the public interest, enable fair access to data, and help utilise digitally-enabled data to advance the green transition in the agri-food sector.

3.5. COMMON DATA SPACE(S)

In 2020, the Commission adopted a new Digital Agenda to drive the EU's digital transformation. This included the Data Strategy, which aims to establish a single market for data. The backbone of this proposal is establishing common European data spaces to enable access to information, sharing of data, and its reuse. Data spaces can help unlock new opportunities, such as optimising the sharing and re-use of data and digital solutions (e.g. AI, Internet of Things) to advance the transition to a more sustainable agri-food system.

It is envisioned that the shared data space(s) will serve as an economic and social governance framework for data use and information exchange across sectors. It will comprise technical standards, such as a common vocabulary and concepts (i.e. the 'ontology'). The data space will also include rules and conditions on accessing and using data, to safeguard confidential information. The legislative pillar to data spaces is the aforementioned data governance legislation, especially the Data Governance Act and the Data Act. The EU is investing – especially via its Digital Europe and Horizon Europe programmes – in the development of necessary technical standards, interoperability rules, and infrastructures, such as secure cloud-based systems that different stakeholders can use. In addition to a 'horizontal' common data space that establishes general rules and standards, there will be a specific governance framework and interconnected data spaces for different sections of the economy and society. One of these will be a common European data space for agriculture or AgriDataSpace with an aim to create a European framework for data sharing, processing, and analysis.

While an ambitious and welcome initiative, there are still many uncertainties concerning the architecture, functioning, and performance of the data space for sustainable agriculture. The common European data space for agriculture is yet to be developed and different projects and initiatives, including farmers, IT industry, data intermediaries, various public data bases (e.g. IACS, FSDN), national and regional data spaces, need to be fully integrated into a single system. This rather echoes the Commission's approach on developing the database gradually, in collaboration with all the relevant stakeholders and without predefining the outcomes too early. As mentioned in section 3.1, under Horizon Europe, a dedicated partnership 'Agriculture of Data' (AgData) aims to enhance research and innovation which can help in the deployment of AgriDataSpace.[100] Given the scale of efforts needed to create data standards, set rules on data governance, and deploy digital tools for information transfer, establishing a functional common data space(s) that can support sustainable agriculture will take years.

While the data space for agriculture focused on the upstream part of the agri-food system, there is also a separate Green Deal data space. Under the Green Deal data space, more specific data spaces are being created such as the one on Sustainable and Smart Cities and Communities. While having separate data spaces is not necessarily a problem, it is crucial to ensure aforementioned data spaces are closely intertwined to ensure that sustainability aspects are included in the digitalisation of the entire agri-food system. This is crucial to connect stakeholders along the value chain, including for example a connection between farmers and consumers interested in purchasing sustainable food right from the source. While the Commission has established a Digital Innovation Board to facilitate data sharing between data spaces and the Data Spaces Support Centre to help interlink the data spaces, the outcome of the work of these mechanisms remains to be seen.

3.6. AI LEGISLATION

As recognised by the Draghi Report, agriculture is one of the strategic sectors where AI should be introduced rapidly.[101] What needs to be underlined, however, is the importance of using AI across the agri-food value chain in a way that supports the green transition. The EU is developing a regulatory framework for AI,[102] offering possibilities to overcome certain challenges regarding limited access to digital solutions and negative side-effects of AI on sustainability (see section 2.3). It builds on a number of Commission proposals, such as on liability rules for the AI usage and revision of the Machinery Regulation to account to the AI-related risks. Most importantly the AI Act aims to reduce AI-related risks and establishes general conditions for placing the AI on the market.

According to the AI Act, if AI might pose a high risk, such as endangering the life and health of citizens, a conformity assessment must be undertaken first. The legislation is not tailored to the agri-food sector but it is relevant to the sector nonetheless given the importance that AI systems could have in collecting data, sharing information, using modern machinery, and providing advice on future agri-food practices. The AI Act contains weak references to environmental protection when placing an AI system on the market. The legislation calls upon the Commission and the member states to encourage and facilitate the development of voluntary codes of conduct by developers of AI systems, aiming to minimise the impact of AI on environmental sustainability. Four years after the entry of the regulation into force the Commission will assess if additional measures are needed on top of codes of conduct. On the one hand, the voluntary approach increases the risk that AI could be used for purposes that

can go against the objectives of the Green Deal. Stronger conditions on AI could slow down its deployment in the EU vis-à-vis other global competitors.

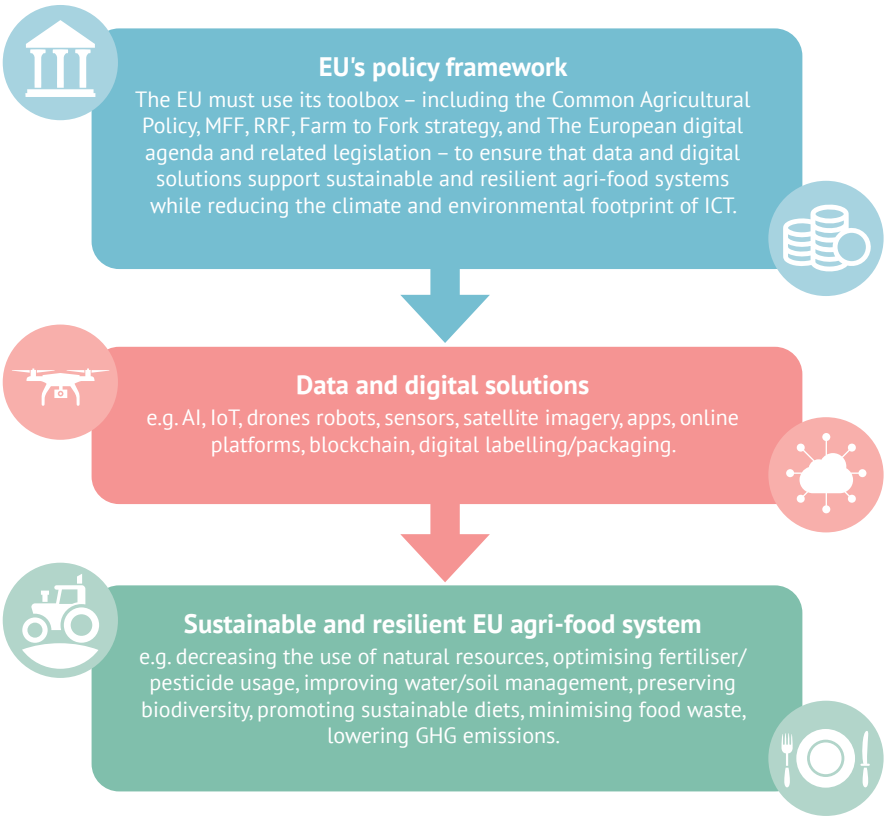
Besides codes of conduct, an alternative to stricter conditions on AI deployment could be to define when AI models can be considered to be sustainable in the agri-food sector. This could be followed by investments into research and deployment of sustainable AI models to assist in decision-making. Deployment of such solutions could be given priority as part of the CAP subsidies that go to farmers. However, there are currently no systematic regulatory attempts nor investments to support development and deployment of AI models for sustainable farming and food consumption.

4. Policy recommendations

The EU's agri-food system is negatively affected by climate change and environmental degradation while adding a significant climate and environmental footprint. It is crucial to benefit from the ongoing digital transformation and advance the green transition in the agri-food sector simultaneously. As shown in the previous chapters, there are significant prospects for using digitalisation as an enabler for sustainable and resilient agri-food system. Nonetheless, there are still challenges with scaling up digital solutions, which are only partially addressed by the current EU policy framework. More ambition is needed from the EU side to align the EU's agri-food, green and digital agendas (see Figure 1). There is a need for a clear strategic direction on the twin transition in the agri-food sector, setting up an enabling regulatory framework to help share data and information and investing in the scaling up of digital solutions. The following recommendations build on the discussion in chapters 2 and 3 and provide a vision for the way forward:

Figure 1

THE ROLE FOR DIGITALISATION FOR A SUSTAINABLE AND RESILIENT EU AGRI-FOOD SECTOR



STRATEGIC DIRECTION FOR THE TWIN GREEN AND DIGITAL TRANSITION IN THE AGRI-FOOD SECTOR

- In the wake of the sustainability crisis, green backlash, and the food crisis exacerbated by the war in Ukraine, **stronger leadership and vision at the EU level are necessary to ensure a future-proof agri-food system that is sustainable, resilient, fair and economically viable.** It must communicate effectively the importance of maintaining the course towards achieving the green transition - in collaboration with member states, farmers, industry, consumers, and the civil society. The importance of the twin green and digital transition in the agri-food sector should be firmly embedded in the Commission's upcoming Vision for Agriculture and Food and the European Data Union Strategy.

- **The EU's agri-food agenda needs to be completely aligned with the objectives of the Green Deal** and build on the potential that data and digital solutions offer for meeting the EU's climate and environmental objectives. Following the European elections, the EU should re-open the discussion on legislative initiatives such as Sustainable Food Systems law and Sustainable Use of Pesticides regulation in consultation with all relevant stakeholders. 2040 climate targets should include decarbonisation targets for the agri-food sector. Post-2027 CAP should set strong and binding requirements on reducing industrial livestock and be fully aligned with EU's biodiversity objectives. Comprehensive risk and effectiveness assessments should be developed for the new proposed rules before their introduction, but also throughout their implementation.

- **The EU must double its efforts and establish a functional digital information system for the sustainable agri-food sector by 2030.** The aim would be to help farmers, producers, retailers, and consumers contribute to the Green Deal objectives with the help of data and digital solutions. It needs to streamline this vision in its financial and regulatory framework across the agri-food value chain and in a holistic manner.

- **The EU must engage with the relevant stakeholders** for information transfer across value chains, including farmers, producers, retailers, food services, consumers, and NGOs. At the same time, private and non-profit organisations should proactively collaborate with the decision-makers. Such multi-stakeholder forum can build on the EU's strategic dialogue on the sustainable future of agriculture while focusing on digitalisation and covering also post-farming stages of the agri-food chain.

- **The EU should use its convening power to exchange good practices** on digitally enabled solutions for monitoring farmers' performance and complying with CAP rules between paying agencies. The Commission's Directorate-General for Environment, Directorate-General for Climate Action, and Directorate-General for Agriculture and Rural Development could take the lead and a task force between the directorates could help coordinate their efforts. In this way, better coordination and common guidance will be provided in collaboration with member states, respecting subsidiarity.

- **The EU must use its Digital Agenda, including data governance and financial instruments, to speed up the deployment of digital solutions** and uptake of digital skills for a sustainable agri-food. Conversely, the EU should streamline digitalisation in the EU's agri-food agenda, namely under CAP and Farm to Fork.

- **Public authorities must take measures to prevent or reduce the negative side effects of digitalisation on the climate, environment, and society at large.** They must develop rules and standards for and invest in digital solutions that are energy- and resource-efficient. Greening data centres and reducing the impacts of IoT, blockchain, and AI will be essential. They should steer the development and uptake of digital solutions towards addressing Europe's environmental and climate challenges.

SPECIFIC OBJECTIVE 1: ENABLE DATA AND INFORMATION SHARING FOR SUSTAINABLE AGRI-FOOD SYSTEMS

This objective corresponds to the following challenges to scaling-up digital solutions that have been identified: data protection, privacy, trust, and ownership concerns; limited access to digital solutions; and unintended side effects of digitalisation (see section 2.4).

- **The EU must establish functional, effective, and safe data spaces to support information transfer and data sharing for sustainable and resilient agri-food sector with the continuous support from Digital Europe and Horizon Europe programmes.** The EU must ensure that these data spaces for agriculture and the Green Deal are inter-connected and contribute to sustainable agri-food. The EU needs to define what data is relevant for sustainable agri-food. Ensuring access to actionable data and interoperability between relevant data spaces should be at the heart of the Commission's work on common data spaces. The EU should develop guidelines and encourage public authorities (e.g. paying and environmental agencies) to connect their databases and enable machine-to-machine exchange for sustainable agri-food.

- **An EU-wide code of conduct should be devised to help different partners in the agri-food chain share and process data fairly and transparently, for the benefit of the climate and environment.** The Code of Conduct on Agricultural Data Sharing by Contractual Arrangement – as agreed by several agricultural associations –[103] sets a basis for further discussion. It aims to set transparent principles, clarify responsibilities and recognises the need to create trust among partners. The EU should ensure that, as part of an EU-wide code of conduct, data of particular

relevance to sustainability is made publicly accessible in a standardised format. The code of conduct could be developed as a voluntary tool first with a possibility of turning it into a legally binding instrument depending on its performance as a voluntary measure.

- **The EU must consider conditionalities for farmers to share data** (e.g. on the use of pesticides, nitrates as fertilisers) with public authorities about their farming practices in exchange for subsidies under post-2027 CAP. This data would be used to boost research and innovation for greening the agri-sector rather than pursuing surveillance and enforcing compliance on the farmers. Public authorities could share this data with private entities provided that data sharing procedures and standards are met to safeguard data protection in accordance with data legislation, especially the GDPR and the DGA. The EU and its member states should explore how to make data from farmers anonymous. The data would thereby become less sensitive when shared with authorities in charge of climate and environment, as well as academia, private companies, and NGOs.

- **The EU should consider introducing digital information tools into packaging and electronics** to help consumers access information about their food and receive advice on how to reduce their food waste and shift to more sustainable diets. In the case of packaging, digital product passport could be considered under the Packaging and Packaging Waste Directive, the revised Regulation on Food Information to Consumers Directive, and revised marketing standards. In case of electronics, the Ecodesign for Sustainable Products Regulation could envisage introduction of smart applications in white appliances such as fridges.

- **The EU should also introduce requirements for large food producers to share data via digital means** (sensors, IoT) about their operations aiming to reduce food waste and the overall climate and environmental impact. The EU should develop Best Available Techniques that can steer the update of digital information systems in the agri-food industry. The EU should consider including agri-food sector in the ETS and facilitate digitally-enabled data sharing for better verification and greater transparency on emission reductions and carbon removals.

- **The EU needs to introduce binding rules for large retailers and food service providers to donate surplus food and to share information about the surplus food with public authorities and private actors involved in food distribution.** Member states should encourage establishment of digital platforms to connect food providers, charities, and food recipients. Retailers and the food service sector should report via digital means to national authorities who would in return report to the Commission on food donations.

SPECIFIC OBJECTIVE 2: INVEST IN THE UPTAKE OF DIGITAL SOLUTIONS FOR SUSTAINABLE AGRI-FOOD SYSTEMS

This objective corresponds to the following challenges to scaling-up digital solutions that have been identified: digital literacy and convenience with using digital tools; limited access to digital solutions; and negative side effects of digitalisation (see section 2.4).

- **The Common Agricultural Policy, coupled with Digital Europe, Horizon Europe programme, and private investments, should ensure that the uptake of digital and AI solutions support environmental and climate objectives systematically.** CAP should especially help young and/or small-scale organic farmers to benefit from sustainable, digital technologies and encourage the scaling-up of sustainable, digital service-based business models. Coupled with the ongoing work on digital data spaces, CAP should incentivise the development of farmers' cooperatives and support joint purchase of digital equipment to be shared between farmers (drones, unmanned ground vehicles) and establishment of digital information sharing platforms. The EU should consider how private investors can be incentivised to invest in both digitalisation and greening of the agri-food sector as part of its ongoing work on the Saving and Investments Union and implementation of the sustainable finance agenda.

- **The EU must invest more and set up workable schemes to enhance digital education and skills** for farmers, food producers, retailers, and consumers and enable the update of digital solutions for sustainable agri-food system. The EU and member states should use European agricultural fund for rural development and encourage the use of Farm Advisory Services and local farmer associations, research institutes, Digital Innovation Hubs, and Agriculture Knowledge Information System to support the development of digital skills for farmers. ESF+ and Digital Skills Agenda should support both farmers, food-related workers, citizens, and consumers to improve their digital skills.

- **The EU should define which AI models are relevant for the sustainable agri-food transition and facilitate the uptake of such solutions.** The EU should consider certification and labelling schemes for AI that can help drive the green transition. Post-2027 CAP should encourage and incentivise the uptake of sustainable AI models by farmers, food producers, retailers, food service providers, and consumers.

- **The EU must invest in modernisation of its ICT infrastructure** to digitalise rural areas. The EU should rely on the Recovery and Resilience Facility, and Cohesion Funds should continue supporting these efforts. In the post-2027 MFF, new financial tool to replace RRF in 2027 should put more emphasis on digitalisation of rural areas so that they catch up with the EU average.

- **The EU and its member states should invest in the monitoring infrastructure** (i.e. advanced satellite imagery and navigation, deployment of AI, drones, and sensors) to ensure the data quality in the monitoring process. The EU could achieve this with the help of instruments such as the European Space programme and Digital Europe programme.

The EU's agri-food sector is at a crossroads. With concerns ranging from sustainability and health to resilience and food security, it is high time to modernise the way Europeans produce and consume food. Data and digital solutions can provide the necessary tools to advance the green transition, improve the efficiency of farming and food production, and enable better access to information for consumers. EU policies can help to steer the digital transformation in a right direction. It is crucial for the EU and member states to seize this opportunity as part of the new institutional cycle and accelerate the process of aligning the European agri-food system with the twin green and digital transition.

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NOTES

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